Related titles

Winemaking problems solved
(ISBN 978-1-84569-475-3)

Managing wine quality Volume 1: Viticulture and wine quality
(ISBN 978-1-84569-484-5)

Managing wine quality Volume 2: Oenology and wine quality,
(ISBN 978-1-84569-798-3)

Woodhead Publishing Series in Food Science, Technology and Nutrition: Number 268

Grapevine Breeding Programs for the Wine Industry

Edited by

Andrew Reynolds

ELSEVIER

AMSTERDAM • BOSTON • CAMBRIDGE • HEIDELBERG
LONDON • NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO
Woodhead Publishing is an imprint of Elsevier

WP WOODHEAD PUBLISHING

Woodhead Publishing is an imprint of Elsevier
80 High Street, Sawston, Cambridge, CB22 3HJ, UK
225 Wyman Street, Waltham, MA 02451, USA
Langford Lane, Kidlington, OX5 1GB, UK

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Control Number: 2015932590

ISBN 978-1-78242-075-0 (print)
ISBN 978-1-78242-080-4 (online)

For information on all Woodhead Publishing publications visit our website at http://store.elsevier.com/

List of contributors

L. Bavaresco CRA-Centro di Ricerca per la Viticoltura (CRA-VIT), Conegliano, Italy; Istituto di Frutti-Viticoltura, Università Cattolica S. Cuore, Piacenza, Italy

L. Brancadoro Università degli Studi, Milano, Italy

G. Breeder University of Minnesota, Horticultural Research Center, Excelsior, MN, USA

U.A. Camargo Vino Vitis Consulting Ltda., Bento Gonçalves, Brazil

J. Carreño Instituto Murciano de Investigación y Desarrollo Agrario y Alimentario, Murcia, Spain

J.R. Clark University of Arkansas, Fayetteville, AR, USA

R. Eibach JKI Institute for Grapevine Breeding, Geilweilerhof, Germany

L. Espen Università degli Studi, Milano, Italy

O. Failla Università degli Studi, Milano, Italy

M.E. Ferreira Embrapa Genetic Resources and Biotechnology, Parque Estação Biológica, PqEB, Brasília, Brazil

K.H. Fisher University of Guelph, Guelph, OM, Canada

S. Foria University of Udine, Udine, Italy

M. Gardiman CRA-Centro di Ricerca per la Viticoltura (CRA-VIT), Conegliano, Italy

G. Di Gaspero University of Udine, Udine, Italy; Istituto di Genomica Applicata, Udine, Italy

E. Gonçalves Instituto Superior de Agronomia - ISA/University of Lisbon, Lisboa, Portugal

E. Hajdu Corvinus University of Budapest, Budapest, Hungary

P. Hemstad University of Minnesota, Horticultural Research Center, Excelsior, MN, USA

J. Ibáñez Instituto de Ciencias de la Vid y del Vino (CSIC, UR, Gobierno de La Rioja), Logroño, Spain

A. Jamieson Agriculture and Agri-Food Canada Research Station, Kentville, NS, Canada

C. Liu Zhengzhou Pomology Research Institute, Zhengzhou, China

J. Lu China Agricultural University, Beijing, China

K. Lund University of California, Davis, CA, USA

J.D.G. Maia Embrapa Grape and Wine, Tropical Viticulture Experimental Station, Jales, Brazil

J.M. Martínez-Zapater Instituto de Ciencias de la Vid y del Vino (CSIC, UR, Gobierno de La Rioja), Logroño, Spain

A. Martins Instituto Superior de Agronomia - ISA/University of Lisbon, Lisboa, Portugal

P. Pavloušek Mendel University, Brno, Czech Republic

V. Quecini Embrapa Grape and Wine, Bento Gonçalves, Brazil

F. Regner Höhere Bundeslehranstalt und Bundesamt für Wein und Obstbau-Klosterneuburg, Klosterneuburg, Austria

B.I. Reisch Cornell University, Geneva, NY, USA

A.G. Reynolds Brock University, St Catharines, ON, Canada

P. Ritschel Embrapa Grape and Wine, Bento Gonçalves, Brazil

E. Ruehl Geisenheim University, Geisenheim, Germany

J. Schmid Geisenheim University, Geisenheim, Germany

A. Scienza Università degli Studi, Milano, Italy

S.M. Sleezer University of Arkansas, Fayetteville, AR, USA

E.T. Stafne Mississippi State University, Poplarville, MS, USA

M. Stefanini Research and Innovation Centre, Fondazione Edmund Mach, San Michele all'Adige, Italy

R. Testolin University of Udine, Udine, Italy; Istituto di Genomica Applicata, Udine, Italy

J. Tonietto Embrapa Grape and Wine, Bento Gonçalves, Brazil

R. Töpfer JKI Institute for Grapevine Breeding, Geilweilerhof, Germany

R. Velasco Research and Innovation Centre, Fondazione Edmund Mach, San Michele all'Adige, Italy

S. Vezzulli Research and Innovation Centre, Fondazione Edmund Mach, San Michele all'Adige, Italy

J. Yuste Instituto Tecnológico Agrario de Castilla y León, Valladolid, Spain

M.C. Zanus Embrapa Grape and Wine, Bento Gonçalves, Brazil

L. Zulini Research and Innovation Centre, Fondazione Edmund Mach, San Michele all'Adige, Italy

Woodhead Publishing Series in Food Science, Technology and Nutrition

1 **Chilled foods: A comprehensive guide**
Edited by C. Dennis and M. Stringer
2 **Yoghurt: Science and technology**
A. Y. Tamime and R. K. Robinson
3 **Food processing technology: Principles and practice**
P. J. Fellows
4 **Bender's dictionary of nutrition and food technology Sixth edition**
D. A. Bender
5 **Determination of veterinary residues in food**
Edited by N. T. Crosby
6 **Food contaminants: Sources and surveillance**
Edited by C. Creaser and R. Purchase
7 **Nitrates and nitrites in food and water**
Edited by M. J. Hill
8 **Pesticide chemistry and bioscience: The food-environment challenge**
Edited by G. T. Brooks and T. Roberts
9 **Pesticides: Developments, impacts and controls**
Edited by G. A. Best and A. D. Ruthven
10 **Dietary fibre: Chemical and biological aspects**
Edited by D. A. T. Southgate, K. W. Waldron, I. T. Johnson and G. R. Fenwick
11 **Vitamins and minerals in health and nutrition**
M. Tolonen
12 **Technology of biscuits, crackers and cookies Second edition**
D. Manley
13 **Instrumentation and sensors for the food industry**
Edited by E. Kress-Rogers
14 **Food and cancer prevention: Chemical and biological aspects**
Edited by K. W. Waldron, I. T. Johnson and G. R. Fenwick
15 **Food colloids: Proteins, lipids and polysaccharides**
Edited by E. Dickinson and B. Bergenstahl
16 **Food emulsions and foams**
Edited by E. Dickinson
17 **Maillard reactions in chemistry, food and health**
Edited by T. P. Labuza, V. Monnier, J. Baynes and J. O'Brien
18 **The Maillard reaction in foods and medicine**
Edited by J. O'Brien, H. E. Nursten, M. J. Crabbe and J. M. Ames
19 **Encapsulation and controlled release**
Edited by D. R. Karsa and R. A. Stephenson
20 **Flavours and fragrances**
Edited by A. D. Swift
21 **Feta and related cheeses**
Edited by A. Y. Tamime and R. K. Robinson

22 **Biochemistry of milk products**
Edited by A. T. Andrews and J. R. Varley
23 **Physical properties of foods and food processing systems**
M. J. Lewis
24 **Food irradiation: A reference guide**
V. M. Wilkinson and G. Gould
25 **Kent's technology of cereals: An introduction for students of food science and agriculture Fourth edition**
N. L. Kent and A. D. Evers
26 **Biosensors for food analysis**
Edited by A. O. Scott
27 **Separation processes in the food and biotechnology industries: Principles and applications**
Edited by A. S. Grandison and M. J. Lewis
28 **Handbook of indices of food quality and authenticity**
R. S. Singhal, P. K. Kulkarni and D. V. Rege
29 **Principles and practices for the safe processing of foods**
D. A. Shapton and N. F. Shapton
30 **Biscuit, cookie and cracker manufacturing manuals Volume 1: Ingredients**
D. Manley
31 **Biscuit, cookie and cracker manufacturing manuals Volume 2: Biscuit doughs**
D. Manley
32 **Biscuit, cookie and cracker manufacturing manuals Volume 3: Biscuit dough piece forming**
D. Manley
33 **Biscuit, cookie and cracker manufacturing manuals Volume 4: Baking and cooling of biscuits**
D. Manley
34 **Biscuit, cookie and cracker manufacturing manuals Volume 5: Secondary processing in biscuit manufacturing**
D. Manley
35 **Biscuit, cookie and cracker manufacturing manuals Volume 6: Biscuit packaging and storage**
D. Manley
36 **Practical dehydration Second edition**
M. Greensmith
37 **Lawrie's meat science Sixth edition**
R. A. Lawrie
38 **Yoghurt: Science and technology Second edition**
A. Y. Tamime and R. K. Robinson
39 **New ingredients in food processing: Biochemistry and agriculture**
G. Linden and D. Lorient
40 **Benders' dictionary of nutrition and food technology Seventh edition**
D. A. Bender and A. E. Bender
41 **Technology of biscuits, crackers and cookies Third edition**
D. Manley
42 **Food processing technology: Principles and practice Second edition**
P. J. Fellows
43 **Managing frozen foods**
Edited by C. J. Kennedy
44 **Handbook of hydrocolloids**
Edited by G. O. Phillips and P. A. Williams
45 **Food labelling**
Edited by J. R. Blanchfield
46 **Cereal biotechnology**
Edited by P. C. Morris and J. H. Bryce
47 **Food intolerance and the food industry**
Edited by T. Dean

48 **The stability and shelf-life of food**
Edited by D. Kilcast and P. Subramaniam
49 **Functional foods: Concept to product**
Edited by G. R. Gibson and C. M. Williams
50 **Chilled foods: A comprehensive guide Second edition**
Edited by M. Stringer and C. Dennis
51 **HACCP in the meat industry**
Edited by M. Brown
52 **Biscuit, cracker and cookie recipes for the food industry**
D. Manley
53 **Cereals processing technology**
Edited by G. Owens
54 **Baking problems solved**
S. P. Cauvain and L. S. Young
55 **Thermal technologies in food processing**
Edited by P. Richardson
56 **Frying: Improving quality**
Edited by J. B. Rossell
57 **Food chemical safety Volume 1: Contaminants**
Edited by D. Watson
58 **Making the most of HACCP: Learning from others' experience**
Edited by T. Mayes and S. Mortimore
59 **Food process modelling**
Edited by L. M. M. Tijskens, M. L. A. T. M. Hertog and B. M. Nicolaï
60 **EU food law: A practical guide**
Edited by K. Goodburn
61 **Extrusion cooking: Technologies and applications**
Edited by R. Guy
62 **Auditing in the food industry: From safety and quality to environmental and other audits**
Edited by M. Dillon and C. Griffith
63 **Handbook of herbs and spices Volume 1**
Edited by K. V. Peter
64 **Food product development: Maximising success**
M. Earle, R. Earle and A. Anderson
65 **Instrumentation and sensors for the food industry Second edition**
Edited by E. Kress-Rogers and C. J. B. Brimelow
66 **Food chemical safety Volume 2: Additives**
Edited by D. Watson
67 **Fruit and vegetable biotechnology**
Edited by V. Valpuesta
68 **Foodborne pathogens: Hazards, risk analysis and control**
Edited by C. de W. Blackburn and P. J. McClure
69 **Meat refrigeration**
S. J. James and C. James
70 **Lockhart and Wiseman's crop husbandry Eighth edition**
H. J. S. Finch, A. M. Samuel and G. P. F. Lane
71 **Safety and quality issues in fish processing**
Edited by H. A. Bremner
72 **Minimal processing technologies in the food industries**
Edited by T. Ohlsson and N. Bengtsson
73 **Fruit and vegetable processing: Improving quality**
Edited by W. Jongen
74 **The nutrition handbook for food processors**
Edited by C. J. K. Henry and C. Chapman

75 **Colour in food: Improving quality**
Edited by D. MacDougall
76 **Meat processing: Improving quality**
Edited by J. P. Kerry, J. F. Kerry and D. A. Ledward
77 **Microbiological risk assessment in food processing**
Edited by M. Brown and M. Stringer
78 **Performance functional foods**
Edited by D. Watson
79 **Functional dairy products Volume 1**
Edited by T. Mattila-Sandholm and M. Saarela
80 **Taints and off-flavours in foods**
Edited by B. Baigrie
81 **Yeasts in food**
Edited by T. Boekhout and V. Robert
82 **Phytochemical functional foods**
Edited by I. T. Johnson and G. Williamson
83 **Novel food packaging techniques**
Edited by R. Ahvenainen
84 **Detecting pathogens in food**
Edited by T. A. McMeekin
85 **Natural antimicrobials for the minimal processing of foods**
Edited by S. Roller
86 **Texture in food Volume 1: Semi-solid foods**
Edited by B. M. McKenna
87 **Dairy processing: Improving quality**
Edited by G. Smit
88 **Hygiene in food processing: Principles and practice**
Edited by H. L. M. Lelieveld, M. A. Mostert, B. White and J. Holah
89 **Rapid and on-line instrumentation for food quality assurance**
Edited by I. Tothill
90 **Sausage manufacture: Principles and practice**
E. Essien
91 **Environmentally-friendly food processing**
Edited by B. Mattsson and U. Sonesson
92 **Bread making: Improving quality**
Edited by S. P. Cauvain
93 **Food preservation techniques**
Edited by P. Zeuthen and L. Bøgh-Sørensen
94 **Food authenticity and traceability**
Edited by M. Lees
95 **Analytical methods for food additives**
R. Wood, L. Foster, A. Damant and P. Key
96 **Handbook of herbs and spices Volume 2**
Edited by K. V. Peter
97 **Texture in food Volume 2: Solid foods**
Edited by D. Kilcast
98 **Proteins in food processing**
Edited by R. Yada
99 **Detecting foreign bodies in food**
Edited by M. Edwards
100 **Understanding and measuring the shelf-life of food**
Edited by R. Steele
101 **Poultry meat processing and quality**
Edited by G. Mead

102 **Functional foods, ageing and degenerative disease**
Edited by C. Remacle and B. Reusens
103 **Mycotoxins in food: Detection and control**
Edited by N. Magan and M. Olsen
104 **Improving the thermal processing of foods**
Edited by P. Richardson
105 **Pesticide, veterinary and other residues in food**
Edited by D. Watson
106 **Starch in food: Structure, functions and applications**
Edited by A.-C. Eliasson
107 **Functional foods, cardiovascular disease and diabetes**
Edited by A. Arnoldi
108 **Brewing: Science and practice**
D. E. Briggs, P. A. Brookes, R. Stevens and C. A. Boulton
109 **Using cereal science and technology for the benefit of consumers: Proceedings of the 12th International ICC Cereal and Bread Congress, 24 – 26th May, 2004, Harrogate, UK**
Edited by S. P. Cauvain, L. S. Young and S. Salmon
110 **Improving the safety of fresh meat**
Edited by J. Sofos
111 **Understanding pathogen behaviour: Virulence, stress response and resistance**
Edited by M. Griffiths
112 **The microwave processing of foods**
Edited by H. Schubert and M. Regier
113 **Food safety control in the poultry industry**
Edited by G. Mead
114 **Improving the safety of fresh fruit and vegetables**
Edited by W. Jongen
115 **Food, diet and obesity**
Edited by D. Mela
116 **Handbook of hygiene control in the food industry**
Edited by H. L. M. Lelieveld, M. A. Mostert and J. Holah
117 **Detecting allergens in food**
Edited by S. Koppelman and S. Hefle
118 **Improving the fat content of foods**
Edited by C. Williams and J. Buttriss
119 **Improving traceability in food processing and distribution**
Edited by I. Smith and A. Furness
120 **Flavour in food**
Edited by A. Voilley and P. Etievant
121 **The Chorleywood bread process**
S. P. Cauvain and L. S. Young
122 **Food spoilage microorganisms**
Edited by C. de W. Blackburn
123 **Emerging foodborne pathogens**
Edited by Y. Motarjemi and M. Adams
124 **Benders' dictionary of nutrition and food technology Eighth edition**
D. A. Bender
125 **Optimising sweet taste in foods**
Edited by W. J. Spillane
126 **Brewing: New technologies**
Edited by C. Bamforth
127 **Handbook of herbs and spices Volume 3**
Edited by K. V. Peter

128 **Lawrie's meat science Seventh edition**
R. A. Lawrie in collaboration with D. A. Ledward
129 **Modifying lipids for use in food**
Edited by F. Gunstone
130 **Meat products handbook: Practical science and technology**
G. Feiner
131 **Food consumption and disease risk: Consumer–pathogen interactions**
Edited by M. Potter
132 **Acrylamide and other hazardous compounds in heat-treated foods**
Edited by K. Skog and J. Alexander
133 **Managing allergens in food**
Edited by C. Mills, H. Wichers and K. Hoffman-Sommergruber
134 **Microbiological analysis of red meat, poultry and eggs**
Edited by G. Mead
135 **Maximising the value of marine by-products**
Edited by F. Shahidi
136 **Chemical migration and food contact materials**
Edited by K. Barnes, R. Sinclair and D. Watson
137 **Understanding consumers of food products**
Edited by L. Frewer and H. van Trijp
138 **Reducing salt in foods: Practical strategies**
Edited by D. Kilcast and F. Angus
139 **Modelling microorganisms in food**
Edited by S. Brul, S. Van Gerwen and M. Zwietering
140 **Tamime and Robinson's Yoghurt: Science and technology Third edition**
A. Y. Tamime and R. K. Robinson
141 **Handbook of waste management and co-product recovery in food processing Volume 1**
Edited by K. W. Waldron
142 **Improving the flavour of cheese**
Edited by B. Weimer
143 **Novel food ingredients for weight control**
Edited by C. J. K. Henry
144 **Consumer-led food product development**
Edited by H. MacFie
145 **Functional dairy products Volume 2**
Edited by M. Saarela
146 **Modifying flavour in food**
Edited by A. J. Taylor and J. Hort
147 **Cheese problems solved**
Edited by P. L. H. McSweeney
148 **Handbook of organic food safety and quality**
Edited by J. Cooper, C. Leifert and U. Niggli
149 **Understanding and controlling the microstructure of complex foods**
Edited by D. J. McClements
150 **Novel enzyme technology for food applications**
Edited by R. Rastall
151 **Food preservation by pulsed electric fields: From research to application**
Edited by H. L. M. Lelieveld and S. W. H. de Haan
152 **Technology of functional cereal products**
Edited by B. R. Hamaker
153 **Case studies in food product development**
Edited by M. Earle and R. Earle
154 **Delivery and controlled release of bioactives in foods and nutraceuticals**
Edited by N. Garti

155 **Fruit and vegetable flavour: Recent advances and future prospects**
Edited by B. Brückner and S. G. Wyllie
156 **Food fortification and supplementation: Technological, safety and regulatory aspects**
Edited by P. Berry Ottaway
157 **Improving the health-promoting properties of fruit and vegetable products**
Edited by F. A. Tomás-Barberán and M. I. Gil
158 **Improving seafood products for the consumer**
Edited by T. Børresen
159 **In-pack processed foods: Improving quality**
Edited by P. Richardson
160 **Handbook of water and energy management in food processing**
Edited by J. Klemeš, R. Smith and J.-K. Kim
161 **Environmentally compatible food packaging**
Edited by E. Chiellini
162 **Improving farmed fish quality and safety**
Edited by Ø. Lie
163 **Carbohydrate-active enzymes**
Edited by K.-H. Park
164 **Chilled foods: A comprehensive guide Third edition**
Edited by M. Brown
165 **Food for the ageing population**
Edited by M. M. Raats, C. P. G. M. de Groot and W. A. Van Staveren
166 **Improving the sensory and nutritional quality of fresh meat**
Edited by J. P. Kerry and D. A. Ledward
167 **Shellfish safety and quality**
Edited by S. E. Shumway and G. E. Rodrick
168 **Functional and speciality beverage technology**
Edited by P. Paquin
169 **Functional foods: Principles and technology**
M. Guo
170 **Endocrine-disrupting chemicals in food**
Edited by I. Shaw
171 **Meals in science and practice: Interdisciplinary research and business applications**
Edited by H. L. Meiselman
172 **Food constituents and oral health: Current status and future prospects**
Edited by M. Wilson
173 **Handbook of hydrocolloids Second edition**
Edited by G. O. Phillips and P. A. Williams
174 **Food processing technology: Principles and practice Third edition**
P. J. Fellows
175 **Science and technology of enrobed and filled chocolate, confectionery and bakery products**
Edited by G. Talbot
176 **Foodborne pathogens: Hazards, risk analysis and control Second edition**
Edited by C. de W. Blackburn and P. J. McClure
177 **Designing functional foods: Measuring and controlling food structure breakdown and absorption**
Edited by D. J. McClements and E. A. Decker
178 **New technologies in aquaculture: Improving production efficiency, quality and environmental management**
Edited by G. Burnell and G. Allan
179 **More baking problems solved**
S. P. Cauvain and L. S. Young
180 **Soft drink and fruit juice problems solved**
P. Ashurst and R. Hargitt

181 **Biofilms in the food and beverage industries**
Edited by P. M. Fratamico, B. A. Annous and N. W. Gunther
182 **Dairy-derived ingredients: Food and neutraceutical uses**
Edited by M. Corredig
183 **Handbook of waste management and co-product recovery in food processing Volume 2**
Edited by K. W. Waldron
184 **Innovations in food labelling**
Edited by J. Albert
185 **Delivering performance in food supply chains**
Edited by C. Mena and G. Stevens
186 **Chemical deterioration and physical instability of food and beverages**
Edited by L. H. Skibsted, J. Risbo and M. L. Andersen
187 **Managing wine quality Volume 1: Viticulture and wine quality**
Edited by A. G. Reynolds
188 **Improving the safety and quality of milk Volume 1: Milk production and processing**
Edited by M. Griffiths
189 **Improving the safety and quality of milk Volume 2: Improving quality in milk products**
Edited by M. Griffiths
190 **Cereal grains: Assessing and managing quality**
Edited by C. Wrigley and I. Batey
191 **Sensory analysis for food and beverage quality control: A practical guide**
Edited by D. Kilcast
192 **Managing wine quality Volume 2: Oenology and wine quality**
Edited by A. G. Reynolds
193 **Winemaking problems solved**
Edited by C. E. Butzke
194 **Environmental assessment and management in the food industry**
Edited by U. Sonesson, J. Berlin and F. Ziegler
195 **Consumer-driven innovation in food and personal care products**
Edited by S. R. Jaeger and H. MacFie
196 **Tracing pathogens in the food chain**
Edited by S. Brul, P. M. Fratamico and T. A. McMeekin
197 **Case studies in novel food processing technologies: Innovations in processing, packaging, and predictive modelling**
Edited by C. J. Doona, K. Kustin and F. E. Feeherry
198 **Freeze-drying of pharmaceutical and food products**
T.-C. Hua, B.-L. Liu and H. Zhang
199 **Oxidation in foods and beverages and antioxidant applications Volume 1: Understanding mechanisms of oxidation and antioxidant activity**
Edited by E. A. Decker, R. J. Elias and D. J. McClements
200 **Oxidation in foods and beverages and antioxidant applications Volume 2: Management in different industry sectors**
Edited by E. A. Decker, R. J. Elias and D. J. McClements
201 **Protective cultures, antimicrobial metabolites and bacteriophages for food and beverage biopreservation**
Edited by C. Lacroix
202 **Separation, extraction and concentration processes in the food, beverage and nutraceutical industries**
Edited by S. S. H. Rizvi
203 **Determining mycotoxins and mycotoxigenic fungi in food and feed**
Edited by S. De Saeger
204 **Developing children's food products**
Edited by D. Kilcast and F. Angus

205 **Functional foods: Concept to product Second edition**
Edited by M. Saarela
206 **Postharvest biology and technology of tropical and subtropical fruits Volume 1: Fundamental issues**
Edited by E. M. Yahia
207 **Postharvest biology and technology of tropical and subtropical fruits Volume 2: Açai to citrus**
Edited by E. M. Yahia
208 **Postharvest biology and technology of tropical and subtropical fruits Volume 3: Cocona to mango**
Edited by E. M. Yahia
209 **Postharvest biology and technology of tropical and subtropical fruits Volume 4: Mangosteen to white sapote**
Edited by E. M. Yahia
210 **Food and beverage stability and shelf life**
Edited by D. Kilcast and P. Subramaniam
211 **Processed Meats: Improving safety, nutrition and quality**
Edited by J. P. Kerry and J. F. Kerry
212 **Food chain integrity: A holistic approach to food traceability, safety, quality and authenticity**
Edited by J. Hoorfar, K. Jordan, F. Butler and R. Prugger
213 **Improving the safety and quality of eggs and egg products Volume 1**
Edited by Y. Nys, M. Bain and F. Van Immerseel
214 **Improving the safety and quality of eggs and egg products Volume 2**
Edited by F. Van Immerseel, Y. Nys and M. Bain
215 **Animal feed contamination: Effects on livestock and food safety**
Edited by J. Fink-Gremmels
216 **Hygienic design of food factories**
Edited by J. Holah and H. L. M. Lelieveld
217 **Manley's technology of biscuits, crackers and cookies Fourth edition**
Edited by D. Manley
218 **Nanotechnology in the food, beverage and nutraceutical industries**
Edited by Q. Huang
219 **Rice quality: A guide to rice properties and analysis**
K. R. Bhattacharya
220 **Advances in meat, poultry and seafood packaging**
Edited by J. P. Kerry
221 **Reducing saturated fats in foods**
Edited by G. Talbot
222 **Handbook of food proteins**
Edited by G. O. Phillips and P. A. Williams
223 **Lifetime nutritional influences on cognition, behaviour and psychiatric illness**
Edited by D. Benton
224 **Food machinery for the production of cereal foods, snack foods and confectionery**
L.-M. Cheng
225 **Alcoholic beverages: Sensory evaluation and consumer research**
Edited by J. Piggott
226 **Extrusion problems solved: Food, pet food and feed**
M. N. Riaz and G. J. Rokey
227 **Handbook of herbs and spices Second edition Volume 1**
Edited by K. V. Peter
228 **Handbook of herbs and spices Second edition Volume 2**
Edited by K. V. Peter
229 **Breadmaking: Improving quality Second edition**
Edited by S. P. Cauvain

230 **Emerging food packaging technologies: Principles and practice**
Edited by K. L. Yam and D. S. Lee
231 **Infectious disease in aquaculture: Prevention and control**
Edited by B. Austin
232 **Diet, immunity and inflammation**
Edited by P. C. Calder and P. Yaqoob
233 **Natural food additives, ingredients and flavourings**
Edited by D. Baines and R. Seal
234 **Microbial decontamination in the food industry: Novel methods and applications**
Edited by A. Demirci and M. O. Ngadi
235 **Chemical contaminants and residues in foods**
Edited by D. Schrenk
236 **Robotics and automation in the food industry: Current and future technologies**
Edited by D. G. Caldwell
237 **Fibre-rich and wholegrain foods: Improving quality**
Edited by J. A. Delcour and K. Poutanen
238 **Computer vision technology in the food and beverage industries**
Edited by D.-W. Sun
239 **Encapsulation technologies and delivery systems for food ingredients and nutraceuticals**
Edited by N. Garti and D. J. McClements
240 **Case studies in food safety and authenticity**
Edited by J. Hoorfar
241 **Heat treatment for insect control: Developments and applications**
D. Hammond
242 **Advances in aquaculture hatchery technology**
Edited by G. Allan and G. Burnell
243 **Open innovation in the food and beverage industry**
Edited by M. Garcia Martinez
244 **Trends in packaging of food, beverages and other fast-moving consumer goods (FMCG)**
Edited by N. Farmer
245 **New analytical approaches for verifying the origin of food**
Edited by P. Brereton
246 **Microbial production of food ingredients, enzymes and nutraceuticals**
Edited by B. McNeil, D. Archer, I. Giavasis and L. Harvey
247 **Persistent organic pollutants and toxic metals in foods**
Edited by M. Rose and A. Fernandes
248 **Cereal grains for the food and beverage industries**
E. Arendt and E. Zannini
249 **Viruses in food and water: Risks, surveillance and control**
Edited by N. Cook
250 **Improving the safety and quality of nuts**
Edited by L. J. Harris
251 **Metabolomics in food and nutrition**
Edited by B. C. Weimer and C. Slupsky
252 **Food enrichment with omega-3 fatty acids**
Edited by C. Jacobsen, N. S. Nielsen, A. F. Horn and A.-D. M. Sørensen
253 **Instrumental assessment of food sensory quality: A practical guide**
Edited by D. Kilcast
254 **Food microstructures: Microscopy, measurement and modelling**
Edited by V. J. Morris and K. Groves
255 **Handbook of food powders: Processes and properties**
Edited by B. R. Bhandari, N. Bansal, M. Zhang and P. Schuck
256 **Functional ingredients from algae for foods and nutraceuticals**
Edited by H. Domínguez

257 **Satiation, satiety and the control of food intake: Theory and practice**
Edited by J. E. Blundell and F. Bellisle
258 **Hygiene in food processing: Principles and practice Second edition**
Edited by H. L. M. Lelieveld, J. Holah and D. Napper
259 **Advances in microbial food safety Volume 1**
Edited by J. Sofos
260 **Global safety of fresh produce: A handbook of best practice, innovative commercial solutions and case studies**
Edited by J. Hoorfar
261 **Human milk biochemistry and infant formula manufacturing technology**
Edited by M. Guo
262 **High throughput screening for food safety assessment: Biosensor technologies, hyperspectral imaging and practical applications**
Edited by A. K. Bhunia, M. S. Kim and C. R. Taitt
263 **Foods, nutrients and food ingredients with authorised EU health claims: Volume 1**
Edited by M. J. Sadler
264 **Handbook of food allergen detection and control**
Edited by S. Flanagan
265 **Advances in fermented foods and beverages: Improving quality, technologies and health benefits**
Edited by W. Holzapfel
266 **Metabolomics as a tool in nutrition research**
Edited by J.-L. Sébédio and L. Brennan
267 **Dietary supplements: Safety, efficacy and quality**
Edited by K. Berginc and S. Kreft
268 **Grapevine breeding programs for the wine industry**
Edited by A. Reynolds
269 **Handbook of antimicrobials for food safety and quality**
Edited by T. M. Taylor
270 **Managing and preventing obesity: Behavioural factors and dietary interventions**
Edited by T. P. Gill
271 **Electron beam pasteurization and complementary food processing technologies**
Edited by S. D. Pillai and S. Shayanfar
272 **Advances in food and beverage labelling: Information and regulations**
Edited by P. Berryman
273 **Flavour development, analysis and perception in food and beverages**
Edited by J. K. Parker, S. Elmore and L. Methven
274 **Rapid sensory profiling techniques and related methods: Applications in new product development and consumer research**
Edited by J. Delarue, J. B. Lawlor and M. Rogeaux
275 **Advances in microbial food safety: Volume 2**
Edited by J. Sofos
276 **Handbook of antioxidants for food preservation**
Edited by F. Shahidi
277 **Lockhart and Wiseman's crop husbandry including grassland: Ninth edition**
H. J. S. Finch, A. M. Samuel and G. P. F. Lane
278 **Global legislation for food contact materials**
Edited by J. S. Baughan
279 **Colour additives for food and beverages**
Edited by M. Scotter
280 **A complete course in canning and related processes 14th Edition: Volume 1**
Revised by S. Featherstone
281 **A complete course in canning and related processes 14th Edition: Volume 2**
Revised by S. Featherstone

282 **A complete course in canning and related processes 14th Edition: Volume 3**
Revised by S. Featherstone
283 **Modifying food texture: Volume 1: Novel ingredients and processing techniques**
Edited by J. Chen and A. Rosenthal
284 **Modifying food texture: Volume 2: Sensory analysis, consumer requirements and preferences**
Edited by J. Chen and A. Rosenthal
285 **Modeling food processing operations**
Edited by Serafim Bakalis, Kai Knoerzer and Peter J. Fryer
286 **Foods, Nutrients and Food Ingredients With Authorised EU Health Claims Volume 2**
Edited by Michele Sadler
287 **Feed and Feeding Practices in Aquaculture**
Edited by D. Allen Davis

Traditional grapevine breeding techniques

1

R. Eibach, R. Töpfer
JKI Institute for Grapevine Breeding, Geilweilerhof, Germany

1.1 Introduction

Targeted breeding activities started around the beginning of the nineteenth century, predominantly in North America. The colonists failed to grow the delicately flavoured *Vitis vinifera* vines they were accustomed to, due to severe frost damage as well as the destruction of the grapes by pests like phylloxera or by fungal diseases like powdery and downy mildew. On the other hand, the sturdy native American grapes that could be grown easily produced strong-flavoured wines that they did not like. In 1822, researchers from Harvard University recommended developing hybrids between the European vines and the indigenous grapes in order to combine the hardiness and resistance of the American grapes with the pleasant flavour of the *V. vinifera* grapes (Cattell and Miller, 1980). During the following decades, a lot of engaged breeders like William W. Valk, Nicholas Herbemont, Hermann Jaeger or Thomas Munson developed successful newly introduced cultivars like Ada, Herbemont, Brighton or Diamond. The plethora of cultivars developed during this period are summarized as so-called American hybrids. In Europe, resistance breeding was initiated after the introduction of phylloxera and the mildews from North America in the second part of the nineteenth century. Mainly in France, phylloxera destroyed hundreds of thousands of hectares of grapevines and catalysed a lot of private French breeders to start their own breeding programme. Breeders like Gaillard, Bertille Seyve, Seibel, Couderc, Kuhlmann, Baco, Seyve Villard, Landot and others created thousands of new cultivars with the aim of combining resistance against phylloxera and the mildews as well as producing high quality. Those and other breeders were aiming at so-called direct producers, but many of these cultivars failed. In retrospect, it can be summarized that insufficient suitability tests for other viticultural traits except the resistance characteristics caused failure in the overall performance of the new cultivars. The plants were not checked thoroughly for wine quality, and this was obviously one of the major reasons why, in the public perception, resistance was associated with poor wine quality. Even today, this position is still alive in some minds. The limited reputation of those cultivars and the discovery of the fungicidal properties of copper and sulphur in 1885 led finally to a total surrender of the private breeding activities in France. Nevertheless, the historical merit of these breeders is that they created a highly valuable genetic resource carrying, to some extent, a combination of resistance and quality. These cultivars were summarized as so-called French hybrids, and they have since being used extensively for further breeding activities during the second part of the twentieth century.

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00001-6

In other countries, targeted resistance breeding started later. In Germany, it was initiated by Erwin Baur in 1926. First generations of new varieties resulted in cultivars like Aris or Siegfriedrebe, while Aris was the first cultivar with extensive proof that resistance and poor wine quality are not linked. But because of other viticultural deficiencies, it could not succeed on the market. Considerable breeding activities were also established in the US but also in Eastern European countries like Hungary, the former Yugoslavia, the former Czechoslovakia, the former USSR and others. Newly released cultivars like Traminette (USA), Bianca, Kunbarat (Hungary) or Regent (Germany) are examples of these successful breeding programmes. All these cultivars can be summarized as a new generation of cultivars derived from classical breeding.

Besides resistance breeding, several countries developed breeding programmes restricted to the gene pool of *V. vinifera*, neglecting resistance and focusing mainly on yield and quality traits, as well as other viticultural traits. This led to a series of newly introduced cultivars, mainly in northern European grape-growing countries. The most prominent example is the cultivar Müller-Thurgau, which was crossed in 1882 from Herrmann Müller in Geisenheim, Germany. Meanwhile, these breeding activities have stopped to a great extent and have largely been replaced by resistance breeding.

1.2 Procedures in cross breeding

1.2.1 Generation of crossing populations

1.2.1.1 Emasculation

While wild grapes are dioecious, most of the cultivated grapes are hermaphroditic, and fertilization occurs mainly via self-pollination (Harst et al., 2009). Therefore, emasculation of plants is required to use them as female parents. This, however, is a very laborious process, both for the technique of emasculation itself and for determining the appropriate time for emasculation. Usually emasculation is carried out using tweezers with small and tiny tops. Removing all anthers completely is as important as avoiding any injury of the stigma and pistil. Therefore, good eyes and calm hands are equally important prerequisites for those doing the emasculations. Because fertilization may already happen before ejecting the cap (Staudt, 1999), the removal of anthers must be carried out at the right time ahead of flowering. Changing weather conditions, especially changing temperature cycles in the preflowering phase, complicate a reliable forecast for the determination of the optimal point in time. The beginning of bracing the flowers from the rachis along the inflorescence is the most reliable indicator for determining the optimal time for emasculation. Flowers located in the centre and basal parts of the inflorescence tend to blossom out ahead. Therefore, removing the top and the shoulder parts of the inflorescence favours a more unique flowering of the remaining flowers, promoting an enhanced fruit set after pollination.

After emasculation, the inflorescence has to be protected against random pollination due to dispersal of arbitrary grapevine pollen by wind or insects. For this purpose, bags of glassine paper are quite appropriate. These kinds of bags proved to be suitable to prevent an exceeded increase of temperature inside the bags due to sunlight exposure.

1.2.1.2 Collection of pollen

The collection of pollen from selected male parents is most frequently carried out by enclosing the inflorescences with bags right before the beginning of blooming. During flowering, the pollen drops into the bags, and the bags, including the pollen, can be removed after flowering. In many cases, a crucial point for performing crossings is the availability of pollen from the selected male parents in due time. Several approaches might be considered to solve this challenge. One projection is the use of variation of flowering time between parents by selecting the earlier flowering parent as the male. Furthermore, since pollen is already fertile some days before blooming (Koblet and Vetsch, 1968), inflorescences of pollen donors can be harvested ahead of the blossom. Drying them gently at around 25°C in a heating cabinet and subsequently pulverizing the flowers, including the pollen sacs, allows a gain of several days for pollen access. A further approach comprises the coating of potential pollen donors with a plastic foil (Figure 1.1). Coating should be carried out before or no later than the beginning of bud burst. Especially during sunny periods, this simulates a greenhouse effect. Due to the increased temperatures around the coated canes, bud burst and shoot development (Figure 1.1) are significantly sped up. Depending on weather conditions during that period (temperature, radiation), this treatment leads to an advanced blooming of around 10–12 days. Since the pollen of a grapevine keeps its viability to large extents when stored at –20°C or below (Failla et al., 1991), it can also be superimposed from one year to another. Using these tools increases flexibility for determining crossing combinations on a short-term basis, which will obviously become more important in the future, when new insights about the genetics of important characteristics should be transferred into practical breeding as quickly as possible.

1.2.1.3 Pollination and fruit set

The optimal time for pollination is reached when the stigmatic fluid, a sticky secretion, appears on the stigma of the pistils. The sticky secretion supports adhesion of pollen grains to the stigma. The pollen grains absorb water from the secretion, which is the initial step to forming a pollen tube. Pollination before or, notably, after the presence of the secretion droplet may result in a lower fruit set. Since the secretion droplet does not occur on all flowers of the inflorescence at the same time, it is advisable to carry out the pollination twice or even more frequently. Depending on weather conditions, the intervals between repetitive pollinations may range from one day up to five or

Figure 1.1 Influence of foliage coating on growth (left) compared to control (right).

more days. After pollination, the inflorescence needs to be covered again by a glassine paper bag to prevent undesired pollination.

During blooming, the tip of the shoot acts as a strong sink and competes with the inflorescences for assimilates. Earlier investigations (Koblet, 1969; Loomis, 1979; Luckert, 1976) indicate an improved fruit set after excluding the shoot tip as a competing sink. Our own investigations (Eibach, unpublished) show that the removal of the shoot tip during pollination improves the fruit set, resulting in an increased number of seeds per cluster compared to pollinated inflorescences without shoot tip removal.

1.2.1.4 Seed management

Harvesting of seeds is carried out when the physiological ripening of berries is reached. In fact, since with the beginning of veraison the embryos of the seeds are fully developed, seed harvesting could be carried out earlier. But harvesting at berry ripening is more convenient, especially concerning the extraction of the seeds from the flesh of the fruit. Moreover, it could be demonstrated that germination rate increases, starting from veraison, and reaches its maximum at the physiological berry-ripening stage (Eibach, unpublished). Due to the fact that seeds with no or poorly developed embryos have reduced specific weight, these seeds are swimming on water. These kinds of seeds can be eliminated immediately after seed extraction with a flotation test and can increase the germination rate when using only the residual sinking seeds. Germination rate is determined genetically to a considerable extent. On the species level in general, it can be stated that most wild species exhibit a higher germination rate compared to cultivars belonging to *V. vinifera*. But also within the pool of *V. vinifera*, there is a huge variation. Lott (1969) identified differences of the germination rate reaching up to a factor of 10 when comparing crossing combinations with the reciprocal combinations. This indicates that breeders can use appropriate available information for increasing breeding efficiency by choosing the parent with the higher seed germination rate as female.

Extracted seeds require the break of dormancy before sowing. For breaking dormancy, several physical and chemical treatments, including different combinations, are described. A common practice is a stratification treatment where the seeds are stored for around 75 days at 2–4°C (Rives, 1965). Alternatively, the seeds can be exposed for about 2 weeks at 4°C with a daily period of about 2–4 h of increased temperatures of 30°C (Balthazard, 1969). Kachru et al. (1972) reported that germination rates increased when seeds were kept for 12–16 days under running water. Placing a small cut on the median region of the seed or on the micropyle is another approach for increasing germination rates (Borges do Val et al., 2010). However, the application of this technique in breeding programmes with huge amounts of seeds per year is routinely hardly feasible. Several reports (Borges do Val et al., 2010; Burrows, 1994; Ellis et al., 1983) describe increased germination rates after treating the seeds with gibberellic acid (GA3). However, GA3 treatments induce increased elongation of hypocotyls after germination (Burrows, 1994), which might be unfavourable for further seedling cultivation.

1.2.2 Important traits for selection and applied methods

1.2.2.1 General remarks

The whole procedure of breeding a new cultivar, starting from the initial cross up to the release of a cultivar, lasts about 25–30 years when executing traditional selection techniques. Figure 1.1 shows the different steps of grapevine breeding on a time scale. Compared to most other agricultural crops, the whole breeding cycle lasts notably longer. Since grapevine is propagated vegetatively, each individual seedling derived from a cross-combination is a candidate for a prospective cultivar. In fact, creating genetic variation and its fixed determination needs only a very short time and is achieved after growing the seedlings within one vegetation period. The following breeding activities are exclusively focused on the evaluation of important traits. Due to the fact that a grapevine is a perennial crop, this procedure is very time-consuming and covers nearly the whole breeding cycle. The specification about the importance of traits is basically determined by the final usage of the new cultivar (wine grape, table grape). Within one category, it is mainly influenced by the presence and severity of distinct pests and diseases, the climatic conditions in different regions or countries, as well as by the demands of the wine industry. Along the breeding cycle, the focus of evaluation moves. Usually in the early seedling stage, the main emphasis is placed on screening for resistance to the most important diseases, such as the mildews. Typically, this is a selection which passes only around 20% of the seedlings. With the appearance of the first small crop load, the evaluation of other important traits, such as cluster architecture, phenological traits or more general viticultural traits (such as shoot growth or axillary formation), can be carried out. The next crucial step is the first vegetative propagation of selected seedlings, since this commonly goes along with another reduction of the initial amount of seedlings up to 1%. Increased yield due to more individuals per breeding line allows the shifting toward quality determining traits. This includes the analysis of decisive compounds as well as sensorial evaluation. Finally, trials with promising breeding lines at different locations in a final step prior to variety release serve in validating achieved results on different locations and different environments and investigating interactions of genotype and environment.

The following explanations describe evaluation and selection procedures for a couple of important traits of breeding vine cultivars. However, quite a few of them can be transferred to table grape breeding. Furthermore, all methods and procedures described are based on phenotypic evaluation techniques. Recent progress in grapevine genetics revealed a series of genome loci associated with distinctive traits (further details: http://www.vivc.de/docs/dataonbreeding/20130521_Table%20of%20Loci%20within%20VITIS.pdf) and allowed the application of selection tools based on genetic fingerprinting. These selection tools are not discussed in this chapter.

1.2.2.2 Biotic factors

Downy mildew

Since downy mildew is one of the most serious fungal diseases worldwide, breeding for resistance is a very common breeding goal in different breeding programmes around the world. Important sources for resistance are a series of American *Vitis* species, such as *Vitis rupestris*. Some Asian *Vitis* species also proved to exhibit resistance characteristics, whereas the Asian *Vitis amurensis* is probably the most intensive source used in resistance breeding. Different resistance loci from *V. amurensis* are identified (Schwander et al., 2012; Venuti et al., 2013) and used in breeding programmes.

Phenotypic screening for downy mildew can be carried out in the very first phase of the breeding cycle on young seedlings (Figure 1.2). The degree of resistance can be evaluated after artificial inoculation of the seedlings with sporangiospores of downy mildew. This method was first described by Husfeld (1933) and proved to be very effective and reliable. It can be applied during all phases of seedling development, but its early application, when seedlings reach a growing stage with about four leaves, is advisable. This allows refusing the susceptible seedlings in a very early stage, which increases breeding efficiency by saving resources. Sporangiospores for inoculation experiments may be collected from the infected leaves of susceptible plants, which are separately grown and used for fungus propagation. Sporangiospores are removed by washing the infected leaves in cold water embedded in an ice bath. This low temperature prevents the germination of the sporangiospores ahead of the inoculation. Calculating the number of spores in a counting chamber allows the adjustment of the

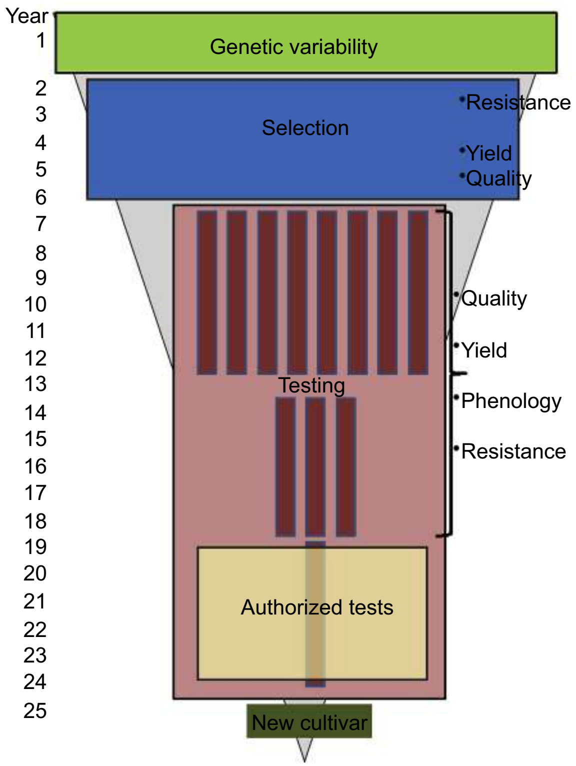


Figure 1.2 Scheme for grapevine breeding.

spore density of the suspension. According to Eibach et al. (1989), a density of 20,000 sporangiospores per millilitre leads to reliable results. Inoculation can be carried out with a manual sprayer, paying attention to distribute the suspension especially on the lower leaf side. Growing the inoculated seedlings at approximately 23°C combined with high humidity, especially immediately after inoculation, increases infection pressure. Evaluation can be carried out about 5–7 days after inoculation and may be completed according to the OIV descriptor following a five-grade scale. Depending on the genetic background of the parents, the frequency distributions of resistance ratings within different offspring may vary considerably. For breeding purposes, it is quite easy to handle the extremes of the frequency distribution, meaning discarding the fully susceptible seedlings and keeping the fully resistant ones. The selection is more sophisticated for seedlings showing a certain degree of resistance. By drawing a threshold, it should be considered that this kind of selection procedure favours extreme fungus development and fungus growth, indicating that a certain degree of resistance under these conditions might be sufficient for avoiding disease damage under natural growing conditions with less fungus pressure.

Alternatively, resistance screening for downy mildew can be executed by bioassays with leaf discs (Calonnec et al., 2013; Eibach et al., 1989). Due to the fact that this method allows a better standardization of some experimental variables, such as leaf age or inoculation procedure, the accuracy of results may increase. On the other hand, the throughput of this protocol is considerably lower, which might be a disadvantage, especially in breeding programmes with a high number of annually created seedlings.

Powdery mildew

Similar to downy mildew, powdery mildew is present in nearly all wine-growing areas of the world and requires intensive plant protection measurements for preventing serious crop loss. All cultivars belonging to *V. vinifera* are susceptible, except a few exceptions coming from Central Asia recently described as highly resistant (Coleman et al., 2009). During the nineteenth century, a range of American *Vitis* species, such as *Vitis riparia*, *V. rupestris* and *Vitis lincecumii*, were the most important sources for resistance breeding. In recent years, an additional valuable source for powdery mildew resistance could be introgressed from *Muscadinia rotundifolia* after overcoming the crossing barriers, which are due to the different number of chromosomes. Also, some Asian species, such as *Vitis romanetii*, are known to be valuable sources for powdery mildew resistance (Ramming et al., 2011).

Screening for powdery mildew resistance is more difficult and requires more time compared to downy mildew resistance screening. This is because the period from infection to visible disease symptoms lasts notably longer, which is about 2 weeks with favourable climatic conditions for the fungus. Since conidia growth is strongly inhibited under wet conditions, a dispersal of spore suspension for artificial inoculation can be excluded. Dispersal of conidia by brushing or blowing them from the infected leaves ahead of the seedling shoots is an alternative option. But doing so, even distribution of the conidia and, hence, a standardized infection pressure for all seedlings to be tested is hard to provide. Miclot et al. (2012) describe a method using detached young leaves, which is adapted to large sample sizes and allows the compilation of quantitative variation. This method is especially valuable if very accurate evaluation figures are required, for example, the accurate ratings of the segregation patterns in crossing populations or for evaluating and describing accessions of genetic resources. In these cases, if precise ratings are required, the exclusive rating of the occurrence of natural infection may not be the method of choice. But for breeding purposes, this approach is quite common and it frequently fits the demands. Natural infections are likely almost everywhere, and they are easy to achieve. Growing conditions favouring fungus development, that is preventing leaf wetting and favouring high humidity, may additionally contribute to increased fungus pressure. Hence, just for making a decision to keep or to withdraw a seedling, this procedure seems to be sufficiently reliable. At that point, it should be recalled that within a routine breeding programme, the applied diagnosis procedures, especially in early breeding stages, are not aligned to describe special characteristics of individual vines in detail. Moreover, they are applied in a decision either to discard or to keep the material.

For breeding programmes focused on mildew resistance, it is advisable to accomplish the two mildew selection steps in a consecutive way, starting with downy mildew screening at the beginning of the growing cycle. Only seedlings with sufficient resistance will be evaluated in the following powdery mildew selection process. Depending on the crossing combination, these two subsequent evaluation steps lead to a considerable reduction of the number of seedlings. The breeding material may be restricted to about 25% or even less of the initial extent. However, recent progress in grapevine genetics will allow making very systematic choices for parent selection, which will increase the percentage of resistant genotypes in the offspring considerably (Eibach et al., 2007) (for details see Section 1.4).

Bunch rot (*Botrytis cinerea*)

Similar to the mildews, *Botrytis* occurs in most grape-growing areas around the world. It may cause severe damage, especially in areas and seasons with humid and/or wet conditions during the late season. Early infection of berries leads to sour rot and reduces yield, as well as quality. Resistance against *Botrytis* is a very complex trait, because it is influenced by different biochemical, morphological and phenological characteristics. Some investigations were carried out to subdivide this complex trait into individual components. Blaich et al. (1982) identified a relation between the formation of stilbenes in the leaf and the degree of *Botrytis* resistance of berries. The application of this method on leaf discs is described by Eibach et al. (1989). But since this correlation is rather weak, this method does not seem suitable for a final decision either to discard or to keep a seedling. Nevertheless, so far this is the only available early diagnosis tool to evaluate disease occurrence on berries. An important morphological factor influencing the degree of *Botrytis* resistance proved to be the presence of perforations in the cuticle, which increased its intensity (Blaich et al., 1984). Further characteristics influencing the degree of *Botrytis* resistance on the berry level are the thickness of the cuticle and the thickness of the wax layer, as well as its composition. On the bunch level, all factors favouring well-aerated bunches reduce the probability of *Botrytis* infection. These comprise, for example, the berry size, the number of berries per cluster and the cluster density, as well as the length of the peduncle. Furthermore, the phenological characteristic 'berry ripening' is also an important factor influencing *Botrytis* resistance. Early berry ripening favours *Botrytis* infection since this coincides regularly with the increased sugar content of berries and increased temperatures during the ripening period: both factors enhance infection pressure.

Finally, it can be stated that selection for *Botrytis* resistance so far is mainly due to the scoring of natural infection prior to harvest. Really efficient tools for the early diagnosis of resistance are not available so far. The evaluation starts when seedlings bear the first crop. Since infection pressure may vary considerably in different years, it should be continued for several years. Even during the testing phase close to variety releasing (Figure 1.2), it is valuable to determine *Botrytis* infection, since at this stage interaction due to different locations and environments can be investigated.

Anthracnose (*Elsinoe ampelina*)

This disease occurs preferably in rainy, humid regions, as well as in subtropical and tropical wine-growing areas and may lead to severe damage and crop loss. Since all varieties belonging to *V. vinifera* are susceptible, they need regular plant protection measurements in these vine-growing areas. Even though there are some reports about genetic resources for resistance against anthracnose (Jang et al., 2011; Mortensen, 1980; Wang et al., 1998), this knowledge is still fragmentary. For evaluating resistance, different methods are specified. Hopkins and Harris (2000) describe a method for screening in the greenhouse after artificial infection with a spore suspension. Yun et al. (2007) developed a bioassay screening method for resistance to anthracnose with culture filtrates from *Elsinoe ampelina*. The consistence of these methods compared to the screening of natural infection in the vineyard was confirmed by Yun et al. (2006). Meanwhile, for selection on a genetic level, first molecular markers associated with resistance are described (Kim et al., 2008).

Black rot

This fungal disease caused by *Guignardia bidwelii* occurs mainly in climatic regions with humid weather conditions. It is one of the most important economical diseases in the northeastern part of America, Canada and South America. In recent years, it also received increased importance in parts of Europe. Reports about sources of resistance are scarce. Jabco et al. (1985) described increased resistance of some 'American hybrids' with *Vitis labrusca* in its parentage, as well as of some 'French hybrids' with complex pedigree. Rex (2012) reports the rootstock cultivar Boerner as highly resistant. Boerner is derived from a cross between *V. riparia* and *Vitis cinerea*. An early diagnosis method for phenotypic resistance screening is described by Rex (2012). It is based on artificial inoculation of the young leaves from the shoot in growth chambers with high humidity initially after infection. About 2 weeks after infection, ratings can be executed. Genetic analysis on a progeny with the resistant cultivar Boerner as one parent revealed two main quantitative trait locus (QTL)-regions (Rex, 2012), allowing the expectation that marker-assisted selection (MAS) for these resistance loci can be routinely introduced into breeding programmes in the near future.

Rotbrenner

This fungus disease is domestic in Europe and was first described by Müller-Thurgau in 1903. It is widely distributed in various European viticultural regions. Its occurrence is sporadic in some years and is focused on limited local areas. All varieties belonging to *V. vinifera* are susceptible, with slightly differing degrees of susceptibility. According to Kozma (1995), many varieties with wild American species in its ancestry are susceptible as well. Within progenies with *V. amurensis* in its parentage, he could identify susceptible and resistant plants, indicating *V. amurensis* as a potential source for resistance. Since there is no appropriate screening method available, resistance evaluation for breeding purposes is exclusively based on recording the natural infection. So far, growing vines to be tested on locations with frequent occurrence of Rotbrenner is the only way to get reliable information.

Pierce's disease

Pierce's disease (PD) is caused by the bacterium *Xylella fastidiosa*, which is spread by xylem-feeding leafhoppers. It is known to be prevalent within the USA from Florida to California and outside the USA in Central and South America. It is less prevalent where winter temperatures are cold, such as more northern areas, high altitudes or inland areas. Sources of resistance are predominantly wild species native to the southern part of North America, such as *M. rotundifolia*, *Vitis arizonica* (Ruel and Walker, 2006) or *Vitis caribea* (Jimenez and Ingalls, 1990), and the latter is preferably a source for tropical regions. For decades, resistance evaluation was based mainly on scoring the natural infection of the offspring. Recently, molecular markers associated with PD-resistance for a resistance locus initially introgressed from *V. arizonica* could be identified (Riaz et al., 2009). This opens substantial new perspectives for resistance breeding in terms of acceleration and efficiency of breeding programmes.

Crown gall

Crown gall is an important disease in all areas where grapes are grown worldwide, but it is particularly severe in regions with cold climates. The causal bacteria *Agrobacterium vitis* survives systemically in grapevines and initiates infections at wound sites, such as those caused by freeze injuries. Screening can be carried out by the infection of artificially wounded shoots with cultures of *A. vitis* (Szegedi et al., 1984). Approximately 8 weeks after inoculation disease symptoms become visible, they can be screened. Sources of resistance can be predominantly traced back to the Asian species *V. amurensis*. Considerable progress in crown gall resistance was achieved mainly in Hungary. Introgression of resistance from *V. amurensis* was pursued intensively, and since the 1980s, the cultivar Kunbarat, exhibiting crown gall resistance, was released to the market. Studies of segregation patterns in crossing populations with the introgressed resistance source from *V. amurensis* revealed a monogenic dominant inheritance (Szegedi and Kozma, 1984). Since Kuczmog et al. (2012) described molecular markers associated with the resistance locus identified in the cultivar Kunbarat, MAS is a very valuable and effective alternative for resistance screening.

1.2.2.3 Abiotic factors

Frost tolerance

In many grape-growing regions, low temperatures during winter may cause severe damage. A grapevine's ability to survive strong winter frosts is influenced by many variables, such as grapevine nutrition, the point in time of severe frost periods during winter, the speed of temperature dropping or the preceding crop load of the vines, which in turn affects the maturity of the cane wood. However, winter frost resistance is also considerably influenced by genetic factors. Substantial variation can be found within the gene pool of *V. vinifera* cultivars, of which the well-known cultivar Riesling is an example, with superior frost tolerance. Distinct higher levels of frost tolerance can be expected within the gene pool of wild species indigenous in regions with stronger continental climate conditions or indigenous in areas of northern latitude. *Vitis* species exhibiting a high degree of frost tolerance are, for example, the North American species *V. riparia* or the Asian species *V. amurensis* (Zhang et al., 2012). High resistance levels of species coming from continental climate regions are frequently linked to early bud burst, which increases the risk for spring frost damage. When using these kinds of resistance sources, it is a challenge for breeding to dissect the linkage of these two traits.

Evaluation of frost resistance based on the natural occurrence of winter frost damage is very unsatisfying, especially in areas with only occasional severe frost periods over the years. Several approaches are reported for a simplified screening of frost resistance. However, any linkage between variables such as water content or sugar levels of the canes with the degree of frost tolerance could not be verified or were disproved (Baranski, 1983). That is why artificial freezing of winter buds is one of the most reliable methods. According to this method, cuttings are kept in a freezer. Subsequently, the cuttings are kept in a growth chamber and after the beginning of the bud burst of control plants, the percentage of bud burst will be scored. Since environmental factors affect the degree of frost resistance considerably, investigations should be carried out under controlled and strictly standardized conditions, including different freezing levels. Due to the substantial environmental interactions of frost resistance, artificial freezing experiments should be repeated over several years and should include varieties for comparison with well-known tolerance levels. This allows a relative ranking of degree of frost resistance, which might be more significant for practical breeding and viticultural purposes rather than absolute figures. Depending on the gene pool used for the introgression of frost resistance, Cindric and Korac (1990) reported maximum frost tolerance levels in different phases during the winter season. Repeated freezing trials in the early, mid and late winter season may provide this additional information. Since artificial freezing tests are destructive and need considerable amounts of buds per genotype to be tested, they are usually carried out in an advanced breeding step after at least one vegetative propagation cycle.

Drought tolerance

Due to its extensive root system, grapevines are able to withstand longer-lasting dry periods. However, extensive periods of drought lead to yield reduction and – frequently more important – deficiencies in the quality of the wine. Factors affecting drought tolerance can be divided into the root- and leaf-related variables. Since grapes are normally grafted, the rootstock cultivar, as well as the scion cultivar, contributes to the performance of the grafted vine. Consequently, breeding for scion varieties can only take into account the leaf-related variables. The degree of drought tolerance can be estimated by determining the water-use efficiency, that is the ratio of the rate of photosynthesis to the rate of transpiration. Differences between varieties are reported by Eibach and Alleweldt (1985). Other variables related to drought tolerance are stomatal conductance and leaf water potential (Düring, 1999). But attempts to correlate values of stomatal conductance, leaf water potential and the ratio of photosynthesis to transpiration with the genetically determined drought tolerance are of limited success because these variables are simultaneously affected by a number of environmental variables. Consequently, breeding programmes with special attention to drought tolerance are mainly based on empirical experiences, which can be supported by planting test plots of candidate selections on dry regions, in comparison with cultivars with well-known performance.

1.2.2.4 Viticultural traits

Phenological data

The most important phenological data considered in grape breeding include bud burst, flowering, veraison and grape maturity. Selection, either for early or for late phenological stages, depends very much on regional situations, and there is no general priority. For example, late bud burst is preferred in regions with an increased risk for spring frost. Selecting for early bud burst is likely in grape-growing areas with continental influenced climate conditions and with short growing seasons. Likewise, regions with short growing seasons will preferably select for early ripening varieties. Climatic conditions may provide an overall frame for the preferred maturity period. However, within this frame, a graduation of ripening time fits the interest of the wine industry. Furthermore, preferences concerning ripening date may change over time, as can be observed in some northern European vine-growing countries, such as Germany. Some decades ago, selection was preferably focused on early ripening cultivars. This was due to the interest of the wine industry to increase sugar content as much as possible. Since overall earlier maturity can be recognized due to climate change and since perception has increased that flavour composition degrades when ripening occurs at increased temperature, there is a reversal and breeders' selection is predominantly focused on later ripening cultivars.

For all these characteristics, especially for 'veraison' and 'grape maturity', there is considerable genetic variation within the gene pool of *V. vinifera*, which can be used for breeding purposes. Marked extended variation, especially for bud burst, can be found in some Asian (Wan et al., 2008) and American species.

Evaluation for these phenological traits may start in seedling plots when the first crop appears. In order to draw any conclusions concerning the genotypic sensitivity of environmental changes (ecovariance), data collection of these traits over several years is mandatory. Genetic analysis revealed a QTL and linked molecular markers for MAS are reported (Fischer et al., 2004).

Growth variables

The growth variables predominantly considered in grape breeding are vigor, formation of axillary shoots and upright shoot growth. Regularly, vines with medium vigor and with a well-balanced ratio of vegetative and generative growth are preferred. Usually, poor or very weak growing seedlings become discarded in an early seedling stage. Since the vigor of grafted vines is also influenced to some extent by the rootstock, the vigor of a grafting can be adjusted, that is by combining a strong growing rootstock with a weak growing scion cultivar and vice versa.

Excessive formation of axillary shoots favours high humidity within the canopy, which regularly goes along with increased disease pressure, notably *Botrytis*. Therefore, seedlings without or with weak formation of axillary shoots are preferably selected.

Upright shoot growth is highly desired by viticulturists because this simplifies canopy management considerably, especially when vines are trained in a trellis system. Detailed evaluation of these variables is usually carried out at advanced breeding material after a first propagation of selected vines. Since environmental influence on the formation of axillary shoots and upright shoot growth is rather narrow, ratings during 2 or 3 years should be enough for reliable data. However, evaluation of vigor should include experimental plots on different places with different rootstocks in an advanced breeding stage in order to identify interactions with soil type and rootstock variety.

1.2.2.5 Yield and quality

The individual yield components of (1) berry weight, (2) number of berries per cluster, (3) number of clusters per shoot and (4) number of shoots per vine finally determine the total yield, whereas (1) to (3) are genetically determined. Existing genetic variability especially for components (1) and (2) is considerable and can be used in breeding. Special attention may be drawn to the berry weight because reduced berry size increases the ratio of berry surface to berry volume. Since several compounds with a strong influence on wine quality are predominantly located in the skin of the berries, smaller berries may lead to an increased concentration of these substances and, hence, to a pronounced flavour and taste in juice and wine. Additionally, reduced berry size decreases the risk of berry squeezing and successive *Botrytis* infection during the ripening period.

As already indicated, yield variables interact with berry composition ('quality') variables. Due to the existence of the 'quantity–quality ratio' (Sartorius, 1926), yield and quality cannot be considered separately in grapevine breeding. Similar to the dissection of yield variables, the overall term 'quality' can also be dissected in many individual classes of compounds, such as sugars, acids, anthocyanins, tannins or volatile components. The final breeding goal is a well-balanced composition of individual compounds rather than maximizing individual compounds. In fact, things become even more complicated when considering that the definition of wine quality is not an objective, clearly scalable dimension; moreover, it is based on subjective impressions and is influenced by individual preferences.

When applying traditional breeding techniques, the selection based on quality and yield variables starts in the seedling field. Only those individuals with appropriate ripening time, appropriate yield, satisfactory taste of berry and no or minimal *Botrytis* infection are selected. Harvest data are collected and chemical analyses are focused on variables like sugars, acids and pH value. Total yield per selection is very limited, and microvinification in this breeding stage is a challenge. Nevertheless, this is an important step since sensorial evaluation provides valuable additional information and supports the early identification of those seedlings with unsatisfactory quality. The sensorial evaluation is even of more importance in the frame of resistance breeding because due to wild species in the pedigree, off-flavours may occur. Hence, carriers of off-flavours can be identified and discarded very early. Field evaluation for yield and quality variables, analytical and sensorial evaluation leads finally to a considerable restriction of the breeding material. Based on empirical data, about 0.1% of the initial seedlings are selected for further propagation. During the following propagation steps, sensorial and chemical analysis is continued. Perennial data are of special importance for grape-growing regions with frequently altering climate conditions.

1.3 Limitations for cross breeding

1.3.1 Crop-specific limitations

Plant breeding activities can basically be divided into three phases: (1) establishing genetic variation, (2) selection and (3) test phase for selections. All these phases recover crucial bottlenecks in grapevine breeding. Adequate genetic variation is a prerequisite for the perspective of successful breeding. Fulfilling this request for grapes requires sufficient population sizes. But creating successful crossings with high numbers of seeds that yield successful seedlings is very often limited. This is due to several reasons. One of the most important reasons is the process of emasculation itself, which is very slow due to the small and tiny florescence. Only limited amounts of emasculations can be carried out during the limited time frame where successful emasculation is possible. By using female parents, this problem could be reduced. But very frequently, female parents do not fit the breeding goals, and this is why they are not used as parents. Consequently, the genetic variability in crossing populations is usually limited due to the limited number of individuals. Plant breeding programmes with other important agricultural crops typically achieve considerably larger population sizes.

Progress in grapevine breeding is also hampered by the fact that a grapevine is a perennial crop. This is especially expressed during the selection phase (2) and the test phase (3). Evaluation of many important characteristics needs yielding vines, which is typically not achieved until the third year after planting. This is very time-consuming since this loss of time follows every propagation step and each establishment of new test trials. This is one of the main reasons that the time for releasing a new cultivar to the market is doubled compared to other important agricultural crops. Moreover, individual vines need a lot of space for growing and their cultivation is extremely labour-intensive. This requires considerable resources, and available resources usually depict clear limits for breeding activities.

Finally, a further important barrier that may become important, especially at the end of the breeding cycle, is the limited propagation rate. Low propagation rates limit introduction on the market.

1.3.2 Availability of genetic resources

The access to genetic resources is of pivotal importance for breeding. Genetic resources are typically stored as ex situ collections. Usually breeders establish their own collections or provide access to adequate collections. Maintenance of ex situ collections is costly and the extent of collections is frequently limited by the limited recourses for collection management.

Even more important are limitations due to restrictions for exchanging all kinds of material (cuttings, seeds, pollen) of genetic recourses. Worldwide, a tendency can be expected that phytosanitary obligations, including compulsory quarantine restrictions, increase. Phytosanitary aspects may justify this practice, but it complicates the exchange of genetic material considerably. It leads to a distinct retardation of access to genetic resources, and consequently it delays breeding progress.

1.3.3 Lack of knowledge about grapevine genetics

Until the end of the last century, grapevine breeding was almost exclusively based on experience accumulated over decades and over a breeder's generation. This led to remarkable success and, so far, a lot of newly bred cultivars in various countries were successfully introduced to the market. But despite this remarkable success, the lack of knowledge about the genetics and the inheritance of important traits may explain why results are somewhat disappointing when related to the huge efforts carried out in grapevine breeding. The lack of knowledge can be explained because investigations on grapevine genetics were hindered by the fact that a grapevine is a perennial, and its cultivation is very time- and labour-intensive. Hence, genetic analyses were hardly feasible for a long time. Breeding progress was based for a long time mainly on the breeder's experience rather than on genetically based knowledge. Sustainable change was achieved just recently with the introduction of molecular tools in grapevine breeding at the beginning of the new century.

1.3.4 Socioeconomic aspects

In addition to some technical and scientific-based reasons, there are also some socioeconomic aspects that hamper breeding. One important issue is related to the structure of the wine market and the habit of the consumer. For many consumers, the vine variety is a decisive criterion for buying wine. They relate clearly the name of a variety with their expectations on wine quality. In reverse, this means that they usually doubt the wine quality of a new, unknown cultivar. Detailed and thorough information to the consumers needs to be provided for overcoming this situation. But the extensive additional time- and labour-consuming input for wineries when doing so reduces the willingness of many wine growers to introduce new cultivars. Furthermore, the low propagation rate for a grapevine prevents the wine production of newly introduced varieties on a large scale; thus the application of appropriate marketing concepts for stimulating consumers is not economically founded.

An additional aspect is primarily related to new cultivars derived from resistance breeding. Resistant cultivars from recent traditional breeding programmes in various countries allow a reduction of plant protection measurements of about 50–80% against the mildews. This implies an important economical benefit, but moreover it is a huge ecological benefit. Reduced environment pollution is expected to be a good argument to convince consumers. But this is not necessarily true for wine produced from resistant new cultivars. Wine growers who are curious to test new resistant cultivars grow normally susceptible cultivars in parallel. Informing the consumer about the potential for reducing pollution with resistant cultivars illustrates the extent of pesticide application for traditional cultivars. This conflict leads frequently to the fact that the huge advantage of resistant new cultivars, namely the considerable reduction of air pollution, is not or is hardly communicated. In the end, all these peculiarities slow down the stimulation for the introduction of new cultivars.

1.4 Future perspectives of cross breeding

After about 200 years of grapevine breeding, remarkable success can be ascertained. Despite several grapevine-specific peculiarities and difficulties, quite a number of improved cultivars could be developed and released to the market. Applied breeding techniques were predominantly based on traditional methods, and the selection of parents for creating genetic variation was based on the breeder's experience. Since the beginning of the new millennium, enormous progress was achieved in grapevine genetics. After the introduction of polymerase chain reaction (PCR)-based DNA analyses, Lodhi et al. (1995) established the first genetic map. After the identification of QTL for important traits (Fischer et al., 2004), the way was paved for the routine introduction of MAS in a grapevine (Eibach et al., 2007). A recent important milestone was the successful sequencing of the grapevine genome (Jaillon et al., 2007). So far, for many different traits, QTLs (including related molecular markers) have been identified. The application of MAS offers beneficial perspectives in many respects. For example, this applies to the selection of parent varieties for establishing genetic variation. Genotyping the genetic resources with molecular markers related to important traits allows the identification of optimized crossing combinations. Concerning mildew resistance, for example, MAS allows a targeted selection of parents with the potential for combining different resistance loci in the offspring in order to increase the degree of resistance, as well as sustainability of resistance.

Subsequently, MAS can be applied in the offspring in order to identify in a very early stage those genotypes with the most suitable combination of loci. Due to this early selection and subsequent directed propagation and testing, it can be expected that MAS will shorten the breeding cycle by about 5–10 years.

A further application for MAS is the introgression of valuable traits from wild species into the gene pool of *V. vinifera*. MAS applied for the target trait combined with a background selection allows, in the third backcross generation (pBC_3), the identification of genotypes with 98% genomic portion of the recurrent parent (Herzog et al., 2013). Together with optimized culture techniques, this can be achieved in a time frame of only about 10 years, while without markers about 30 years or more are required. Consequently, this offers new perspectives to access valuable traits from wild species.

Recent breeding research revealed special progress for the genomic identification of resistance characteristics that are often monogenic with dominant inheritance. For the near future, it can be expected that the genetically more complex traits related to quality will be genetically determined to some extent. MAS considering individual loci, as it is currently applied, may be complemented with selection procedures considering the whole genome.

Along with future developments of high-throughput techniques for genotyping, the availability of adequate and reliable phenotypic data becomes more and more important. The development of high-throughput phenotyping platforms (Herzog et al., 2014) may provide the appropriate tools for collecting reliable data in a short time frame.

In summary, it can be stated that the introduction of new tools for genomic analysis will stimulate grapevine breeding tremendously. Crop-specific limitations, such as perennial and long-lasting breeding cycles, may be partly balanced and an increase of breeding efficiency and breeding progress can be expected.

References

Balthazard, J., 1969. Alternating temperatures, embryo length, and germinability of vine seeds. C. R. Hebd. Seances Acad. Sci. (Paris) 269, 2355–2358.

Baranski, S., 1983. Entwicklung einer Methode zur Bestimmung der Winterfrostresistenz von Rebsorten (Dissertation). Universität Hohenheim.

Blaich, R., Bachmann, O., Stein, U., 1982. Biochemical factors in the resistance of vines to *Botrytis cinerea*. Rev. Oenologues (Macon) 8 (26), 11–12.

Blaich, R., Stein, U., Wind, R., 1984. Perforationen in der Cuticula von Weinbeeren als morphologischer Faktor der Botrytisresistenz. Vitis 23, 242–256.

Borges do Val, A.D., Motoike, S.Y., Alvarenga, E.M., Cecon, P.R., 2010. Breaking the dormancy of Niagara Rosada seeds without stratification. Rev. Ceres 57 (2), 234–238.

Burrows, G., 1994. Seed propagation of grapevines – a comparison of GA3 and K-GA3. Aust. Grapegrower Winemaker 370, 16–17.

Calonnec, A., Wiedemann-Merdinoglu, S., Deliere, L., Cartolaro, P., Schneider, C., Delmotte, F., 2013. The reliability of leaf bioassays for predicting disease resistance on fruit: a case study on grapevine resistance to downy and powdery mildew. Plant Pathol. 62, 533–544.

Cattell, H., Miller, L.S., 1980. The Wines of the East – Native American Grapes. Eastern Wine Publications; L & H Photojournalism, Lancaster, PA.

Cindric, P., Korac, N., 1990. Frost resistance of grapevine cultivars of different origin. In: Proceedings of the Fifth International Symposium on Grape Breeding, September 12–16, 1989, St. Martin/Pfalz, Federal Republic of Germany, pp. 340–351. Vitis Special Issue.

Coleman, C., Copetti, D., Cipriani, G., Hoffmann, S., Kozma, P., Kovacs, L., Morgante, M., Testolin, R., di Gaspero, G., 2009. The powdery mildew resistance gene *REN1* co-segregates with an NBS-LRR gene cluster in two Central Asian grapevines. BMC Genet. 10, 89.

Düring, H., 1999. Wege zur züchterischen Verbesserung der Trockentoleranz bei Reben. Ber. Landwirtsch. 77 (1), 43–48.

Eibach, R., Alleweldt, G., 1985. Einfluss der Wasserversorgung auf Wachstum, Gaswechsel und Substanzproduktion traubentragender Reben. III. Die Substanzproduktion. Vitis 24, 183–198.

Eibach, R., Diehl, H., Alleweldt, G., 1989. Untersuchungen zur Vererbung von Resistenzeigenschaften bei Reben gegen Oidium tuckeri, *Plasmopara viticola* und *Botrytis cinerea*. Vitis 28, 209–228.

Eibach, R., Zyprian, E., Welter, L., Töpfer, R., 2007. The use of molecular markers for pyramiding resistance genes in grapevine breeding. Vitis 46, 120–124.

Ellis, R.H., Hong, T.D., Roberts, E.H., 1983. A note on the development of a practical procedure for promoting the germination of dormant seed of grape (*Vitis* spp.). Vitis 22, 211–219.

Failla, O., Marro, M., Pizzocchero, I., 1991. Storage and use of pollen in grapevine breeding programs. Rivista di Viticoltura e di Enologia, Conegliano 44 (2), 31–36.

Fischer, B.M., Salakhutdinov, I., Akkurt, M., Eibach, R., Edwards, K.J., Töpfer, R., Zyprian, E.M., 2004. Quantitative trait locus analysis of fungal disease resistance factors on a molecular map of grapevine. Theor. Appl. Genet. 108, 501–515.

Harst, M., Cobanov, B.A., Hausmann, L., Eibach, R., Töpfer, R., 2009. Evaluation of pollen dispersal and cross pollination using transgenic grapevine plants. Environ. Biosafety Res. 87–99 (2).

Herzog, E., Töpfer, R., Hausmann, L., Eibach, R., Frisch, M., 2013. Selection strategies for marker-assisted background selection with chromosome-wise SSR multiplexes in pseudo-backcross programs for grapevine breeding. Vitis 52, 193–196 .

Herzog, K., Roscher, R., Wieland, M., Kicherer, A., Läbe, T., Förster, W., Läbe, T., Kuhlmann, H., Töpfer, R., 2014. Initial steps for high-throughput phenotyping in vineyards. Vitis 53, 1–8.

Hopkins, D.L., Harris, J.W., 2000. A greenhouse method for screening grapevine seedlings for resistance to anthracnose. HortScience 35, 89–91.

Husfeld, B., 1933. Über die Züchtung plasmoparawiderstandsfähiger Reben. Die Gartenbauwissenschaft 7 (1), 15–92.

Jabco, J.P., Nesbitt, W.B., Werner, D.J., 1985. Resistance of various classes of grapes to the bunch and muscadine grape forms of black rot. J. Am. Soc. Hortic. Sci. 110, 762–765.

Jaillon, O., Aury, J.-M., Noel, B., Policriti, A., Clepet, C., Casagrande, A., Choisne, N., Aubourg, S., Vitulo, N., Jubin, C., Vezzi, A., Legeai, F., Hugueney, P., Dasilva, C., Horner, D., Mica, E., Jublot, D., Poulain, J., Bruyere, C., Billault, A., Segurens, B., Gouyvenoux, M., Ugarte, E., Cattonaro, F., Anthouard, V., Vico, V., DelFabbro, C., Alaux, M., DiGaspero, G., Dumas, V., Felice, N., Paillard, S., Juman, I., Moroldo, M., Scalabrin, S., Canaguier, A., LeClainche, I., Malacrida, G., Durand, E., Pesole, G., Laucou, V., Chatelet, P., Merdinoglu, D., Delledonne, M., Pezotti, M., Lecharny, A., Scarpelli, C., Artiguenave, F., Pe, M.E., Valle, G., Morgante, M., Caboche, M., Adam-Blondon, A.-F., Weissenbach, J., Quetier, F., Wincker, O., 2007. The grapevine genome sequence suggests ancestral hexaploidization in major angiosperm phyla. Nature 449, 463–468.

Jang, Myung Hwan, Ahn, Soon Yung, Kim, Seung Hui, Noh, Jeong Ho, Yun, Hae Keun, 2011. Evaluation of grapevine varietal resistance to anthracnose through treating culture filtrates from *Elsinoë ampelina*. Hortic. Environ. Biotechnol. 52, 152–157.

Jimenez, A.L.G., Ingalls, A., 1990. *Vitis caribaea* as a source of resistance to Pierce's disease in breeding grapes for the tropics. In: Proceedings of the Fifth International Symposium on Grape Breeding, September 12–16, 1989, St. Martin/Pfalz, Federal Republic of Germany, pp. 262–270 Vitis Special Issue.

Kachru, R.B., Singh, R.N., Yadav, I.S., 1972. Physiological studies on dormancy in grape seeds (*Vitis vinifera* var. Black Muscat). Vitis 11, 289–295.

Kim, G.H., Yun, H.K., Choi, C.S., Park, J.H., Jung, Y.J., Park, K.S., Dane, F., Kang, K.K., 2008. Identification of AFLP and RAPD markers linked to anthracnose resistance in grapes and their conversion to SCAR markers. Plant Breed. 127, 418–423.

Koblet, W., Vetsch, U., 1968. Entwicklung der Rebenblüte und Fruchtansatz. Schweiz. Z. für Obst- Weinbau 15, 383–388.

Koblet, W., 1969. Wanderungen von Assimilaten in den Rebtrieben und Einfluß der Blattfläche auf Ertrag und Qualität der Trauben. Wein-Wiss 24, 277–319.

Kozma, P., 1995. Studies on the resistance sources to roter brenner (Pseudopeziza tracheiphila H. Müll. Thurg.) in interspecific grapevine hybrids. Horticultural Science-Kertészeti Tudomány 27, 79–84.

Kuczmog, A., Galambos, A., Horvath, S., Matai, A., Kozma, P., Szegedi, E., Putnoky, P., 2012. Mapping of crown gall resistance locus Rcg1 in grapevine. Theor. Appl. Genet. 125, 1565–1574.

Lodhi, M.A., Daly, M.J., Ye, G.N., Weeden, N.F., Reisch, B.I., 1995. A molecular marker based linkage map of *Vitis*. Genome 38, 786–794.

Loomis, N.H., 1979. The effect of pinching of the terminals on yield and cane growth of Champanel grapes. Proc. Am. Soc. Sci. 54, 181–182.

Lott, H., 1969. Über die Samenkeimung bei *Vitis vinifera*-Sorten und Nachkommen aus interspezifischen Kreuzungen. Diss. Justus Liebig-Univ. Gießen, Inst. für Pflanzenbau und Pflanzenzüchtung, Gießen, Germany.

Luckert, A., 1976. Untersuchungen über den Beerenansatz der Rebe (Dissertation). Universität Hohenheim.

Miclot, A.S., Wiedemann-Merdinoglu, S., Duchene, E., Merdinoglu, D., Mestre, P., 2012. A standardized method for the quantitative analysis of resistance to grapevine powdery mildew. Eur. J. Plant Pathol. 133, 483–495.

Mortensen, J.A., 1980. Sources and inheritance of resistance to anthracnose (*Elsinoë ampelina* (d By) shear) in Vitis. In: Third International Symposium on Grape Breeding, Davis, USA.

Ramming, D.W., Gabler, F., Smilanick, J., Cadle-Davidson, M., Barba, P., Mahanil, S., Cadle-Davidson, L., 2011. A single dominant locus, *Ren4*, confers rapid non-race-specific resistance to grapevine powdery mildew. Phytopathology 101, 502–508.

Rex, F., 2012. Resistenz gegen die Schwarzfäule (*Guignardia bidwellii*) in der Weinrebe (*Vitis* spec.) – Etablierung phänotypischer Erfassungsmethoden und genetische Kartierung von Resistenzloci. Diss. Karlsruher Institut für Technologie (KIT).

Riaz, S., Tenscher, A.C., Graziani, R., Krivanek, A.F., Ramming, D.W., Walker, M.A., 2009. Using marker-assisted selection to breed Pierce's disease-resistant grapes. Am. J. Enol. Vitic. 60, 199–207.

Rives, M., 1965. La germination des graines de vigne. I. Essais preliminaries. Ann. Amélior. Plantes 15, 79–91.

Ruel, J.J., Walker, M.A., 2006. Resistance to Pierce's disease in *Muscadinia rotundifolia* and other native grape species. Am. J. Enol. Vitic. 57, 158–165.

Sartorius, O., 1926. Untersuchungen über Bogreben unter Berücksichtigung von Gewicht und Zuckergehalt der einzelnen Trauben. Rebe und Wein 11, 1–14.

Schwander, F., Eibach, R., Fechter, I., Hausmann, L., Zyprian, E., Topfer, R., 2012. *Rpv10*: a new locus from the Asian *Vitis* gene pool for pyramiding downy mildew resistance loci in grapevine. Theor. Appl. Genet. 124, 163–176.

Staudt, G., 1999. Opening of flowers and time of anthesis in grapevines, *Vitis vinifera* L. Vitis 38, 15–20.

Szegedi, E., Korbuly, J., Koleda, I., 1984. Crown gall resistance in East-Asian *Vitis* species and in their *V. vinifera* hybrids. Vitis 23, 21–26.

Szegedi, E., Kozma, P., 1984. Studies on the inheritance of resistance to crown gall disease of grapevine. Vitis 23, 121–126.

Venuti, S., Copetti, D., Foria, S., Falginella, L., Hoffmann, S., Bellin, D., Cindric, P., Kozma, P., Scalabrinz, S., Morgante, M., Testolin, R., 2013. Historical introgression of the downy mildew resistance gene Rpv12 from the Asian species *Vitis amurensis* into grapevine varieties. Plos One 8 (4), e61228.

Wan, Y., Wang, Y., Li, D., He, P., 2008. Evaluation of agronomic traits in Chinese wild grapes and screening superior accessions for use in a breeding program. Vitis 47, 153–158.

Wang, Y., Liu, Y., He, P., Lamikanra, O., Lu, J., 1998. Resistance of Chinese *Vitis* species to *Elsinoë ampelina* (de Bary) shear. HortScience 33, 123–126.

Yun, H.K., Park, K.S., Rho, J.H., Choi, Y.J., Kang, K.K., 2006. Evaluating the resistance of grapevines against anthracnose by pathogen inoculation, vineyard inspection, and bioassay with culture filtrate from *Elsinoë ampelina*. J. Am. Pomol. Soc. 60 (2), 97–103.

Yun, H.K., Park, K.S., Roh, J.H., Choi, Y.J., Jeong, S.B., 2007. Developing a screening system for resistance to anthracnose in grapevines during culture filtrates from *Elsinoe ampelina*. J. Hortic. Sci. Biotech. 82, 360–364.

Zhang, J., Wu, X., Riu, R., Liu, Y., Liu, N., Xu, W., Wang, Y., 2012. Cold-resistance evaluation in 25 wild grape species. Vitis 51, 153–160.

Molecular grapevine breeding techniques

2

G. Di Gaspero[1,2], *S. Foria*[1]
[1]University of Udine, Udine, Italy; [2]Istituto di Genomica Applicata, Udine, Italy

2.1 Introduction

2.1.1 The use of DNA sequence information for assisting conventional breeding

The selection of novel varieties in highly heterozygous species requires observations and measurements of innumerable phenotypic characters that appear with distinct variants and combinations in the progeny created from controlled crosses. DNA sequence information is now routinely used for assisting conventional breeding in the selection of parents and the most valuable progeny. Breeding programmes have stepped up during the past decade as genetic information became increasingly available. Considerable progress has been achieved toward the marker-assisted selection (MAS) of characters controlled by major genes, such as disease and pest resistances, and toward the removal of linkage drag around introgressed chromosome segments carrying valuable wild alleles. A few loci have been discovered in *Vitis vinifera* that are important for wine quality attributes (i.e. those controlling the synthesis of anthocyanins, proanthocyanins, methoxypyrazines and terpenes). However, a swift improvement of our capacity to predict wine quality from fruit composition is demanded before DNA markers can fruitfully help in the selection for oenological value. A breakthrough in the past couple of years was the advent of genotyping-by-sequencing (GBS). GBS removed previous limitations in the generation and scoring of unlimited numbers of markers for interrogating all possible loci controlling the phenotypic variation for a trait of interest. Advances in our understanding of genome architecture and population structure in natural and breeding germplasm will indicate future directions in the use of genome-wide selection for characters relevant to the wine industry. In this field, genomic selection (GS), an approach borrowed from animal breeding, is still an option to test as a practical method for wine-related breeding values. At the present time, marker assisted-selection of desirable traits, especially disease-resistance loci, and genome-wide analyses are trustworthy, auxiliary means available to the breeders for foreground and background selection. As long as they are fully integrated into breeding strategies, this knowledge will serve conventional breeding in the design and creation of novel wine grape cultivars that can successfully compete with traditional and genetically engineered varieties.

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00002-8

2.2 Technical outline

2.2.1 Global structure of genetic diversity

Little is known about the structure of genetic diversity in the grape germplasm, beyond the parentages of many varieties. The state-of-the-art technology before the advent of next-generation sequencing (NGS) provided partial insight into the historical effects of human activity on the selection of wine grape varieties. The decay of linkage disequilibrium (LD) in varieties of *V. vinifera* is as rapid as in undomesticated populations of the same species. The reduction of haplotype diversity is generally irrelevant, with only a couple of exceptions associated with berry colour and domestication syndrome (Fournier-Level et al., 2010; Myles et al., 2011). This little knowledge of the genetic make-up of elite wine grapes, historically selected by ancient viticulturists and adopted by modern viticulture, has largely left to each breeder's sensibility the burden to find the best empirical way for breeding and selecting new varieties. As a result, only a few wine grape varieties intentionally bred in the past two centuries excelled enough to acquire popularity, even among those varieties that have exclusively high-quality *V. vinifera* in their ancestry (i.e. Müller-Thurgau). Breeding activity in this crop was highly focused on improving biotic resistances, usually introgressed from other grape species. The recurrent use of a few excellent donors of disease resistance led to little genetic diversity being captured in grape breeding germplasm (Di Gaspero et al., 2012).

2.2.2 Architecture of the grapevine genome

The exploitation of beneficial alleles in conventional breeding is dependent upon the chromosomal location of the interesting loci and upon their genome landscape. Molecular breeders should always consider that genetic variation is structured in haplotypes, and haplotypes are portions of the chromosome structure. The grapevine genome is highly heterogeneous along each chromosome and among chromosomes (Figure 2.1).

2.2.3 Gene-rich and gene-poor chromosomal regions

Gene density varies along each chromosome, showing an inverse relationship with the density of transposable elements (TE). Gene density is the lowest in pericentromeric regions of the grapevine genome (Figure 2.1). A gene-poor landscape extends symmetrically over millions of nucleotides in pericentromeric regions of some chromosomes (i.e. chr4, chr16). In other chromosomes, genes are dislodged from small chromosome segments, corresponding exactly to the centromeric tandem repeats (i.e. chr3, chr8). Genetic diversity in pericentromeric regions is expected to suffer more constraints than in the rest of the genome because of lower recombination rate. Linkage drag is also more persistent in those regions. In corn, 95% of the total recombination rate is restricted to slightly more than half of the genome, decreasing dramatically in pericentromeric regions, possibly as a consequence of high structural variation in TE-rich regions.

2.2.4 Chromosomal regions with expanded gene families

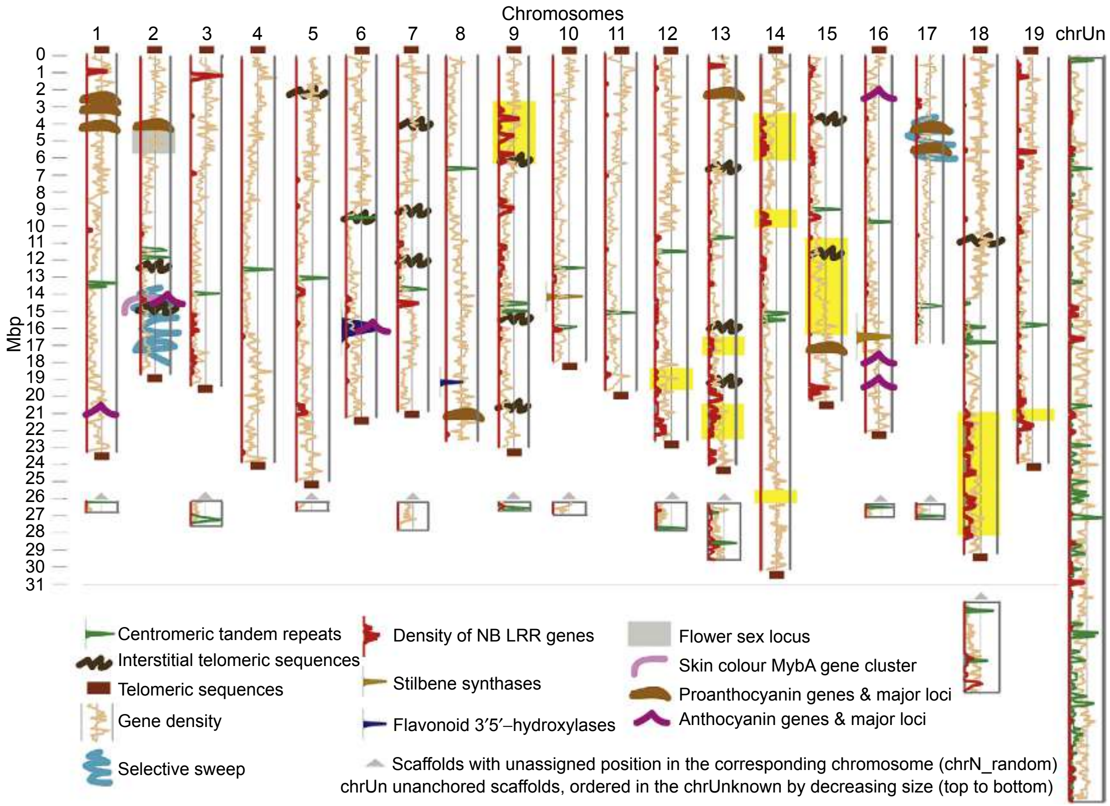
Several gene families have proliferated by local duplications in the grape genome. NB-LRR genes encode receptors for pathogen- and pest-surveillance systems and are present in clusters located in subtelomeric regions. Entire chromosome arms (i.e. in chromosomes 12, 13, 18) are densely populated by potential resistance genes against biotic threats. Several haplotypes carry functional alleles for disease and pest resistance across these regions in geographically and genetically unrelated accessions of grapevines. Some resistance haplotypes have been introgressed into *V. vinifera* for many decades and retained during backcross breeding by phenotypic selection, before the advent of molecular breeding. Fewer resistance haplotypes have naturally evolved within the population of *V. vinifera* (Coleman et al., 2009; Rouxel et al., 2013). Other gene families are present with a higher number of gene copies compared to other plant genomes. Some of them are important for berry composition and wine sensory attributes, i.e. flavonoid 3′,5′-hydroxylases (Falginella et al., 2010) and stilbene synthases (Vannozzi et al., 2012). Most of these gene copies are in physical proximity and have evolved some sort of functional specialization. MAS for haplotypes that span these large gene clusters will probably have a major impact on berry-related traits. By contrast, single-copy genes encoding key enzymes in other metabolic pathways are dispersed across the chromosomes and may require a more meticulous MAS of each favourable allele (Figure 2.1).

2.2.5 Other components of chromosome structure

Telomeric repeats guide a multiprotein complex that distinguishes native DNA ends from DNA double-strand breaks (DSBs), thereby protecting chromosome ends from DNA repair mechanisms and preventing chromosome fusion. In the PN40024 reference genome, 31 of the expected 38 telomeric ends are present in the outermost ends of the scaffolds anchored at the termini of linkage groups. Another seven regions with telomeric repeats were assembled into scaffolds not yet assigned to chromosomes. Telomeric-like repeats are present not only in the chromosome ends but also at interstitial sites of some chromosomes. We identified 16 interstitial telomeric sequences (ITSs) on eight chromosomes. Notably, chr7, chr9 and chr13 have three ITSs, while chr2 and chr15 have two ITSs. The presence of ITSs is posited to be the result of ancestral chromosome fusion, intrachromosomal rearrangements and insertion of telomeric DNA within unstable sites during DSB repair. Once generated, ITSs are unstable regions that may undergo rearrangements, including amplification, deletion and transposition/translocation, and they are possibly signatures of past DSBs in fragile sites. In humans, the ITSs most prone to cause chromosomal aberrations are those located in centromeric regions. Physical vicinity of ITSs and centromeric repeats occur in a number of notable cases in the grapevine genome, two spots on each chromosome for chr2 and chr7 and a single spot on chromosomes 6, 9 and 15.

2.2.6 Chromosomal regions with selective sweeps

Significant selective sweeps were detected in wine grape varieties on chromosomes 2 and 17 (Myles et al., 2011). Genetic diversity is severely reduced in the terminal part



Chromosomes
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 chrUn
Mbp
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Centromeric tandem repeats
Interstitial telomeric sequences
Telomeric sequences
Gene density
Selective sweep
Density of NB LRR genes
Stilbene synthases
Flavonoid 3′5′–hydroxylases
Flower sex locus
Skin colour MybA gene cluster
Proanthocyanin genes & major loci
Anthocyanin genes & major loci
Scaffolds with unassigned position in the corresponding chromosome (chrN_random)
chrUn unanchored scaffolds, ordered in the chrUnknown by decreasing size (top to bottom)

Figure 2.1 Grapevine genome structure and relevant regions for molecular breeding. Prediction of structural characteristics is based on the 12X genome assembly of the PN40024 reference sequence. Chromosome length is indicated in million base pairs (Mbp). Telomeric sequences were searched by Blast using the eptamer [TTTAGGG]$_n$. Terminal telomeric sequences are indicated by *brown boxes* at the end of the chromosomes and ITSs are indicated by *brown wavy lines*. The locations of centromeric repeats were predicted by Blast using the 107-nt monomer AGTACCGAAAAAGGGTCGAATCAGTGTGAGTACCGAAAAATGGTAGAATCCGGGCGAGTACCGGGAAAAGGTAGAATCCGTGCGAGTATCGAAAAACTGTCCGGGCG and are indicated by the *green plot*. Regions with selective sweeps in cultivated varieties of *Vitis vinifera* are indicated by *cyan symbols* according to Myles et al. (2011). Density of genes (*peach plot*, scale 0–20 genes per 100 kbp, according to 29,970 genes of the V1 gene prediction) and NB-LRR genes, pseudogenes and homologous gene fragments (*red plot,* scale 0–20 genes per 100 kbp) is shown in adjacent windows of 100 kbp. *Yellow boxes* indicate major loci with disease- and pest-resistance haplotypes identified across clusters of NB-LRR genes (DM-*Rpv10* on chr9; DM/PM-*Run1/Rpv1* on chr12; PM-*Ren1* and phylloxera-*Rdv1* on chr13; DM-*Rpv8*, DM-*Rpv12*, PM-*Ren5* and *Xylella fastidiosa-PdR1a* on chr14; PM-*Ren3* and *Agrobacterium-Rcg1* on chr15; DM-*Rpv2*, DM-*Rpv3*, PM-*Run2* and PM-*Ren4* on chr18; *Xiphinema index-XiR1* on chr19). The reported proanthocyanin genes are *LAR1*, *MybC2-L1* and *Trans-like* on chr1; *LDOX* on chr2; *Myb5a* on chr8; *CHI* on chr13; *MybPA1* on chr15; *LAR2* and *COBRA-like* on chr17 (Carrier et al., 2013; Huang et al., 2012). The reported anthocyanin genes are the *OMT* gene cluster associated with the level of methylation on chr1, the *MybA* gene cluster on chr2, the *F3′5′H* gene cluster on chr6, the *UFGT* gene associated with a *cis*-eQTL, the *anthoMATE* gene cluster associated with transport of acylated anthocyanidins and the *ABCC1* ATP-binding cassette protein associated with transport of glucosylated anthocyanidins on chr16. The flower sex locus is indicated according to Fechter et al. (2012). Location of flavonoid 3′,5′-hydroxylase and stilbene synthase gene clusters is indicated according to Falginella et al. (2010) and Vannozzi et al. (2012), respectively.

of chr2, as a consequence of positive selection for the most common white-skinned haplotype at the MybA gene cluster (Figure 2.1). White-skinned wine grape varieties have low genetic diversity because they are invariantly homozygous across this chromosome segment, but this reduction is also noteworthy in red-skinned varieties, because the majority of them are heterozygous for a red haplotype and the white haplotype. Another strong signature of selective sweep is present on chr17. The only phenotypic trait known to be partially dependent upon genes located within this region is berry proanthocyanidin content (Figure 2.1).

2.2.7 Genomic tools and breeding strategies in the genome sequencing era

The grapevine nuclear genome has been entirely assembled in 2007, following a whole-genome shotgun Sanger sequencing of the highly inbred line PN40024 (Jaillon et al., 2007). The reference sequence offered the framework against which to compare genome-wide polymorphisms present in natural and breeding germplasm by the exploitation of NGS. This has led to the development of high-density single nucleotide polymorphism SNP chips (Le Paslier et al., 2013; Myles et al., 2011) and facilitated the application of GBS. The availability of these genomic tools has made technically feasible a number of breeding strategies for precise introgression of wild alleles, removal of linkage drag, combination of multiple favourable haplotypes and selection of the desired background in novel varieties – briefly, precision breeding. These strategies comprise marker-assisted backcrossing (MABC), marker-assisted background selection (MABS), advanced backcross QTL strategy (AB-QTL) and marker-assisted pyramidization (MAP).

2.2.8 MABC and MABS

The pace and precision of backcross breeding can be significantly improved when (1) tightly linked markers are available for relevant traits, (2) favourable and unfavourable haplotypes are known for the relevant loci and (3) many DNA polymorphisms are available to monitor the transmission of nonsister chromatids from one generation to the next and to map the location of each recombination event. Recent advances in high-throughput genotyping have removed the bottlenecks that previously limited the level of resolution and the haplotype information content required for mapping the genetic backgrounds. The high number of SNPs included in the most advanced chips (and the extent of genetic diversity that they are able to capture) ensure that a large proportion of SNPs is informative irrespective of the type of breeding material under screening. The grapevine community converged on the use of commonly developed and publicly available tools, thereby dumping the cost of SNP chips and facilitating cross-comparison of results, as well as sharing of knowledge. SNP chip hybridizations and GBS experiments are now commonly outsourced from genotyping/sequencing facilities of private companies, saving money otherwise required to equip the breeder's laboratory with modernized and cost-efficient technologies. Outsourcing saves labour and money, but it is not a replacement for the capability of the breeder's laboratory to design the experiment and elaborate crude data. With these capabilities, SNP haplotyping will allow breeders to move from MABC, which was so far aimed at reassembling a species-specific recipient genome under the guide of microsatellite markers, to MABS, which is aimed more ambitiously to select for favourable combinations of chromosomal segments donated by different *V. vinifera* varieties.

2.2.9 Advanced backcross QTL strategy

The frequent presence of favourable QTL alleles for biotic stresses in an unadapted species, interfertile with cultivated varieties, and the wish to introgress these traits into cultivated germplasm have led to the proposal of the concept of AB-QTL. AB-QTL combines QTL analysis and variety development by designing a mapping/breeding scheme for the simultaneous identification and introgression of wild haplotypes. AB-QTL relies on segregating populations in which most of the wild-parent genome that donates the trait of interest has been purged in early segregating generations by phenotypic selection. This strategy has been more commonly adopted in grapevines, eventually tracing back the QTL haplotype in the pedigree, rather than using early segregating generations (F1, F2, BC1) for QTL mapping. Favourable QTL alleles identified in early generations often vanish in later backcross generations, once other donor genes that have epistatic interactions with the beneficial QTL alleles are removed from highly *V. vinifera* genetic backgrounds. QTL stability should also be carefully considered for fruit-related and phenology-related traits mapped in *V. vinifera*, before the linked markers are proposed to breeders. Nonadditive genetic effects may partially explain the plethora of different QTL regions that appeared in journal articles in recent years, and their variable relevance with the genetic background of the mapping populations. Breeders' faith in the use of MAS for fruit- and phenology-related traits has often been shaken by the lack of validation of QTL-marker associations in a comprehensive sample of breeding germplasm.

2.2.10 Marker-assisted pyramidization

Simultaneous MAS for independent genes controlling the same trait, also referred to as MAP, is conducted for enduring the desired phenotype or, in the case of pathogen resistance, for securing the trait from the possible effects of adaptive evolution in the population of the pathogen. The concept of MAP also extends to the assisted selection for multiple target traits. High-throughput genotyping has the highest utility when it assists breeders in assembling all desirable haplotypes into the same genome. A gene pyramiding scheme is usually implemented by intermating the best AB-lines, each one carrying complementary genes/haplotypes of interest, then the progeny is screened for individuals that have inherited all beneficial alleles at target loci.

2.3 Relevance and role in current and future scientific and commercial work

2.3.1 Improvement for disease and pest resistance

Several examples of the successful use of molecular breeding are now available in wine grapes. However, MAS is routinely used only for the improvement of traits related to pathogen and pest resistance (reviewed in Töpfer et al., 2011). The reasons for this confined success are numerous. Pathogen and pest resistances are quantitative traits, but single loci account for the vast majority of the phenotypic variation observed in biparental populations. Significant effort has been put into mapping major loci at high resolution, thereby providing the community with tightly linked markers on both sides of the causal genes. The haplotypes of interest are widely present in the breeding material used by the community, beyond the original populations in which the loci were mapped. For grape disease-resistance, it has become a good practice to validate the markers across the germplasm before releasing them, which makes them trustworthy upon publication (Di Gaspero et al., 2012; Venuti et al., 2013). This also gives breeders a sense of the relevance of the tagged haplotypes in the breeding germplasm. A proof-of-concept for the superiority of MAS over phenotypic selection in the improvement of downy and powdery mildew resistance has been provided by the breeding team at Julius Kuhn Institute, Germany (Eibach et al., 2007). MAS is the only mean for pyramiding genes for a certain disease resistance. For both downy and powdery mildew, pyramidization of resistance haplotypes from different grape species into resistant wine grape varieties has become a common practice (Li et al., 2013; Schwander et al., 2012; Venuti et al., 2013), because host specialization in natural populations of both pathogens is more extensive than commonly assumed (Brewer and Milgroom, 2010; Rouxel et al., 2013). Equally remarkable is the breeding work done by Andrew Walker's team at the University of California in Davis for fighting Pierce's disease. They identified two different resistant alleles of *PdR1*, a major resistance gene against *Xylella fastidiosa* in *Vitis* species endemic to the Southwestern US, that are now introgressed into a wide range of wine grape backgrounds over multiple generations, thanks to the assistance of tightly linked markers (Riaz et al., 2008).

2.3.2 Elimination of linkage drag

Traits associated with resistance to many biotic threats are necessarily introduced into *V. vinifera* from wild species. The elimination of linkage drag around the introgressed haplotypes has become a priority for reducing the contribution of the undomesticated genome. In backcross and intercross breeding for downy and powdery mildew, the use of the latest generation of breeding lines that carry the resistance genes *Rpv3*, *Rpv10*, *Rpv12*, *Run1*/*Rpv1*, *Ren1* and *Ren3* in a highly *vinifera* genetic background generates progeny with oenological potential comparable to traditional varieties, as long as the population size is large enough to let parental alleles affecting wine quality shuffle into many combinations. In our empirical experience, seedlings with wine quality attributes as high as in their parents occur in the order of magnitude of one seedling out of a few thousands, regardless of the fact that the cross-combination involves only pure *V. vinifera* varieties or introgression lines with a highly *vinifera* background. Progress has also been made in conventional breeding for other resistance traits, originally present only in wild grapes. The wine grape selections resistant to Pierce's disease are among the brightest examples. Other valuable wild haplotypes for disease and pest resistances are now being discovered, which will require intensive backcrossing before being introduced into breeding material.

2.3.3 Improvement of other traits and quest for genetic variation

Molecular breeding in grapevines has taken important steps to translate the accuracy of DNA-guided selection into practice. However, the number of reports on the successful incorporation of MAS into breeding programmes lags behind the number of scientific publications reporting the identification of QTLs for traits potentially interesting to breeders. Most QTLs have been mapped in small-size biparental populations, appropriately generated for scoring the segregation of phenotypes, and the genetic variation revealed by the linked markers may not be detectable in other breeding germplasm. Fine mapping and haplotype analysis are increasingly used as a validation step to ensure that the published markers maintain their predictive power in breeding germplasm (Di Gaspero et al., 2012; Venuti et al., 2013). Alternatively, a mixed approach of linkage/association mapping is used to assess the relevance in the germplasm of the haplotypes of candidate genes underlying mapped QTLs (Carrier et al., 2013). Haplotype analysis of important loci also assists breeders in their quest for novel genetic variation in breeding germplasm and in the wilderness. This has become a necessity for some practical applications, i.e. finding new sources of major genes for disease resistance, because the genetic basis of the current breeding germplasm is narrow.

2.4 Future trends

2.4.1 Precision breeding

Precision breeding in grapevines should aim at assembling an ideal genome that is a mosaic of desirable chromosome segments – donated by multiple ancestors – each one carrying a favourable haplotype for a target trait or providing a suitable genetic background. This accumulation of favourable alleles for loci with large effects on interesting traits should provide measurable genetic gain. The genetic gain in a specialty crop with a highly heterozygous genome diverges from the original concept developed for staple crops, in which quantitative traits associated with the maximization of production and productivity are common targets in all breeding programmes, and they are expressed by measurable parameters. Estimation of genetic gain, which would be important to monitor efficiency of the process and to adjust actions and strategies accordingly, is difficult to conduct in wine grape breeding. Grape breeding has been an empirical activity in which the evaluation of many viticulturally and oenologically important traits in the candidate parents and in the progeny is left to the intuitive perception of the breeder. A large effort is still needed to overcome this limitation.

2.4.2 Haplotype mapping

Ancestral genomic segments are passed down from parents to kin and they are shared by descent across generations as discrete units (haplotypes), until being shuffled by genetic recombination. Kinship in high-quality varieties of *V. vinifera* implies that large blocks of DNA along the chromosomes are conserved among varieties. Most wine grapes are derived from a few founders and are removed from them by a few generations, thereby grouping into a dozen of family groups (Bacilieri et al., 2013). Thus, most variation is structured into haplotypes. What breeders would need is a dynamic map showing the chromosome segments in founder varieties and how these segments became fragmented in their descendents. Once the biological relevance of each haplotype or its frequency in highly regarded varieties has been assessed, the ideal genetic background can be planned as a mosaic of the most wanted haplotypes. Haplotype mapping in *V. vinifera* has the potential to provide the fundamental information to revolutionize breeding strategies. The intermating of major lineages of wine grapes, carrying interesting haplotypes that underlay quantitative variation in *V. vinifera*, followed by the production of inbred lines, should fix important traits in a few individuals. The removal of constraints for the generation of dihaploid plants and nearly homozygous lines may open the door to breakthroughs in conventional breeding in the years to come. The future availability of parental lines with fixed traits for wine sensory attributes could represent a paradigm shift in the next decades from outcrossing to hybrid breeding in grapevines.

2.4.3 Short-cycling vines

The long generation time is still a significant limitation for grape breeding. Juvenility and annual reproductive cycle are major constraints against a rapid and exhaustive evaluation of seedlings for berry-related characteristics and wine sensory attributes. Breeding can be significantly accelerated by the use of short-cycling dwarf mutants with precocious and continuous flowering, also known as microvines (Chaïb et al., 2010). Double homozygous plants were developed for precocious flowering, and female flowers, which bloom within two months after seed germination, do not require emasculation prior to cross-pollination and generate large progeny populations, themselves precociously flowering. Development of near-homozygous isogenic lines, rapid introgression of wild haplotypes, gene pyramidization and construction of a planned genetic background are now more rapidly feasible with the appropriate use of microvines.

2.4.4 Fruit and wine composition: so many metabolites, so little known

We are still a long way off from deciphering the complexity of wine aroma. Chemistry has to hurdle many obstacles in the discovery of all relationships between berry composition and wine sensory attributes. And genetics lags behind. Carotenoids, *S*-cysteine conjugates, glycoconjugates, unsaturated lipids and phenolic acids are all metabolites present in the grape berry that are capable of generating odorants. A few odorant volatiles in the wines were traced back to their precursors in the berry, and for even fewer, the genetic control of their synthesis has been elucidated. Methoxypyrazines impart green pea and bell pepper characters. The 2-methoxy-3-isobutylpyrazine is the major methoxypyrazine in berries of Bordeaux cultivars and is released from its nonvolatile precursor by the gene product of an *S*-adenosyl-methionine-dependent *O*-methyltransferase (Dunlevy et al., 2013; Guillaumie et al., 2013). Floral odours of many white wine grapes are imparted by monoterpenes and monoterpene alcohols that are synthesized under the control of several genes in the terpenoid pathway (Battilana et al., 2011; Martin et al., 2011). The volatiles 2-aminoacetophenone and methyl-anthranilate are responsible for the distinctive foxy aroma in some wild grapes and in their interspecific crosses. An alcohol acyltransferase catalyzes the formation of methyl-anthranilate from the substrates anthraniloyl-coenzyme A and methanol (Wang and De Luca, 2005). All of these publications have demonstrated the contribution of terpenoid genes, *O*-methyltransferase and alcohol acyltransferase to the synthesis of key odorants that are important for varietal components of wine aroma, but this knowledge has yet to provide practical breeding with markers that effectively predict wine sensory attributes in new seedlings. What lies beneath the synthesis of other odorants conferring varietal characters, such as the pepper aroma of rotundone and the precursors of passion fruit/grapefruit thiols 3-mercaptohexan-1-ol and 3-mercaptohexyl acetate, remains completely unknown at the genetic level. Insights into the genetic control of metabolites that are important for the structure and colour of red wines (i.e. proanthocyanidins and anthocyanins) were provided by Patrice This team at INRA Montpellier. QTL regions for proanthocyanidin content and degree of polymerization of condensed tannins in berry skin and seeds were identified on several chromosomes and associated with a bunch of structural genes and transcription factors (Figure 2.1). QTL regions for anthocyanin content, level of hydroxylation and level of methoxylation were identified on chromosomes 1, 2 and 6 and associated with key structural genes and transcription factors (Carrier et al., 2013; Huang et al., 2012, 2013). These papers tackle the complexity of quantitative genetics acting behind metabolite traits.

2.4.5 Genomic selection: think wide!

GS is an approach borrowed from livestock breeding (mainly dairy cattle) that simultaneously estimates the effect of each marker across the entire genome to predict the breeding value of individuals, theoretically capturing more genetic variation for small effects underneath complex traits (Jonas and de Koning, 2013). Contrary to MAS, the contribution of all genome-wide DNA polymorphisms to the breeding value is accounted for in the diagnostic model during the calibration of the system. Then all markers, not exclusively those linked to significant QTLs, are used to measure the genomic estimated breeding value of each individual. In plant science, GS has been initiated in cereals and forest trees. It is also becoming attractive to grape breeders, because it promises to help even in the selection of those traits for which the genetics basis remains obscure.

However, the key factor in the utility and success of GS is the accurate measurement and prediction of breeding values, which is particularly critical for oenological potential and for species in which the genetic structure of the breeding material is not fixed. The application of GS to wine grape breeding should also take into consideration the fact that successful prediction of breeding values in livestock currently applies to traits affected mainly by additive genetic effects, while we still ignore the relevance of dominance, epistasis and genetic × environment interactions on wine sensory attributes.

2.4.6 Genetics and breeding: who is ancillary to whom?

Mapping and breeding mutually benefit from a coordinated exploitation of the same genetic resources. The role of geneticists as mere providers of molecular tools to breeders in the classical genetics-to-breeding approach is obsolete. Geneticists should consider the possibility to build on the breeders' knowledge and get the best breeding germplasm – appropriately selected or generated on purpose – for QTL mapping and gene discovery, with the side-effect that the novel markers will more likely find a practical application in relevant breeding germplasm. In this breeding-to-genetics approach, QTLs and genes are mapped in custom-made populations generated with the most advanced lines that passed multiple cycles of phenotypic selection, in which the inheritance of traits of interest is largely purged from nonadditive effects. This approach has been widely and successfully adopted for genetic mapping of disease resistances. Biparental populations encompass restricted allelic variation, allow to map one or a few segregating traits and may not capture the entire genetic architecture of complex traits because of nonadditive effects transmitted by the genetic background of those particular parents. Many traits with a more complex genetic architecture vary quantitatively among high-quality varieties. This subtle variation makes the difference for the success of a variety, and breeders wish to control the underlying haplotype variation during the cycles of background selection. The rapid decay of LD has vanished efforts of genome-wide association mapping for these traits, and the situation is not going to change until millions of SNP are mappable by GBS. For these kinds of traits, the breeding-to-genetics path should lead to the development of a few large segregating populations, generated after trait selection and cycles of intermating between multiple parental lines. The reward for the investment required by the preparation of this segregating material should be provided by the advantage of mapping simultaneously and at higher resolution favourable alleles from different sources, the same used in the ongoing breeding programme. In our view, genetics and breeding are different sides of the same coin, intimately interconnected as never before.

2.5 Conclusions

The first varieties newly bred and selected in the last decade with the fundamental aid of molecular and genomic information are now ready to enter the market. The applied value of molecular tools in the domain of wine grape breeding is likely to further increase in the near future, accelerating progress in the (1) characterization of genetic variation in natural and breeding germplasm, (2) precise introgression of genes and QTLs, (3) differentiation and pyramidization of valuable genetic variation in breeding material and selected varieties and (4) identification of the best breeding stock and fewer meritorious lines that will be taken to the ultimate step of plot selection and large-scale vinification. With these prospects, we are pretty convinced that wine grape varieties bred and selected through genomic-assisted breeding can compete with traditional varieties and genetically engineered lines with the same chance to succeed in consumer choice, making a contribution to the sustainable development of viticulture.

2.6 Sources of further information and advice

An excellent and up-to-date review of grapevine molecular breeding is provided by the book chapter by Töpfer et al. (2011). A general overview on the possibilities of precision breeding in crop improvement is given by Peleman and van der Voort (2003) in their seminal work about Breeding by Design™. More recent perspectives of the application of genomic-assisted breeding for grapevine improvement are explored by the review articles of Di Gaspero and Cattonaro (2010) and Myles (2013).

References

Molecular breeding the post-genomics era

Chaïb, J., Torregrosa, L., Mackenzie, D., Corena, P., Bouquet, A., Thomas, M.R., 2010. The grape microvine – a model system for rapid forward and reverse genetics of grapevines. Plant J. 62, 1083–1092.

Di Gaspero, G., Cattonaro, F., 2010. Application of genomics to grapevine improvement. Aust. J. Grape Wine Res. 16, 122–130.

Jonas, E., de Koning, D.J., 2013. Does genomic selection have a future in plant breeding? Trends Biotechnol. 31, 497–504. http://dx.doi.org/10.1016/j.tibtech.2013.06.003 (Epub ahead of print).

Le Paslier, M.-C., Choisne, N., Bacilieri, R., Bounon, R., Boursiquot, J.-M., Bras, M., Brunel, D., Di Gaspero, G., Hausmann, L., Lacombe, T., Laucou, V., Launay, A., Martinez-Zapater, J.M., Morgante, M., Raj, P.S., Ponnaiah, M., Quesneville, H., Scalabrin, S., Torres-Perez, R., Adam-Blondon, A.-F., 2013. The GrapeReSeq 18k *Vitis* genotyping chip. In: IX International Symposium on Grapevine Physiology and Biotechnology. April 21–26, 2013, La Serena, Chile.

Myles, S., 2013. Improving fruit and wine: what does genomics have to offer? Trends Genet. 29, 190–196.

Peleman, J.D., van der Voort, J.R., 2003. Breeding by design. Trends Plant Sci. 8, 330–334.

Töpfer, R., Hausmann, L., Eibach, R., 2011. Molecular breeding. In: Zapater, M.M., Adam-Blondon, A.F., Kole, C. (Eds.), Genetics, Genomics and Breeding of Grapes. Sciences Publishers, Enfield, NH, USA, pp. 160–185.

Features of the grapevine genomes and genetic diversity relevant to breeding

Bacilieri, R., Lacombe, T., Le Cunff, L., Di Vecchi-Staraz, M., Laucou, V., Genna, B., Péros, J.P., This, P., Boursiquot, J.M., 2013. Genetic structure in cultivated grapevines is linked to geography and human selection. BMC Plant Biol. 13, 25.

Brewer, M.T., Milgroom, M.G., 2010. Phylogeography and population structure of the grape powdery mildew fungus, *Erysiphe necator*, from diverse *Vitis* species. BMC Evol. Biol. 10, 268.

Fechter, I., Hausmann, L., Daum, M., Sörensen, T.R., Viehöver, P., Weisshaar, B., Töpfer, R., 2012. Candidate genes within a 143 kb region of the flower sex locus in *Vitis*. Mol. Genet. Genomics 287, 247–259.

Jaillon, O., Aury, J.M., Noel, B., Policriti, A., Clepet, C., Casagrande, A., Choisne, N., Aubourg, S., Vitulo, N., Jubin, C., Vezzi, A., Legeai, F., Hugueney, P., Dasilva, C., Horner, D., Mica, E., Jublot, D., Poulain, J., Bruyère, C., Billault, A., Segurens, B., Gouyvenoux, M., Ugarte, E., Cattonaro, F., Anthouard, V., Vico, V., Del Fabbro, C., Alaux, M., Di Gaspero, G., Dumas, V., Felice, N., Paillard, S., Juman, I., Moroldo, M., Scalabrin, S., Canaguier, A., Le Clainche, I., Malacrida, G., Durand, E., Pesole, G., Laucou, V., Chatelet, P., Merdinoglu, D., Delledonne, M., Pezzotti, M., Lecharny, A., Scarpelli, C., Artiguenave, F., Pè, M.E., Valle, G., Morgante, M., Caboche, M., Adam-Blondon, A.F., Weissenbach, J., Quétier, F., Wincker, P., 2007. The grapevine genome sequence suggests ancestral hexaploidization in major angiosperm phyla. Nature 449, 463–467.

Myles, S., Boyko, A.R., Owens, C.L., Brown, P.J., Grassi, F., Aradhya, M.K., Prins, B., Reynolds, A., Chia, J.M., Ware, D., Bustamante, C.D., Buckler, E.S., 2011. Genetic structure and domestication history of the grape. Proc. Natl. Acad. Sci. U.S.A. 108, 3530–3535.

Rouxel, M., Mestre, P., Comont, G., Lehman, B.L., Schilder, A., Delmotte, F., 2013. Phylogenetic and experimental evidence for host-specialized cryptic species in a biotrophic oomycete. New Phytol. 197, 251–263.

Metabolites and genetics of wine sensory attributes

Battilana, J., Emanuelli, F., Gambino, G., Gribaudo, I., Gasperi, F., Boss, P.K., Grando, M.S., 2011. Functional effect of grapevine 1-deoxy-D-xylulose 5-phosphate synthase substitution K284N on Muscat flavour formation. J. Exp. Bot. 62, 5497–5508.

Carrier, G., Huang, Y.F., Le Cunff, L., Fournier-Level, A., Vialet, S., Souquet, J.M., Cheynier, V., Terrier, N., This, P., 2013. Selection of candidate genes for grape proanthocyanidin pathway by an integrative approach. Plant Physiol. Biochem. 72, 87–95. http://dx.doi.org/10.1016/j.plaphy.2013.04.014.

Dunlevy, J.D., Dennis, E.G., Soole, K.L., Perkins, M.V., Davies, C., Boss, P.K., 2013. A methyltransferase essential for the methoxypyrazine-derived flavour of wine. Plant J. 75, 606–617. http://dx.doi.org/10.1111/tpj.12224.

Falginella, L., Castellarin, S.D., Testolin, R., Gambetta, G.A., Morgante, M., Di Gaspero, G., 2010. Expansion and subfunctionalisation of flavonoid 3',5'-hydroxylases in the grapevine lineage. BMC Genomics 11, 562.

Fournier-Level, A., Lacombe, T., Le Cunff, L., Boursiquot, J.M., This, P., 2010. Evolution of the VvMybA gene family, the major determinant of berry colour in cultivated grapevine (*Vitis vinifera* L.). Heredity 104, 351–362.

Guillaumie, S., Ilg, A., Réty, S., Brette, M., Trossat-Magnin, C., Decroocq, S., Léon, C., Keime, C., Ye, T., Baltenweck-Guyot, R., Claudel, P., Bordenave, L., Vanbrabant, S., Duchêne, E., Delrot, S., Darriet, P., Hugueney, P., Gomès, E., 2013. Genetic analysis of the biosynthesis of 2-methoxy-3-isobutylpyrazine, a major grape-derived aroma compound impacting wine quality. Plant Physiol. 162, 604–615.

Huang, Y.F., Doligez, A., Fournier-Level, A., Le Cunff, L., Bertrand, Y., Canaguier, A., Morel, C., Miralles, V., Veran, F., Souquet, J.M., Cheynier, V., Terrier, N., This, P., 2012. Dissecting genetic architecture of grape proanthocyanidin composition through quantitative trait locus mapping. BMC Plant Biol. 12, 30.

Huang, Y.F., Bertrand, Y., Guiraud, J.L., Vialet, S., Launay, A., Cheynier, V., Terrier, N., This, P., 2013. Expression QTL mapping in grapevine - revisiting the genetic determinism of grape skin colour. Plant Sci. 207, 18–24. http://dx.doi.org/10.1016/j.plantsci.2013.02.011.

Martin, D.M., Chiang, A., Lund, S.T., Bohlmann, J., 2011. Biosynthesis of wine aroma: transcript profiles of hydroxymethylbutenyl diphosphate reductase, geranyl diphosphate synthase, and linalool/nerolidol synthase parallel monoterpenol glycoside accumulation in Gewürztraminer grapes. Planta 236, 919–929.

Vannozzi, A., Dry, I.B., Fasoli, M., Zenoni, S., Lucchin, M., 2012. Genome-wide analysis of the grapevine stilbene synthase multigenic family: genomic organization and expression profiles upon biotic and abiotic stresses. BMC Plant Biol. 12 (1), 130.

Wang, J., DeLuca, V., 2005. The biosynthesis and regulation of biosynthesis of Concord grape fruit esters, including 'foxy' methylanthranilate. Plant J. 44, 606–619.

Marker assisted selection

Coleman, C., Copetti, D., Cipriani, G., Hoffmann, S., Kozma, P., Kovács, L., Morgante, M., Testolin, R., Di Gaspero, G., 2009. The powdery mildew resistance gene REN1 co-segregates with an NBS-LRR gene cluster in two Central Asian grapevines. BMC Genet. 10, 89.

Di Gaspero, G., Copetti, D., Coleman, C., Castellarin, S.D., Eibach, R., Kozma, P., Lacombe, T., Gambetta, G., Zvyagin, A., Cindrić, P., Kovács, L., Morgante, M., Testolin, R., 2012. Selective sweep at the *Rpv3* locus during grapevine breeding for downy mildew resistance. Theor. Appl. Genet. 124, 277–286.

Eibach, R., Zyprian, E., Welter, L., Töpfer, R., 2007. The use of molecular markers for pyramiding resistance genes in grapevine breeding. Vitis 46, 120–124.

Li, C., Erwin, A., Pap, D., Coleman, C., Higgins, A.D., Kiss, E., Kozma, P., Hoffmann, S., Ramming, D.W., Kovács, L.G., 2013. Selection for *Run1-Ren1* dihybrid grapevines using microsatellite markers. Am. J. Enol Vitic 64, 152–155.

Riaz, S., Tenscher, A.C., Rubin, J., Graziani, R., Pao, S.S., Walker, M.A., 2008. Fine-scale genetic mapping of two Pierce's disease resistance loci and a major segregation distortion region on chromosome 14 of grape. Theor. Appl. Genet. 117, 671–681.

Schwander, F., Eibach, R., Fechter, I., Hausmann, L., Zyprian, E., Töpfer, R., 2012. *Rpv10*: a new locus from the Asian *Vitis* gene pool for pyramiding downy mildew resistance loci in grapevine. Theor. Appl. Genet. 124, 163–176.

Venuti, S., Copetti, D., Foria, S., Falginella, L., Hoffmann, S., Bellin, D., Cindric, P., Kozma, P., Scalabrin, S., Morgante, M., Testolin, R., Di Gaspero, G., 2013. Historical introgression of the downy mildew resistance gene *Rpv12* from the Asian species *Vitis amurensis* into grapevine varieties. PLoS One 8 (4), e61228.

Grapevine breeding in Austria

3

F. Regner
Höhere Bundeslehranstalt und Bundesamt für Wein und Obstbau-Klosterneuburg, Klosterneuburg, Austria

3.1 Introduction to the Austrian situation

Due to the former size of the Austrian–Hungarian Empire, today's traditional grapevine cultivars represent the genetic background of Central Europe. Traditional cultivars were developed by improving their traits in numerous selection steps. Breeders of former times are usually not known, and it is also supposed that wineries of monasteries and churches were involved in selecting new genotypes (Bassermann-Jordan, 1975). Despite a huge number of autochthonous grapevines (Goethe, 1887), only a small number of traditional cultivars are still planted (Bauer et al., 2013). Contrary to most other wine producing countries, Austrian growers and customers quickly accepted new crossed varieties, and therefore it is not amazing that the most frequently used vine for red wines is a variety introduced in the 1960s (Bauer et al., 2013). Nevertheless, this variety, named Zweigelt (Mehofer et al., 2011), is a cross of the old autochthonous varieties St. Laurent and Blaufränkisch (Sefc et al., 1997a). Hence, the variety is young, but the genetic traits are old ones available only in new combinations. In summary, more classified varieties are traditional vines; within them we could define several families and offspring (Regner, 2000a).

As everywhere in the wine-growing world, a few international varieties have also reached Austria. Especially cultivars from the Cabernet family and Syrah, which have been introduced recently (www.austrianwine.com, information platform of the Austrian wine marketing board). The international white varieties Chardonnay, Sauvignon Blanc, and Riesling have already been available for centuries (Trummer, 1841).

Austria has been a member of the European community since 1995 and, therefore, also has to accept the "acquis communautaire," which includes a law for grapevine propagation and wine production. This law regulates the conditions for propagation of grapevine material (www.bka.ris.gv.at, Rechts informationssystem, law informations of the Austrian government), the certification process, and steps of the quality categories (Lacombe et al., 2011). Certified grapevine material has to fulfill genetic and phytosanitary demands (directive 68/193 EC). Since that time, more than 160 clones have been certified and represent the genetic background of the Austrian viticulture. Furthermore, we would need several more clones to represent the diversity of all traditional varieties (Regner, 2009a).

The area of viticulture has decreased in the last years and is already <50,000 ha (Table 3.1). The main reason for the reduction of the viticultural area is the final closing of small wineries when the owner retires. The wine production is mainly located in the Eastern regions of Austria, and 90% are produced in Lower Austria and Burgenland.

Grapevine Breeding Programs for the Wine Industry. **http://dx.doi.org/10.1016/B978-1-78242-075-0.00003-X**

Table 3.1 Structure of Austrian growers, reduction of growers and area, increase of average vineyard size, 1987–2009

Year	Number of estates	Production area	Size per producer
1987	45,380	58,188	1.2 ha
1999	32,044	48,558	1.52 ha
2009	20,181	45,586	2.26 ha

Remarkable viticulture is also found in Vienna and the regions close to or within the Alps in Styria, Carinthia, and Upper Austria (www.austrianwine.at).

Quality wine production is restricted to 35 cultivars and more than 100 cultivars are used for simple wines without any protected origin/designation of origin on the label (http:rebsortenkatalog.weinobstklosterneuburg.at). In Austria, the percentage of quality wines compared to other wines is amazingly high and is probably the result of the preferences of the local customers and the historical development. Two-thirds of the wine on the market are quality wines (www.austrianwine.at). The Austrian market prefers local wines and, therefore, about 70% are homemade. The amount of imported wines is as high as the exports. The home market prefers importing Italian red wines and the main export, with a majority of white wines, goes to Germany and Switzerland (www.austrianwine.at). Therefore, the production is more or less stable and is adapted to the consumption. On average, Austrian growers produce 250 million liters of wine per year (www.austrianwine.com, information platform of the Austrian wine marketing board).

For a couple of years, the system of controlled origin (DAC—Districtus Austriae Controllatus) has been established and has reinforced the marketing of quality wines for some growing regions. The following regions have established wines with controlled origin: Weinviertel, Traisental, Kamptal, Kremstal, Vienna, Neusiedlersee, Leithaberg, Mittelburgenland, and Eisenberg (Figure 3.1). In most cases, only a few varietal wines may be sold with the DAC label, and most preferred wines are made from grapes of Grüner Veltliner and Riesling among the whites, and Zweigelt and Blaufränkisch among the reds. Famous wine-growing regions like Wachau Valley or South Styria neglected this opportunity, as they want to sell all their wines under the protected name of their region. Establishing DAC wines has led to an increase in both the typicity of these wines and the prices for this quality level.

3.2 Professional bodies, research, and interest groups

An analysis of the structure of wine-growing estates in Austria shows that small-scale wineries are the majority, and therefore the average size of a viticultural estate is around 2 ha (Table 3.1). Compared to other wine-growing regions, especially overseas, this is really extremely small. Usually the estates are family-owned and some belong to monasteries or official bodies, but almost none are owned by companies

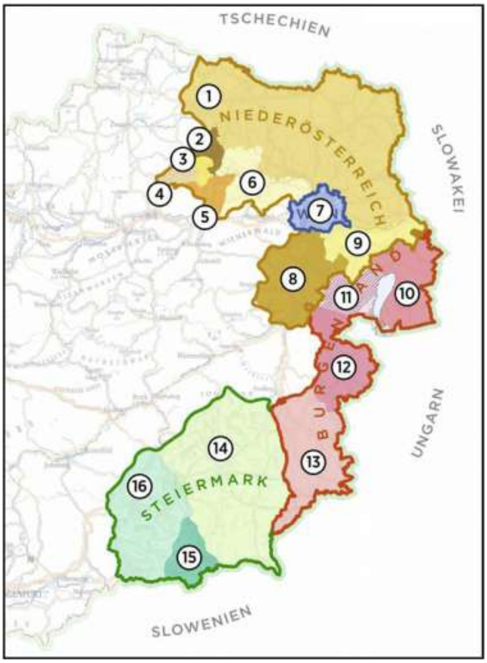


Figure 3.1 Austrian DAC regions. *Regions with DAC wines*: (1) Weinviertel, (2) Kamptal, (3) Kremstal, (5) Traisental, (7) Vienna, (10) Neusiedlersee, (11) Leithaberg, (12) Mittelburgenland, (13) Eisenberg.

(www.austrianwine.at). In former times, almost all farmers in the regions where vines could be grown used to have their own small-scale wine production. Most people were poor, but they liked to have their own wine (Keppl, 1990). In the meantime, things have been changing, and more and more growers have specialized in wine production. On the other hand, the number of growers has been halved in the last 20 years (Table 3.1). Nowadays, more than 20,000 people grow vines, but most of them have their main occupation in other fields (Bauer et al., 2013). Still, a good chance to keep the farm alive with an adequate income is the opportunity to directly sell wines together with meals to customers at one's own "Buschenschank," a typically Austrian wine tavern, which can be found in all wine-growing regions (Steurer, 1995). This privilege has existed since the eighteenth century and allows small wineries to achieve an adequate income.

All wine producers are organized within the Federal Austrian Growers Association, which is the official body to support the wineries and represent their interests. The voice of this organization is usually heard and also has influence on political processes. The Federal organization is based on the membership of several associations of different regions, and the growers are organized by districts or communities. Finally, federal organization proposes the members of the regional committees, which create the DAC wines and organize their marketing (Bauer et al., 2013). The Chamber of Agriculture takes care of wine production by offering professional help concerning not only all aspects of production but also marketing and economic affairs. On the other hand, technical assistance can be obtained from the educational centers existing in each wine-producing federal state. At these centers, education at a basic level for viticulture and oenology is offered. Teachers are also committed researchers and therefore also teach the practical aspects of field experiments. Most of them work together with the Federal College and Research Centre for Viticulture and Pomology Klosterneuburg (HBLA und BA Klosterneuburg) in the field of breeding and other research activities. Cooperation also exists with the University of Natural Resources and Life Sciences in Vienna (BOKU). Lectures and courses at both institutions contribute to the only "diploma enologist" education in Austria. At this University, several groups are occupied with the specific aspects of viticulture (Sefc et al., 1997a; Forneck et al., 2002), but none is involved in classical breeding. At the Institute of Applied Microbiology, transgenic grapevines were developed (Gölles et al., 2000), but the lacking interest of the whole Austrian wine community and, furthermore, the widespread concern regarding genetic engineering in European society stopped these activities.

3.3 Purpose of grapevine breeding

Considering the small-scale wineries, it is clear that only limited personal resources are available. One or two persons have to cover the expertise from the vine to the wine and also to the market and customer. Therefore, technical consulting is an essential necessity, and growers are also grateful for hints concerning grapevine material. Currently, around 10% of the Austrian grapevine production is performed under organic conditions (www.austrianwines.com). Organic wineries are more interested in new developed varieties than conventional ones. Their need for varieties that are resistant against the main diseases, such as mildew and grape rot, is urgent (Bauer et al., 2013).

Customers have become increasingly critical when it comes to plant protection by using chemicals. The acceptance of minimal residues of pesticides within grapes has declined dramatically. Some supermarkets do not accept wines with residues, even if the concentration is below legal limits.

Therefore, the growers have a narrow position between the high-quality demands of the market and the limited use of plant protection products. In this situation, a high percentage of them are ready to use new crossed varieties to improve the phytosanitary status of their production. Traditional cultivars offer the highest wine quality but lack an essential resistance against mildew diseases (Kaserer et al., 2000). The idea of breeding new varieties for wine production is to combine both these essential traits. In the meantime, several generations of breeders have tried to deliver cultivars which carry both of them (Zweigelt and Stummer, 1929). It is still an ongoing process, and the breeding institutes create numerous genotypes, hoping that one or even more will be accepted for high-quality wines (Jörger, 2002). Meanwhile, too many new cultivars with some kind of mildew resistance have been offered to the growers. Finally, most of them decide to wait as long as a single or a few of them show the clear advantages for production (ICV, 2013). What is needed are cultivars with all-around qualities for the production process, wine quality at the same level as traditional varieties, and improvements concerning disease sensitivity (Regner, 2012). On the other hand, the majority of growers are not very interested in new releases, and for them, only specific selected clones can improve their situation (Schönhals et al., 2009). In general, the wine market is conservative, and it takes a long time until new cultivars become accepted (Kaserer et al., 2000). As in nature no stable status can be reached, steadily effort is necessary for selecting favorable types from the traditional varieties. Without selecting the right genotypes and replanting with certified material, degeneration of grapevine material would diminish the potential of traditional varieties (Bauer et al., 2013). Types with loose clusters and thicker skin of the berry are appreciated, as these traits usually contribute to a higher stability against Botrytis (Rühl and Mend, 2009). Especially varieties with dense clusters, such as Riesling, Pinots, and Chardonnay, are concerned, but it seems it is not a simple task to find or create suitable variations.

Clonal selection in Austria is performed mainly by institutions: if a private winery or nursery is selecting, they usually cooperate with an institutional partner. Most clones were developed by the Austrian Nursery Association, abbreviated VÖR (Regner et al., 2008). Other clones were selected by the Styrian Department for Viticulture in Haidegg, by the HBLA Klosterneuburg and some growers in cooperation with the Institute for Viticulture in Eisenstadt. Technical support for virus testing is required by private breeders (Gangl et al., 2009; Regner et al., 2000d). All registered clones of Austria can be found in the online catalog (http:rebsortenkatalog.weinobstklosterneuburg.at).

3.4 Today's cultivars and their genetic background

Only 35 grapevine varieties are registered in Austria for quality wine.

The *white cultivars* are the following: Bouvier, Müller Thurgau, Frühroter Veltliner, Muskat Ottonel, Neuburger, Ruländer, Chardonnay, Pinot blanc, Traminer, Goldburger, Grüner Veltliner, Rotgipfler, Sylvaner, Muskateller, Riesling, Roter Veltliner, Sauvignon Blanc, Scheurebe, Zierfandler, Welschriesling, Jubiläumsrebe, and Furmint.

The *red cultivars* are the following: Blauer Portugieser, Blauburger, St. Laurent, Zweigelt, Pinot noir, Merlot, Rathay, Roesler, Blaufränkisch, Cabernet Sauvignon and Cabernet franc, Blauer Wildbacher, and Syrah.

It is a wish of the Grower Association to keep the list of quality grapevines small, as it is considered advantageous to the markets to produce only with a smaller range of cultivars but powerful varietal wines. Therefore, acceptance on this list is not a right which can be gained, but is a political decision (Regner, 2008). More than 100 other cultivars are allowed for production, but they are not accepted for the production of quality wine. One reason may be the lack of quality in general but also the incidence of aromas associated with "hybrid wines" or content of malvidin diglucoside within the anthocyanins, inhibiting the acceptance of a new variety for quality wine (Regner, 2009b).

In former times, no quarantine or border inhibited the spread of new grapevine cultivars. The exchange of material could easily happen. In Mid Europe, cultivars from far away had the chance to become established, and in some cases, they are still cultivated today. Prominent imports done centuries ago are the Pinot family (Jahnke et al., 2011) or Portugieser (Regner et al., 1999). The most important argument to keep a variety was the economical aspect. In most cases, an agreeable quality was demanded and even the quantity had to reach a specific level. It is assumed that the Pinots were brought to Austria from France by Cistercian monks, and these cultivars (gris, noir, and blanc) represent an essential contribution to quality production (Regner and Stadlbauer, 1999). As these cultivars are not so well adapted to the Pannonian climate conditions, they never act as the most important varieties. Moreover, outcrossings of Pinot outclass the original vines of the family (Regner et al., 2000c). While Chardonnay is an international example in Austria, two offspring varieties (Bouvier and St. Laurent) have gained importance (Regner et al., 2001). Bouvier is a white-berried seedling of Pinot combined with Muscat and has been available since the beginning of the twentieth century. The most estimated trait is the early ripening and the nice flavor, even though the Muscat flavor is not present. It is frequently used in Burgenland for the production of juice, fermenting juice, and sweet wines by late harvest (Bauer et al., 2013). More important for the market is the blue-berried seedling St. Laurent. It is better adapted to the Pannonian climate than Pinot noir and, in former times, was only differentiated from Pinot by definition as a dark red Pinot type (Burger, 1837). The variety was introduced by the monks of Klosterneuburg, and this winery is still the most important producer. Most vineyards of St. Laurent are located south of Vienna and in Burgenland. The sensitivity of the cultivar during bloom limits the spread of the cultivar (Steurer, 1995). Mr. Zweigelt, one of Austria's most successful breeders, combined St. Laurent with Blaufränkisch to overcome this obstacle. The resulted cultivar now bears his name and is the most planted red variety in Austria, and it is even present in Hungary, Slovakia, Czech Republic, and other neighboring countries (Ambrosi et al., 1998). This cultivar is useful for producing high quality or, due to high crop load, simple pleasant wines. The genetic base was used in a combination with a breeding line (Kl 1189-9-77) to create a partly mildew resistant variety named Roesler (Figure 3.2). This is the actual end of the Pinot noir derivation and Roesler is still a full *Vitis vinifera* type without off-flavors and without malvidin 3,5-diglucoside anthocyanin (Regner, 2009b). The variety was released in 1995, and since 2000, it has been possible to sell quality wines from this new variety. In the meantime, 170 ha of Roesler have been planted. Roesler is the first cultivar with genetic influence of

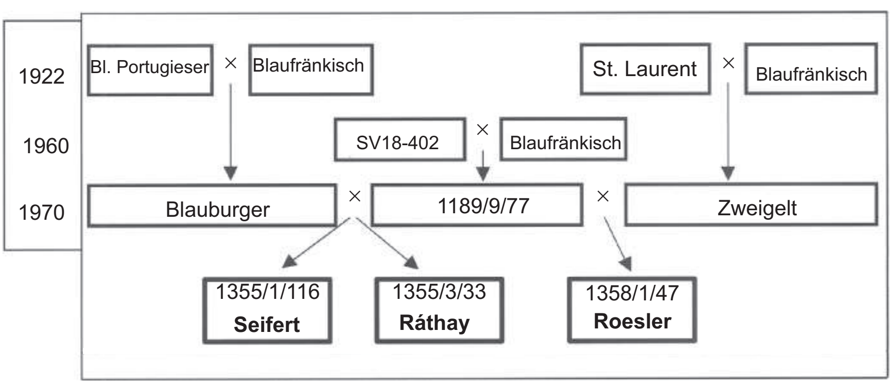


Figure 3.2 Crossing steps for the creation of Roesler and Rathay.

American species allowed for quality wine production in Austria (Kaserer et al., 2000). Especially for organic production and cool climate regions, this variety combats all others with amazing quality parameters of extract and color. At the same time, together with Roesler, a half-sister variety named Rathay (Figure 3.2) was released (Kaserer et al., 2000). The *Vitis vinifera* parent of Rathay is Blauburger, which was combined with the breeding line (Kl 1189-9-77). Rathay is not so favored by the growers, as this cultivar has an extremely high content of anthocyanins, however, without any malvidin 3,5-diglucoside. The levels of anthocyanins in Rathay, which are even higher than in teinturier varieties, have the effect that traces of consumption can easily be found on lips, teeth, and sometimes on tablecloths (Kaserer et al., 2000). The parent Blauburger is also a release of Klosterneuburg, crossed by Zweigelt and introduced in the 1970s (Bauer et al., 2013). As a combination of Blauer Portugieser × Blaufränkisch, the cultivar represents more the early ripening smooth red wine for cooler climate regions similar to Portugieser (Sefc et al., 1997b). More than 900 ha in Austria and recommendations for growing in Eger (Hungary) attribute at least moderate importance to the cultivar. Nevertheless, Rathay and Blauburger show several similarities to Blauer Portugieser and can be regarded as further development of its original Portuguese genetic (Regner et al., 1999). The high yields and early ripeness, as well as the early maturity of wines, helped to spread the cultivar to all cool climate regions in Europe. In Austria, Portugieser still ranks third among red varieties. Doubts that the cultivar has a different origin, which have been articulated for centuries, were refuted by genetic fingerprinting (Regner et al., 1999).

3.5 Ancient donor vines and their key role

Pinot and numerous outcrossings of the cultivar (Regner et al., 2006a) are one of the major sources for the varietal diversity in cooler regions of Europe. Nevertheless, the genetic origin of Pinot is based on Traminer (Regner et al., 2000a), and this cultivar represents a key function for the development of quality grapevines under specific circumstances. It can be supposed that the cultivar was already spread to several Roman provinces during the first boom of viticulture in Mid Europe (Regner and Kaserer, 2002). The geographical origin of this variety is unclear, but due to the long periods passed by will be unclear in future (Imazio et al., 2002). The Roman name was *Vitis aminea*. Each Roman soldier had the privilege to get a daily ration of wine. For agreeable quality, grapevine cultivars were brought to the provinces by Roman settlers (Bassermann-Jordan, 1975). The introgression of Traminer to the local, already existing genotypes enabled the new cultivars to combine local adaptation with high wine quality (Myles et al., 2011). Therefore, you can nowadays find genetic traces of Traminer as a parental or a grandparental donor vine in several important varieties (Regner, 2000b). For the Austrian viticulture, the influence of the Traminer genetic is tremendous. Grüner Veltliner, Rotgipfler, Sylvaner, Sauvignon, Riesling, and Pinots are characterized by a high amount of Traminer alleles (Regner et al., 2000e). The positive influence of derivations with Traminer can still be observed by ongoing breeding activities (Hajdu, 2000).

The second important variety for the development of grapevine diversity in Europe is Heunisch (Regner et al., 1998b). As this variety was not favored for high-quality wines during the last century, more and more vines disappeared from the vineyards. Contrary to Traminer, this variety brought traits for high yield, high acidity, good growth, and winter stability. Several of today's cultivars represent an introgression of Heunisch and, furthermore, allow us to recognize the influence as a grandparental variety (Bowers et al., 1999b). The name of the cultivar is derived from the Huns. It is supposed that Heunisch was an imported variety brought from the Antasiatica gene pool. During the Middle Ages, it was recommended to plant half the vineyard to Heunisch and the other half to "Fränkisch." Heunisch contributed more to yield, while Fränkisch varieties (Traminer, Pinot, and other autochthonous varieties) reached higher sugar content and aroma density (Regner et al., 1998b). What was a mixture of two components at the beginning resulted in varieties that represent a fusion of these gene pools (Regner, 2000b). Prominent cultivars of Heunisch parentage that were classified for Austria are Riesling, Chardonnay, Furmint, Sylvaner, Blaufränkisch, and Wildbacher. All these cultivars are still in use but with different importance. Sylvaner is the cultivar that is most closely connected to the viticulture along the Danube. It could be identified as a cross of Traminer × Österreichisch Weiß (an ancient Heunisch seedling; Sefc et al., 1998). While in Austria, Sylvaner has decreased due to the canopy management change to Lenz Moser trellising in Germany and Switzerland, and Alsace is still appreciated for quality wines. Due to local warming and a higher frequency of "early ripening" years, the high acidity stability of Heunisch offspring is gaining more importance again. Chardonnay and Riesling are very popular at the moment, and the size of the viticultural area planted to them has been increasing steadily for more than 20 years (Regner et al., 2000b). Chardonnay has become one of the most widespread white varieties in the meantime. The wines are not favored to support the Austrian wine style (Regner et al., 1998a). On the other hand, Riesling is tricky in cultivation, but under the changeable weather of Lower Austria, quality reaches a very high level. The cultivar ranks fourth among white wines and will continue this way. Along the Danube and especially on the terraces of the Wachau Valley, it reaches a quality level comparable to the famous Mosel and Rhine wines (www.austrianwines.com). Furmint, representing the Hungarian wine style, was traditionally used around like Neusiedl to harvest very late, extremely sweet berries, or nobly rotten berries. While in Hungary, several thousand hectares are planted, in Austria a few vineyards can only be found in Rust (Burgenland).

Further Heunisch seedlings are Blaufränkisch and Wildbacher. Both varieties share not only the same parentage but also a high degree of genetic similarities and color distribution (Regner, 2007b). It seems that both cultivars are very close from a genetic point of view. The wine typicity does not reflect that fact, but differences are also based on the different climatic conditions (Renner et al., 2006b). While Blaufränkisch is mostly cultivated in the Pannonian area of Burgenland, Wildbacher is restricted to Styria, and at this region, an Illyrian climate with Alpine influence can be registered. Wildbacher still shows some influence from the wild vines and will be discussed later on under these aspects. The origin of Blaufränkisch is highly confusing due to several historical synonyms and numerous related varieties. Most of these historical varieties with the potential for misinterpretations no longer exist today (Regner, 2007b).

The most probable genetic origin is the cultivar Blauer Grober, which mutated to the Blaufränkisch. Even the Blauer Grober cultivar allows recognition of the Heunisch heritage. One of the growing regions in Burgenland is focused mainly on this variety and, in the meantime, is designated as Blaufränkischland. It is Austria's second and Hungary's most commonly planted red variety with a long tradition and has spread also to Italy, Croatia, Slovakia, and Germany. Besides the extent of the viticultural area, this variety passed on important traits to the offspring varieties Zweigelt, Blauburger, Roesler, and Rathay (Kaserer et al., 2000).

Finally, Austrian grapevines cannot be discussed without mentioning the Veltliner family. Today's most planted variety is Grüner Veltliner (Figure 3.3); however, it is not closely related to most other Veltliner varieties (Regner et al., 2006b). One of the former synonyms, Weißgipfler, would be more correct and takes into account that it shares Traminer heritage with Rotgipfler. While Rotgipfler derived from a cross of Roter Veltliner × Traminer, Grüner Veltliner has no parentage of a Veltliner-related cultivar. By luck, the second parent of Grüner Veltliner was found at a reservation land where viticulture was given up a few centuries ago (Regner, 2007b). The vine is an individual genotype, which was never detected again, and therefore it was named according to the place where it was found (St. Georgen). Grüner Veltliner displays some disagreeable traits, which are also responsible for the limited number of useful seedlings in breeding. In the meantime, some overseas growers would like to reinforce their white wine potential by introducing Grüner Veltliner (Berger, 2008).

Figure 3.3 Oldest ampelographic picture of Grüner Veltliner.

Roter Veltliner is the variety in the center of the Veltliner vines and is much older than all other members (Regner and Hack, 2009). Due to high yield but very dense clusters, the acreage planted to this cultivar is steadily decreasing. As the quality can reach amazing nuances under specific circumstances, the "Slow Food" organization now supports the marketing of these wines. The idea is to stop the gradual disappearance of this variety. The genetics of Roter Veltliner was passed over to the offspring varieties: Frühroter Veltliner, Rotgipfler, Zierfandler, and Neuburger. All these cultivars are typically Austrian varieties and could be designated as autochthonous for our country (Regner et al., 1996). Zierfandler and Rotgipfler are already limited to areas south of Vienna but still delight growers with very dense wines and amazing flavors (Ambrosi et al., 1998). Quality is also based on high extract values and longevity of the wines. Zierfandler has the same origin from a Roter Veltliner × Traminer cross as Rotgipfler, but offers some mismatches in the genetic profile due to mutations (Regner et al., 2000e).

Frühroter Veltliner was spread under different aspects, but as an early ripening variety, its importance is diminishing due to global warming. The same genetic origin from a Roter Veltliner × Sylvaner cross is shared with the cultivar Neuburger (Regner et al., 2000e). Neuburger is a relatively young cultivar and spread from the Wachau Valley to several other northern growing areas in the last century. Therefore, it is not surprising to find this cultivar also in the Czech Republic and in Slovakia. It is a very vigorous vine building very dense clusters, which are a source of trouble (Ambrosi et al., 1998). Under deep soil conditions, the flowering is disturbed and colure frequently happens. The most interesting production is for sweet wines with the incidence of Botrytis (Bauer et al., 2013).

Another cultivar that is important for Austrian viticulture is Welschriesling, which covers more than 4000 ha and is even widespread in Hungary, Croatia, Slovenia, and Slovakia (Regner, 2008). The origin is very unclear, but due to the synonym Riesling Italico, it is supposed to come from Italy. Based on the genetic distance, we could find two closely related cultivars without defining a perfect heritage. One of the parents is supposed to be Grobriesling (Elbling), an ancient cultivar of Central Europe, and the second is an Italian one, called Verduzzo Trevignano. Welschriesling was not used to create further cultivars; therefore, this genetic seems to be more individual than all other classified varieties (Regner, 2007a).

3.6 Diversity of grapevines and grapevine families

Studying old ampelographies by Goethe (1887), Babo (1881), or Burger (1837), it is clear that the high diversity of grapevines has its source in the intention of man to optimize viticulture under changeable conditions. The first step of development was planting selected wild vines in fields far away from their natural habitat in the forests. Among the selection criteria, there was always higher yield and pleasant taste of grapes and wines (Schöffling and Stellmach, 1993). As grapevines were widespread in Europe, the domestication process took place at numerous locations and was still described for the cultivar Orangetraube in the twentieth century (Bauer et al., 2013).

Essential improvement usually could only be reached by introgression of cultivars with specific traits. This introduction of new genetic traits was not intended but happened due to the usage of seedlings for propagation (Zweigelt and Stummer, 1929). In the same way, mutations were picked out and spread to the vineyards (Riaz et al., 2002). It is assumed that the introduction of Traminer by the Romans and Heunisch from Near East regions changed the quality and vitality of many cultivars (Myles et al., 2011). Despite this phenomenon, grapevine families could be enlarged at several places by propagating mutations and outcrossings (Franks et al., 2002). Vine families with importance for the commercial viticulture, such as the Pinot or the Veltliner cultivars, have already been mentioned (Regner and Hack, 2009). Other not so successful varieties are threatened to disappear and can only be found in old vineyards, which often were planted to a range of varieties. The idea of this kind of planting was to minimize the risks by usage of different traits. For instance, the Portugieser family also contains a gray- and a white-berried type. The cultivar Chasselas, which was also used for wine production in former times, was present in different berry colors and even in cluster types. In some places in Austria, we could find individual outcrossing of Chasselas Blanc. That is a clear indication of its frequent use in former times. From the Roter Veltliner family, some disappeared genotypes carried names such as Beerheller, Hansen, Gelbling, Weißroter, and Silberweiß. We could also detect a vine derived from a cross of Roter Veltliner × Heunisch twice, but the designation of a historical grapevine is delicate, and therefore, we hesitated to rename it under a wrong name (Regner, 2009a).

For all these reasons, the need of identifying, conserving, and describing ancient and neglected varieties is of high priority. In several European countries, there are still unexplored varieties that will be lost without having been defined (Maul et al., 2012). Current activities in the frame of European Agricultural Genetic Resources projects are on the way to assist survival of rare autochthonous cultivars. One of the steps is the documentation of these varieties in a European Database (www.genres.de/eccdb/vitis) by their morphological and genetic profiles (Maul et al., 2012).

3.7 Wild vines and their link to actual genotypes

In former times, grapes of wild vines were collected by poor people for fresh consumption and small-scale wine production (Kirchheimer, 1944). Wild vines were extremely diminished by phylloxera (Schuhmann, 1968, 1971), but at some places along the rivers Danube or March, small populations could survive (Tiefenbrunner et al., 2005). The genetic of these cultivars was compared to the *Vitis vinifera* cultivars of today, but the common alleles are rare. Only the traditional cultivar Blauer Wildbacher allows the recognition of similarities to the wild vines (Renner et al., 2006b). It is named after the small village Wildbach in Styria, and its origin is not documented. Goethe (1887) was convinced that Wildbacher was selected from wild vines and spread due to vigor and fruitfulness independent of soil, terroir, and canopy management; Babo and Mach (1881) also favored this hypothesis. They supposed that the name Wildbacher was related to the wild vines or the unusual type of wine. In fact, Wildbacher Spätblau (a special type) shows a morphological and genetic relationship to the wild vines (Renner et al., 2006a). Actually, Wildbacher is mainly planted in West Styria due to the high stability in growing under humid conditions on poor soils. The main wine is a rosé type with high acidity and berry fruit aromas. Wines are offered under the protected name of Schilcher (Keppl, 1990). In the west, Styrian vineyards with more than 450 ha of Wildbacher are still cultivated (Ambrosi et al., 1998). Wildbacher is globally seen as a rare and threatened variety. Some types (Trummer, 1841) of this variety seem to be already extinct. Single vines named Wildbacher could also easily be found in other European countries such as Italy, Slovenia, Hungary, and Germany, and it is supposed that these samples were derived from original Styrian material in former times (Meneghetti et al., 2009). In 1841, Trummer mentioned different types of Wildbacher, such as Frühblauer, Schlehenblauer, Spätblauer, and Rotblättriger, as originating from Styria, giving their first detailed ampelographic description. Renner et al. (2006a), using molecular markers and ampelographic descriptions, showed that the name Blauer Wildbacher can be regarded as a homonym, and the most widely spread type in Austria was the so-called "Frühblauer," covering more than 90% of planted Wildbacher vines. It was indicated as a reference for Blauer Wildbacher true-to-type (Morten, 1895). Today, Blauer Wildbacher represents the most widely spread and better performing type and ripens earlier than Wildbacher Spätblau. They are morphologically and genetically very similar, and they share at least one allele at each of the SSR loci analyzed for cultivar identification. The conclusion is that even Wildbacher exists as a grape family and not as a single variety (Meneghetti et al., 2009).

3.8 Newly crossed varieties of recent years

The last release of a newly crossed variety in Austria is Donauriesling (Regner, 2012). The name already allows identification with the *Vitis vinifera* parent Riesling. The second partner in the cross was the elite vine Fr. 589-54, which inherited some resistance from the Seyve Villard 12-481. The source of resistance was derived from different American species (Figure 3.4). The first steps were already done in 1978, but the vine was planted at a place that could not be easily managed. In 1994, the vine was selected before the whole vineyard was removed, and since that time, evaluations were carried out annually. We observed higher stability against both mildew diseases, and more important, the susceptibility to Botrytis of Riesling could be overcome due to loose clusters. A satisfying vitality, moderate to high yields with high sugar values, and high acidity enable the growers to produce late harvest wines with an amazing complexity of aromas comparable to Riesling wines (Regner, 2012). Finally, the field behavior and the good ratings at a wine sensory evaluation convinced us to start with plantings at different wine-growing regions with the cooperation of local wineries. At least the wine growers working with this cultivar demanded from us to continue the way of introduction to the market. In the meantime, Donauriesling is allowed to grow in the different wine-growing regions, and it is legal to sell the wines with the name of the variety on the label (www.bka.ris.gv.at, Rechtsinformationssystem, law informations

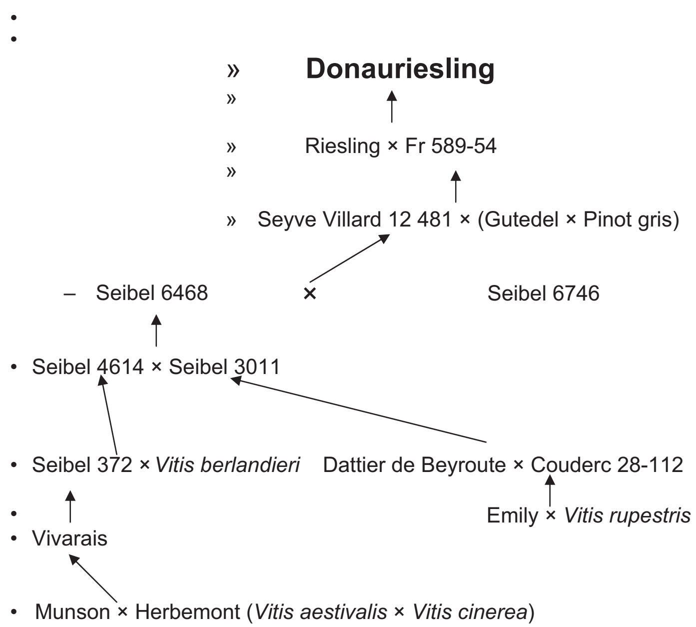


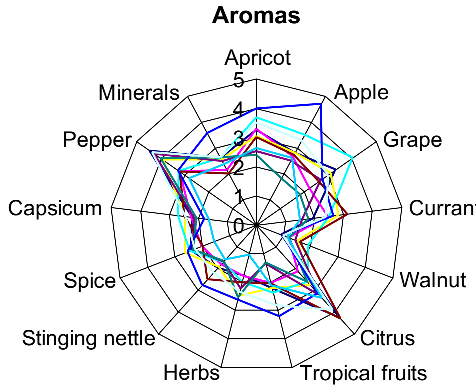
Figure 3.4 Heritage of Donauriesling: it could not be completely reconstructed.

of the Austrian government). However, our intention is to get it accepted for quality wines. At official tastings, wines were already introduced and estimated as typical Riesling wines. At this time, we are occupied to collect all scions that we can utilize to satisfy the wishes of innovative growers. Application for varietal protection was submitted and is on the way.

3.9 Future perspectives for new varieties

Currently in Mid Europe, we are confronted with a huge amount of new varieties with more or less stability against the mildew diseases (ICV, 2013). The first problem is that not all of them reach a wine quality that would be necessary to convince customers. It will be a task to select the best out of the pool and focus on a very few for each growing region (Regner, 2012). The advantage will be the creation of strong wine labels with a well-known name. It is not feasible to transport more than 30 new varieties to the markets. From the HBLA, Klosterneuburg expects us to deliver new genotypes close to Grüner Veltliner (Mehofer et al., 2006) but fortified in the stability against mildew diseases. The wine should be identical to the established style and preferably should contain peppery notes caused by the terpene rotundone. In any case, it is expected that the wine shows a Veltliner typicity (Flak et al., 2007; Figure 3.5). In the meantime, we are already verifying some genotypes for their cultural quality with experimental plantings in different growing regions. On the other hand, we are still making crossings with Grüner Veltliner to come closer with the genetic profile to the *Vitis vinifera*

Figure 3.5 Aroma profile of Grüner Veltliner: comparison of 10 clones (one value represents the mean of eight evaluations).



behavior (Regner et al., 2006b). In our opinion, the genotypes that are currently tested already fulfill the demands, but we try further backcrosses to get more data for the final decisions. It could also be a result that not one new "PiWi" cultivar meets the demands but a few of them show different options for different requirements. Therefore, we will introduce these different genotypes and create names, where the heritage from Veltliner should be recognizable. If all these criteria are fulfilled, I am sure that Austrian growers will continue their way to a sustainable production on a very high quality level. Breeding activities enable this development, and with new promising genotypes, it will be much easier to follow (Regner, 2012).

3.9.1 Rootstocks and the success of Kober's selection

On the way to overcome phylloxera damages, grafting on American species seemed to provide the right tool. Finally, the climatic and soil condition for growth in the wine regions was not appropriate for this kind of rootstock. The first trials in 1883 with *Vitis riparia* allowed us to detect the limits of this genotype in use as a rootstock. As a second choice, grapevines grafted on Rupestris were planted at several locations around Vienna. It was recognized that all the needed traits were at disposal but not available in a single rootstock (Kober, 1903). Resseguier in France was successful in selecting valuable *Vitis berlanderi* genotypes. In 1896, he sent a huge amount of seeds to Teleki in Villany, Hungary. The seeds gained by open pollination were developed to plants and finally classified according to their morphology. As several of the plants allowed us to identify the influence of *Vitis riparia*, the populations were grouped according to their genetic–morphological behavior. Several European researchers visited these plantings and observed growth and vigor of the vines. Teleki started with a first selection. One of the first visitors was Franz Kober (Figure 3.6), who took a large sample with him and started with field experiments (Kober, 1910). More than 20 years later, after steady observation and selection processes, he proposed two of his genotypes due to the good performance under calcareous soil and in the Pannonian climate. The code of the rootstocks were 5BB and 125AA (Manty, 2006). A second Austrian researcher named Reckendorfer isolated two rootstocks out of the Teleki

Figure 3.6 Franz Kober, Austria's most successful breeder.

pool and gave them the numbers 7 and 27. At least R 27 is still used in a region where deep loess soil is not appropriate for Kober's selection. In the meantime, you can find several different rootstocks in Austrian viticulture; nevertheless, Kober 5BB is still the most important one (Bauer et al., 2013).

3.9.2 Considerations about actual breeding activities

The grapevine is a high heterozygous plant and therefore cross-breeding is not comparable to other crops, such as wheat. The most disappointing fact is that the expectations of customers for the wine's sensorial profile are much smaller than the genetic possibilities. That means only a few resources can be used to reach new genotypes that fulfill the criteria of resistance and high wine quality (Husfeld, 1962). First of all, we should be aware what happens in the process of pollination. Meiosis takes place and provides the vine with haploid cells in pollen and eggs and creates the preconditions for the new combination reached by hybridization. In the heterozygous grapevine, two possibilities exist for each chromosome to be transferred to the gametophytes. In combination of all chromosomes, either in pollen or in the eggs, there exist 2^{19} different arrangements of chromosomes. The extent of possibilities (524,288) is amazing when taking homogenous crops, such as wheat, into account. With a wheat inbred line (homozygous), you already know the outcome of a cross, as it is theoretically one hybrid. Creation of haploid grapevines from pollen cultures was not successful (Sefc et al., 1997c). When crossing two grapevines with a different genetic background, you may observe $2^{19} \times 2^{19}$ possible different genotypes. Neglecting mutations and crossing over the result of such a breeding step is calculable. The cross of heterozygous grapevines will deliver more than 274 billion different combinations of possible genotypes. Considering the enormous amount, it is clear that the result of a cross is not predictable, and it is a game of pure chance to reach specific combinations of chromosomes. Therefore, it seems to be an illusion that from large populations it is easy to find the ideal offspring. Huge populations in the practical breeding consist of several thousand plants, and it is not feasible in the working life of a breeder to observe all the combinations of one cross. This is the real limiting fact of grapevine breeding! However, if the combination was chosen with care and the donor vines are proofed to provide the offspring with valuable traits, promising seedlings will be found (Regner, 2012). That means not only one ideal combination will be a successful genotype, and useful combinations are not the proverbial needle in the haystack. If the population is huge, which is important for the possibility of finding a right genotype, it is a necessity to discard most of the seedlings very soon. It is not feasible to prove thousands of different vines under viticultural aspects. A decision should be made as soon as possible and useful plants should be maintained, while others should be rejected (Jörger, 2002). The selection process should diminish seedlings very fast and only a few promising genotypes should be compared in the field. While selection without phenotyping is useless, tremendous efforts have to be taken to find the ideal genotypes out of a population. In recent times, genetic markers have been applied more and more frequently to improve the selection process. From the practical point of view, beside the resistances against mildew diseases, wine quality is the most important trait for selection. We have observed that our potential customers expect wines with a sensorial profile, which is well-known from traditional varieties like Veltliner (Figure 3.5). That means if a new crossed variety is very close to the wine of an established variety, the acceptance is much higher than for a wine that is not easily assignable. Therefore, in the selection process, we favor genotypes that could not be differentiated from their *Vitis vinifera* parent by sensorial evaluations (Eibach et al., 2002). For instance, we introduced wines of our new variety Donauriesling to the official sensorial evaluation under the varietal name Riesling, and they were accepted without any remarks about varietal identity. The hope for the future is that European wine markets will be more open for new varieties and allow promising genotypes a fast-spreading development.

Besides the creation of new genotypes, it is always a topic to select the most appropriated phenotypes out of a variable pool of genotypes within a traditional variety. Future goals for clonal selection will be very specific for each variety and depend on the agronomical traits. In the case of Veltliner, it would be helpful to find mutants more unaffected by hot and dry weather conditions, while for Riesling it would be helpful to achieve stability against sunburn by UV radiation. There are definitely more wishes for mutants than natural genetic variation may grant with new genotypes.

3.10 Molecular tools for grapevine breeding

Genetic analyses were introduced in grapevine breeding with increasing possibilities to explore the genome of plants. At the beginning, when only insufficient sequence information was available, it was already helpful to estimate the genetic diversity by comparing RAPD fingerprints (Büscher et al., 1993; Regner and Messner, 1993). For instance, this kind of genetic profile was used to select five clones out of 20 possible samples in the certification process of new clones of Grüner Veltliner (Regner et al., 2006b).

Later on, sequencing of microsatellite fragments derived from *Vitis riparia* Gloire de Montpellier enabled us to characterize loci spread over the genome (Sefc et al., 1999). Using these SSR markers and other published ones (Thomas and Scott, 1993; Thomas et al., 1993; Bowers et al., 1996, 1999a), it was feasible to identify varieties and specific genotypes. We essentially contributed to the effort of establishing a European database for grapevine genetic resources with SSR profiles (Maul et al., 2012). At the beginning, six markers (VVS2, VVMD5, VVMD7, VVMD27, VrZag62, and VrZag79) were chosen to characterize the cultivars (This et al., 2004). Finally, in a second project, the profile was enlarged and the markers VVMD25, VVMD28, and VVMD32 were added. Comparing genetic profiles with above 30 loci, it could be conceded that a relationship exists between several varieties (Tessier et al., 1999). As a very helpful hint for the future, breeding was the illumination of some traditional cultivars with a key function for the development of today's cultivars. For the Austrian varieties, these key cultivars are Traminer, Heunisch, and Roter Veltliner. Only a few markers are necessary to ensure if a genotype is derived by a cross or is a product of self-pollination. Nevertheless, there is a risk that single loci change their allele length due to chromosomal arrangements, and parentage cannot be clarified by this information.

A worldwide cooperation called *Vitis* Microsatellite Consortium characterized more than 400 SSR loci (www.agrogene.com, VMC Collaboration Agreement for the Development of Grape Microsatellite Markers), and at the moment, more than 600 are available. We also tried to find enough polymorphism with SSRs to be able to characterize clonal variability (Regner et al., 2000b). It was much easier to find deviations in the microsatellites of ancient cultivars, such as Traminer, Pinot, and Riesling, than in other traditional cultivars of younger age. In the case of Grüner Veltliner, we also applied AFLP technology to differentiate five certified clones (Lang et al., 2010). Also, inter-SSR markers seemed to provide more potential to find polymorphism within one cultivar (Regner et al., 2006a). The real issue will be to reproduce a clonal profile with once defined alleles, as it would allow us to recognize clones by their fingerprint. Additional information about heritage could be gained with chloroplast markers (Imazio et al., 2006). However, it seems that their usage is also limited by weak polymorphism (Table 3.2) and unexpectedly high variation within one cultivar (Regner and Hack, in press).

As the grapevine is very heterozygous, the segregation of the alleles in a population makes it possible to anticipate the genetic potential of this combination. SSRs and other markers were applied to anchor specific chromosomes as linkage groups and finally connect QTL with specific loci (Mandl et al., 2006). Hence, gene mapping has become a valuable tool for that purpose (Adam-Blondon et al., 2004). In the meantime, markers were developed to accelerate selection processes. Markers linked with resistances against mildew disease are especially appreciated (Fischer et al., 2004). Sometimes it is helpful to already know which chromosome is inherited from a non-*Vitis vinifera* donor plant (Santiago et al., 2006). It is not a simple task to transfer one marker from one population to others. We failed by using markers for seedlessness from different populations. In the meantime, stable markers for resistances have been developed, which are an efficient tool in early selection (Calonnec et al., 2012).

Table 3.2 **Chloroplast profiles of traditional grapevine varieties**

Variety	ccmp 10	ccmp 3	cSSR 5	cSSR 9
Traminer	**117**	107	238	170
Traminer main	**116**	107	238	170
Traminer Kl 23	**115**	107	238	170
Sylvaner main	116	107	**240**	170
Sylvaner(N) St 25	116	107	**238**	170
Pinot blanc	**116**	106	240	**170**
Pinot noir	**116**	106	240	**170**
Pinot gris	**115**	106	240	**170**
Pinot gris	**115**	106	240	**172**
Schwarzriesling	**115**	106	240	**172**

The samples of the different chlorotypes have different origins and allowed to detect mutations in the chloroplast genome within one variety.

3.11 Transgenic vines

At the University of Natural Resources and Life Sciences in Vienna (BOKU), there existed a work group dealing with transgenic breeding approaches. Its first aim was achieving resistance against Plum Pox Virus in plums and apricots (Laimer da Câmara Machado et al., 1991; Regner et al., 1992). As the methods were established, they also started to apply this technology to reach transgenic grapevines. It was also the approach in grapevines to use coat protein-mediated resistance for breeding resistant vines (Gölles et al., 2000). The methods seemed to be successful in the case of GFLV and ArMV viral coat protein-expressing vines. No effect was observed in transgenic Russalka vines expressing GVA and GVB proteins (Laimer et al., 2009). The activities with transgenic grapevines did not get the support from official institutions or political parties. Finally, the research and development of transgenic grapevines at the BOKU was closed. It seems that central Europe is not a proper place to develop transgenic plants.

References

Adam-Blondon, A.F., Roux, C., Claux, D., Butterlin, G., Merdinoglu, D., This, P., 2004. Mapping 245 SSR markers on the *Vitis vinifera* genome: a tool for grape genetics. Theor. Appl. Genet. 109, 1448–1458.

Ambrosi, H., Dettweiler, E., Rühl, E.H., Schmid, J., Schumann, F., 1998. Farbatlas Rebsorten, 300 Sorten und ihre Weine, second ed. Ulmer, Stuttgart.

Babo, A., Mach, E., 1881. Handbuch des Weinbaus und der Kellerwirtschaft. Paul Parey Verlag, Berlin.

Bassermann-Jordan, F., 1975. Geschichte des Weinbaus, third ed. vol. 2. Pfälzische Verlagsanstalt, Neustadt an der Weinstraße.

Bauer, K., Regner, F., Schildberger, B., 2013. Weinbau, ninth ed. AV-Cadmos Verlag, Wien. ISBN: 978-3-7040-2284-4.

Berger, D., 2008. Go Ahead Say It: Umpqua Better You Should Taste It. www.wine.appellationamerica.com.

Bowers, J.E., Dangl, G.S., Vignani, R., Meredith, C.P., 1996. Isolation and characterization of new polymorphic simple sequence repeat loci in grape (*Vitis vinifera* L.). Genome 39, 628–633.

Bowers, J.E., Dangl, G.S., Meredith, C.P., 1999a. Development and characterization of additional microsatellite DNA markers for grape. Am. J. Enol. Vitic. 50, 243–246.

Bowers, J., Boursiquot, J.-M., This, P., Chu, K., Johansson, H., Meredith, C., 1999b. Historical genetics: the parentage of chardonnay, gamay, and other wine grapes of Northeastern France. Science 285, 1562–1565.

Burger, J., 1837. Systematische Klassifikation und Beschreibung in den österreichischen Weingärten vorkommenden Traubenarten. Gerold Verlag, Wien.

Büscher, N., Zyprian, E., Blaich, R., 1993. Identification of grapevine cultivars by DNA analyses: pitfalls of random amplified polymorphic DNA techniques using 10-mer primers. Vitis 32, 187–188.

Calonnec, A., Wiedemann-Merdinoglu, S., Delière, L., Cartolaro, P., Schneider, C., Delmotte, F., 2012. The reliability of leaf bioassays for predicting disease resistance on fruit: a case study on grapevine resistance to downy and powdery mildew. Plant Pathol. 62, 533–544.

Eibach, R., Hastrich, H., Töpfer, R., 2002. Inheritance of aroma compounds. In: VIII International Conference on Grape Genetics and Breeding, Kecskemet, Hungary.

Franks, T., Botta, R., Thomas, M.R., 2002. Chimerism in grapevines: implications for cultivar identity, ancestry and genetic improvement. Theor. Appl. Genet. 104, 192–199.

Fischer, B.M., Salakhutdinov, I., Akkurt, M., Eibach, R., Edwards, K.J., Töpfer, R., Zyprian, E.M., 2004. Quantitative trait locus analysis of fungal disease resistance factors on a molecular map of grapevine. Theor. Appl. Genet. 108, 501–515.

Flak, W., Krizan, R., Kutscher, W., Tscheik, G., Wallner, E., 2007. Charakterisierung von Weinen der Sorte Grüner Veltliner aus verschiedenen Herkünften im Weinbaugebiet Weinviertel. Mitt. Klosterneuburg 57, 131–139.

Forneck, A., Konradi, J., Blaich, R., 2002. A genetic variation analysis of *Vitis vinifera* cv. Pinot noir. Acta Hortic. 603, 167–170.

Gangl, H., Leitner, H., Hack, C., Tiefenbrunner, W., 2009. Rebschädigende Viren, Bakterien und bodenbürtige Vektoren im Nordburgenland. Mitt. Klosterneuburg 59, 134–143.

Goethe, H., 1887. Handbuch der Ampelographie. Paul Parey Verlag, Berlin.

Gölles, R., Moser, R., Puhringer, H., Katinger, H., da Camara Machado, M.L., Minafra, A., Savino, V., Saldarelli, P., Martelli, G.P., da Camara Machado, A., 2000. Transgenic grapevines expressing coat protein gene sequences of grapevine fanleaf virus, arabis mosaic virus, grapevine virus A and B. Acta Hortic. 528, 305–311.

Hajdu, E., 2000. Population analysis in Roter Traminer hybrids. Acta Hortic. 528, 645–654.

Husfeld, B., 1962. Rebenzüchtung. In: Kappert, H., Rudorf, W. (Eds.), Handbuch der Pflanzenzüchtung. Paul Parey Verlag, Berlin-Hamburg.

ICV, 2013. Les cépages résistants aux maladies cryptogamiques. Imprimé par Impàct imprimerie Imprim'Vert.

Imazio, S., Labra, M., Grassi, F., Winfield, M., Bardini, M., Scienza, A., 2002. Molecular tools for clone identification: the case of the grapevine cultivar Traminer. Plant Breed. 121, 531–535.

Imazio, S., Labra, M., Grassi, F., Scienza, A., Failla, O., 2006. Chloroplast microsatellites to investigate the origin of grapevine. Genet. Resour. Crop Evol. 53, 1003–1011.

Jahnke, G., Majer, J., Varga, P., Szöke, B., 2011. Analysis of clones of Pinots grown in Hungary by SSR markers. Sci. Hortic. 129, 32–37.

Jörger, V., 2002. Pilzwiderstandsfähige Rote aus Freiburg. Der badische Winzer 12, 36–40.

Kaserer, H., Regner, F., Blahous, D., Schöffl, G., Stadlbauer, A., Eisenheld, C., Wendelin, S., Steidl, R., Schmuckenschlager, B., Barna, J., 2000. Roesler und Ráthay: Neue Qualitätsrotwein- Rebsorten aus Klosterneuburg- Charakterisierung pilztoleranter Rotwein-Neuzüchtungen. Mitt. Klosterneuburg 50 (2–3), 100–115.

Keppl, H., 1990. Einführung in das weinbauliche Versuchswesen und aktueller Stand der Versuchsergebnisse im Steirischen Weinbau, Weinkultur. Kulturreferat der Steiermärkischen Landesregierung.

Kirchheimer, F., 1944. Die wilde Weinrebe, ihre Bedeutung und ihr nördliches Vorkommen. Der Deutsche Weinbau 23, 207–209.

Kober, F., 1903. Erfahrungen über das Vortreiben veredelter Schnittreben. Verlag des Vereins zum Schutze des österr. Weinbaues, printed by Kehl, Krems.

Kober, F., 1910. Schlüssel zur Lösung der Rebhybridenfrage für Kalkböden in Österreich. Selbstverlag Hitschmann, printed by Gerold, Vienna.

Lacombe, T., Audegiun, L., Boselli, M., Buchetti, B., Cabello, F., Chatelet, P., Crespan, M., Onofrio, C.D., Eiras Dias, J., Ercisli, S., Gardiman, M., Grando, S., Imazio, S., Jandurova, O., Jung, A., Kiss, E., Kozma, P., Maul, E., Maghradze, D., Martinez, M.C., Munoz, G., Patkova, J.K., Pejic, I., Peterlunger, E., Pitsoli, D., Preiner, D., Raimondi, S., Regner, F., Savin, G., Savvides, S., Schneider, A., Spring, J.L., Szoke, A., Veres, A., Boursiquot, J.M., Bacilieri, R., This, P., 2011. Grapevine European catalogue: towards a comprehensive list. Vitis 50 (2), 65–68.

Laimer da Câmara Machado, M., da Câmara Machado, A., Mattanovich, D., Regner, F., Steinkellner, H., Hanzer, V., Weiss, H., Knapp, E., Katinger, H., 1991. Transformation and regeneration of plants of *Prunus armeniaca* with the coat protein gene of plum pox virus. XV ISHS Symposium on Fruit Tree Viruses, 1992 Vienna, Acta Hortic. 309, 183–189.

Laimer, M., Lemaire, O., Herrbach, E., Goldschmid, V., Minafra, A., Bianco, P., Wetzel, T., 2009. Resistance to viruses, phytoplasmas and their vectors in the grapevine in Europe: a review. J. Plant Pathol. 91, 7–23.

Lang, S., Buchholz, G., Brendl, G., Regner, F., Reustle, G., 2010. Discrimination of grapevine clones by methylation sensitive AFLP analysis. In: X International Conference on Grapevine Breeding and Genetics, Geneva, USA.

Mandl, K., Santiago, J.L., Hack, R., Fardossi, A., Regner, F., 2006. A genetic map of Welschriesling × Sirius for the identification of magnesium-deficiency by QTL analysis. Euphytica 149, 134–144.

Manty, F., 2006. Hintergründe zur Entstehung der Bezeichnungen der Unterlagenselektionen von Sigmund Teleki und Franz Kober. Deutsches Weinbau Jahrbuch, 57, 159–164.

Maul, E., Sudharma, K.S., Kecke, G., Marx, C., Müller, L., Audegiun, M., Boselli, J.M., Boursiquot, B., Buchetti, F., Cabello, R., Carraro, M., Crespan, M.T., De Andres, J., Eiras Dias, J., Ekhvaia, L., Gaforio, M., Gardiman, S., Grando, D., Gyropoulos, O., Jandurova, E., Kiss, J., Kontic, P., Kozma, T., Lacombe, V., Laucou, D., Legrand, D., Maghradze, D., Marinoni, E., Maletic, F., Moreira, G., Munoz-Organero, G., Nakhutsrishvili, I., Pejic, E., Peterlunger, D., Pitsoli, D., Pospisilova, D., Preiner, S., Raimondi, F., Regner, G., Savini, S., Savvides, A., Schneider, C., Sereno, S., Simon, M., Staraz, L., Zulini, R., Bacilieri, R., This, P., 2012. The European Vitis Database (www.eu-vitis.de) – a technical innovation through an online uploading and interactive modification system. Vitis 51 (2), 79–85.

Mehofer, M., Schmuckenschlager, J., Schmuckenschlager, B., Regner, F., 2006. Der Einfluss der Standweite auf Triebwachstum, Ertrag und Traubenqualität bei der Rebsorte Grüner Veltliner. Mitt. Klosterneuburg 56, 193–198.

Mehofer, M., Schmuckenschlager, B., Vitovec, N., Hanak, K., Regner, F., Riedle-Bauer, M., 2011. Untersuchungen zum Einfluss von 32 Unterlagsrebsorten auf Ertrag und Qualität der Rebsorte Zweigelt. Mitt. Klosterneuburg 61, 196–215.

Meneghetti, S., Costacurta, A., Crespan, M., Maul, E., Hack, R., Regner, F., 2009. Deepening inside the homonyms of Wildbacher by means of SSR markers. Vitis 48 (3), 123–129.

Morten, E., 1895. Il Wildbacher. Riv. Vit. Enol. Anno I, Series IV, 9, 135–136.

Myles, S., Boyko, Adam R., Owens, C.L., Brown, P.J., Grassi, F., Aradhya, Mallikarjuna K., Prins, B., Reynolds, A., Jer-Ming, Ch., Ware, D., Bustamante, C.D., Buckler, E., 2011. Genetic structure and domestication history of the grape. PNAS. http://dx.doi.org/10.1073/pnas.1009363108.

Regner, F., da Câmara Machado, A., Laimer da Câmara Machado, M., Steinkellner, H., Mattanovich, D., Hanzer, V., Weiss, H., Katinger, H., 1992. Coat protein mediated resistance to plum pox virus in *Nicotiana clevelandii* and *N. benthamiana*. Plant Cell Rep. 11, 30–33.

Regner, F., Messner, R., 1993. Molekulare Differenzierung von Rebsorten mittels RAPD Analyse. Mitt. Klosterneuburg 43, 160–164.

Regner, F., Steinkellner, H., Turetschek, E., Stadlhuber, A., Glössl, J., 1996. Genetische Charakterisierung von Rebsorten (*Vitits* v.) durch Mikrosatelliten-Analyse. Mitt. Klosterneuburg 46, 52–60.

Regner, F., Stadlbauer, A., Kaserer, H., Eisenheld, C., 1998a. Evaluierung von Burgunder Klonen unter agrarisch genetischen Aspekten. Mitt. Klosterneuburg 48, 193–202.

Regner, F., Stadlbauer, A., Eisenheld, C., 1998b. Heunisch × Fränkisch, ein wichtiger Genpool europäischer Rebsorten (*Vitis vinifera* L. *sativa*). Vitic. Enol. Sci. 53, 114–118.

Regner, F., Eiras–Dias, J.E., Stadlbauer, A., Blahous, D., 1999. "Blauer Portugieser" the dissemination of a grapevine. Cienc. Tec. Vitivinic 14 (2), 37–44.

Regner, F., Stadlbauer, A., 1999. Genetic analysis of traditional grapevine cultivars- perception of viticulture. XXIV OIV Congres Mondial de la Vigne et du Vin, vol. 1, pp. 53–59.

Regner, F., 2000a. On the trace of grapevinès (*Vitis vinifera*) diversification, vol. 11,Viticulture de Montagne, CERVIM, pp. 59–63.

Regner, F., 2000b. Genetische Analyse von Rebsorten. Deutsches Weinbau Jahrbuch, vol. 51, pp. 125–132.

Regner, F., Stadlhuber, A., Eisenheld, C., Kaserer, H., 2000a. Considerations about the evolution of grapevine and the role of Traminer. Acta Hortic. 528, 177–182.

Regner, F., Wiedeck, E., Stadlbauer, A., 2000b. Differentiation and identification of White Riesling clones by genetic markers. Vitis 39 (3), 103–107.

Regner, F., Stadlbauer, A., Eisenheld, C., Kaserer, H., 2000c. Genetic relationship among pinots and related cultivars. Am. J. Enol. Vitic. 51, 7–14.

Regner, F., Stadlbauer, A., Eisenheld, C., 2000d. Broad-range detection of different strawberry latent ringspot virus isolates by immuno capture-PCR. Mitt. Klosterneuburg 50 (4), 183–191.

Regner, F., Sefc, K., Glößl, J., Steinkellner, H., 2000e. Parentage analysis and pedigree reconstruction of vine cultivars using microsatellite markers. Acta Hortic. 528, 133–138.

Regner, F., Stadlbauer, A., Eisenheld, C., 2001. Molecular markers for genotyping grapevine and for identifying clones of traditional varieties. Acta Hortic. 546, 331–342.

Regner, F., Kaserer, H., 2002. Investigations into the genetic variability of Traminer clones. Mitt. Klosterneuburg 52, 177–186.

Regner, F., 2002. Moderne Entwicklungen in der Rebsortenkunde und Rebenzüchtung. Habilitationsschrift. University of Graz.

Regner, F., 2008. Verzeichnis der Österreichischen Qualitätswein Rebsorten, Rebsortenkatalog der QW Rebsorten und deren Klone, editing by HBLAuBA Klosterneuburg printed by Berger Horn.

Regner, F., Hack, R., Santiago, J.L., 2006a. Highly variable *Vitis microsatellite* loci for the identification of Pinot Noir clones. Vitis 45 (2), 85–89.

Regner, F., Hack, R., Hanak, K., Santiago, J.-L., 2006b. Variability within the cultivar Grüner Veltliner. Acta Hortic. 827, 245–251.

Regner, F., 2007a. Genetische Analyse der Rebsorte Welschriesling und die weinbaulichen Konsequenzen. Deutsches Weinbau Jahrbuch, vol. 58, pp. 139–145.

Regner, F., 2007b. Herkunft unserer Rebsorten: Grüner Veltliner, Blaufränkisch und St. Laurent. Der Winzer (4), 12–15.

Regner, F., Hack, R., Hanak, K., Schreiner, A., Beisert, R., Rauhut, D., 2008. Variabilität innerhalb der Rebsorte Grüner Veltliner. Mitt. Klosterneuburg 58, 105–116.

Regner, F., 2009a. Genetische Ressourcen der Rebe in Österreichs Weingärten. Deutsches Weinbau Jahrbuch, vol. 60, 81–87.

Regner, F., 2009b. Kontrolle von Qualitätswein auf Direktträgerfarbstoff, Züchterische Hintergründe. Der Winzer 1, 8–10.

Regner, F., Hack, R., 2009. Reconstructing the heritages of *Grüner Veltliner* and *Sauvignon blanc* from crossings with Traminer by SSR analyses. Mitt. Klosterneuburg 59, 199–208.

Regner, F., 2012. Donauriesling und Blütenmuskateller, neue Rebsorten für den niederösterreichischen Weinbau. Der Winzer 8, 26–30.

Regner, F., Hack, R. Genotyping grapevine with chloroplast markers and limits of the method. Int. Symposium of Grapevine Physiology and Biotechnology, La Serena, Chile, 22–26 April 2013. Acta Hortic., in press.

Renner, W., Wolf, T., Eder, R., Regner, F., 2006a. Die Rebsorte Blauer Wildbacher unter ampelographischen, analytischen und genetischen Aspekten. Mitt. Klosterneuburg 55, 193–200.

Renner, W., Wolf, T., Konrad, H., Eder, R., Regner, F., 2006b. Typenerfassung bei der Rebsorte Blauer Wildbacher unter ampelographischen, analytischen und genetischen Aspekten. Deutsches Weinbau Jahrbuch, vol. 57, pp. 143–150.

Riaz, S., Garrison, K.E., Dangl, G.S., Boursiquot, J.M., MeRoterith, C.P., 2002. Genetic divergence and chimerism within ancient asexually propagated winegrape cultivars. J. Am. Soc. Hortic. Sci. 127, 508–514.

Rühl, E.H., Mend, M., 2009. Was bringen Klone dem Winzer? Deutsches Weinbau Jahrbuch (60), 162–168.

Santiago, J.-L., Mandl, K., Hack, R., Regner, F., 2006. Quantitative trait loci analysis of erinose (*Eriophyes vitis* Pgst.) sensitivity on a genetic map Welschriesling × Sirius. Acta Hortic. 827, 341–346.

Schöffling, H., Stellmach, G., 1993. Klon–Züchtung bei Weinreben in Deutschland. Waldkirchner Verlag.

Schönhals, E.M., Konrad, H., Lindner, B., Rühl, E.H., 2009. Erfassung, Selektion und Sicherung genetischer Variation von traditionellen Rebsorten. Deutsches Weinbau Jahrbuch (60), 132–139.

Sefc, K., Regner, F., Glössl, J., Steinkellner, H., 1997a. Genotyping of grapevine and rootstock cultivars using microsatellite markers. Vitis 37, 15–20.

Sefc, K., Ruckenbauer, P., Regner, F., 1997b. Embryogenesis in microspore culture of *Vitis* sp. Vitis 36, 15–20.

Sefc, K., Steinkellner, H., Wagner, H., Glössl, J., Regner, F., 1997c. Application of microsatellite markers to parentage studies in grapevine. Vitis 36, 179–183.

Sefc, K., Steinkellner, H., Glössl, J., Kampfer, S., Regner, F., 1998. Reconstruction of a grapevine pedigree by microsatellite analysis. Theor. Appl. Genet. 97, 227–231.

Sefc, K., Regner, F., Turetschek, E., Glössl, J., Steinkellner, H., 1999. Identification of microsatellite sequences in *Vitis riparia* and their applicability to genotype different *Vitis* species. Genome 42, 367–373.

Schuhmann, F., 1968. Die Verbreitung der Wildrebe am Oberrhein. Die Weinwissenschaft 23, 487–497.

Schuhmann, F., 1971. Berichte über die Verwendung der Wildrebe *Vitis vinifera* L.var. silvestris Gmelin. Die Weinwissenschaft 26, 212–218.

Steurer, R., 1995. Weinhandbuch. Carl Ueberreuter, Wien.

This, P., Jung, A., Boccacci, P., Borrego, J., Botta, R., Costantini, L., Crespan, M., Dangl, G.S., Eisenheld, C., Ferreira-Monteiro, F., Grando, S., Ibáñez, J., Lacombe, T., Laucou, V., Magalhaes, R., MeRoterith, C.P., Milani, N., Peterlunger, E., Regner, F., Zulini, L., Maul, E., 2004. Development of a standard set of microsatellite reference alleles for identification of grape cultivars. Theor. Appl. Genet. 109, 1448–1458.

Tessier, C., David, P., This, P., Boursiquot, J.M., Charrier, A., 1999. Optimization of the choice of molecular markers for varietal identification in *Vitis vinifera* L. Theor. Appl. Genet. 98, 171–177.

Thomas, M.R., Matsumoto, S., Cain, P., Scott, N., 1993. Repetitive DNA of grapevine: classes present and sequences suitable for cultivar identification. Theor. Appl. Genet. 86, 173–180.

Thomas, M.R., Scott, N., 1993. Microsatellite repeats in grapevine reveal DNA polymorphisms when analysed as sequence-tagged sites (STSs). Theor. Appl. Genet. 86, 985–990.

Tiefenbrunner, W., Regner, F., Mandl, K., Leitner, G., Gangl, H., 2005. The wild vine (*Vitis vinifera* ssp. *silvestris*) in the riparian forests of Donau and March: evaluation of genetic divergence, presence of grape viruses, bacterial and soil-borne vectors. Plant Genet. Resour. Newsl. 141, 35–41.

Trummer, F., 1841. Systematische Classification und Beschreibung der im Herzogthume Steiermark vorkommenden Rebsorten. k.k. Landwirtschaftsgesellschaft Steiermark, Graz.

Zweigelt, F., Stummer, A., 1929. Die Direktträger. Weinland Verlag, Vienna.

Grapevine breeding in France – a historical perspective

4

A.G. Reynolds
Brock University, St Catharines, ON, Canada

4.1 Introduction

Vitis vinifera has been the hallmark of French viticulture. It is very likely that many traditional cultivars such as Chardonnay, Cabernet Sauvignon and many others were deliberate crosses rather than chance seedlings. For example, the cultivar Petite Sirah (widely believed to be Durif) popular in California is likely to be a seedling of Peloursin × Syrah made around 1880 (Bowers et al., 1993; Meredith et al., 1999). Cabernet Sauvignon originated in the seventeenth century as a cross (likely intentional) between Sauvignon blanc × Cabernet franc (Bowers and Meredith, 1997). Numerous Burgundian cultivars can be traced back to the Middle Ages or before and are hybrids between Gouais blanc (Aligoté, Auxerrois, Chardonnay, Gamay noir, Melon), and many could potentially have Pinot noir as a parent (Bowers et al., 1999). Whether any of these cultivars were the results of deliberate crosses or chance hybridization is a matter of speculation. Myles et al. (2011) provided evidence showing that Pinot noir may be a parent of Chardonnay, Gamay and Muscat blanc. Traminer may be a parent to cultivars as diverse as Petit Manseng, Tinta Madeira and Verdelho, and Chenin blanc and Sauvignon blanc are likely siblings for which the parents are Traminer and Colombard. Further afield, we are now aware that Albillo Mayor × Benedicto is the cross that produced Tempranillo, the main red wine cultivar of Rioja and Ribera del Duero in Spain (Ibanez et al., 2012).

However, the talents of French grape breeders were put to a great test in the late nineteenth century (Cattell and Stauffer, 1978; Wagner, 1955). European viticulture was faced with three major devastating crises beginning in the 1870s. First came phylloxera, and thereafter powdery and downy mildew. There was every indication that European viticulture could be irreparably harmed unless a solution was quickly found. French breeders eventually settled on two distinct approaches: use of rootstocks resistant to phylloxera to preserve those cultivars already being grown, and establishment of grape breeding programmes to combine natural resistance to phylloxera, powdery mildew, downy mildew and perhaps other diseases with oenological qualities of *V. vinifera*. Tens of thousands of hectares of French–American hybrids were planted throughout France starting in the late nineteenth century, and many hectares remained up until the latter part of the twentieth century. A summary of land devoted to cultivation of these hybrids in France, New York State and Ontario is found in Table 4.1 (Galet, 1998). Detailed descriptions of most of the significant French–American hybrids can be found in Galet (1956, 1979, 1998).

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00004-1

Table 4.1 **Main French–American hybrids and cultivated in France, New York State and Ontario**

Cultivar	France (ha)		United States (mainly New York State (ha))		Ontario (ha)
	1958–1968	1975–1998	1975–1998	2011	
Baco noir	12,000	188[c]	260[c]	93	71[c]
Chambourcin	–	3369[a] 1204[b]	33[b]	17	6[b]
Marechal Foch	105	13[b]	112[a]	43	101[a]
Leon Millot	271	21[b]	17[a]	–	–
Vignoles	–	–	19[a]	58	–
Rosette	3683	–	38[c]	–	15[c]
Aurore	289	–	700[c]	275	19[c]
Rougeon	5	–	91[a]	44	–
Chancellor	–	–	30[a]	18	–
De Chaunac	–	–	364[a]	40	–
Chelois	905	651[a]	63[a]	–	3[c]
Cascade	177	–	74[a]	–	–
Seyval blanc	1309	26[b]	35[b]	131	481[b]
Villard blanc (S.V. 12–375)	21,379	2775[b]	–	–	–
Villard noir[b]	30,375	2537	–	–	28
Vidal blanc[c]	–	5	4	93	252

[a]1975 data.
[b]1988 data.
[c]1998 data.
(Galet, 1998). The 2011 New York State data are from the U.S. Department of Agriculture (http://www.nass.usda.gov/Statistics_by_State/New_York/Publications/Statistical_Reports/Fruit/grape.pdf).

4.2 The breeders

Albert Seibel (1844–1936). Albert Seibel was from Aubenas, Department of the Ardeche, in the southern Rhone Valley, north of Avignon. He began his breeding work in 1874, shortly after the discovery of phylloxera in France. Most of his hybrids involve complex pedigrees that go back five to six generations. It is worthy of note that Seibel used table grapes and high-yielding wine grapes as his *V. vinifera* parents. Consequently, his first-generation crosses included Piquepoul de Pinet, Aramon, Black Hamburg and Alicante (*V. vinifera*); Noah, Othello and Clinton (*Vitis labruscana*); and Herbemont (*V. cinerea-aestivalis-vinifera*), *V. rupestris* and *V. lincecumii*. As with all of the French hybridizers, Seibel's objectives were to combine phylloxera and disease resistance inherent in the American species with the quality of *V. vinifera*. Overall, Seibel produced nearly 16,000 selections and 500 cultivars. His introductions represented nearly one-third of the hybrids grown in France. Some descriptions of some of Seibel's most significant contributions are as follows, in order of the original breeder number.

Rosette (Seibel 1000) (Figure 4.1(a)). Rosette was once widely planted in New York State and to a lesser extent in Ontario. Clusters are large, as are the orbicular berries. It has some sensitivity to powdery mildew. Wine is mediocre in quality, and although some varietal wines were produced, it was, and remains, largely used as a blending component.

Aurore (Seibel 5279) (Figure 4.1(b)). Aurore achieved some commercial success in Ontario in the 1970s but was largely abandoned because of low acidity and mediocre wine quality. It remains very popular in New York State and may still be the most widely planted non-*labruscana* white cultivar (Reisch et al., 1993). It ripens very early, frequently in late August. Clusters are medium–large, cylindrical and tight with orbicular berries. Wines are neutral and of mediocre quality. It is occasionally used for varietal wines, but it is most often used as a blending component.

Rougeon (Seibel 5898) (Figure 4.1(c)). Along with Chancellor and Chelois, Rougeon ranks among the very best of the Seibel hybrids from a standpoint of wine quality. It achieved limited popularity in Ontario as a blending component, but in British Columbia beginning in the 1970s it produced some excellent varietal wines. In fact, even after establishment of the Vintners Quality Alliance (VQA) in 1988 in Ontario and British Columbia, Chelois and Rougeon continued to be planted in British Columbia. Rougeon vines are moderately vigorous, productive and winter hardy, with medium-sized, tight cylindrical clusters containing medium- to large-sized berries. There are no known shortcomings with respect to disease susceptibility or winter hardiness.

Chancellor (Seibel 7053) (Figure 4.1(d)). Chancellor was once widely planted in France for table wine production. Many regard it as one of the better, if not best, French–American cultivars from a standpoint of wine quality. It is cold hardy, vigorous and productive. Clusters are conical, quite large (>300 g) and normally benefit from cluster thinning to prevent overcropping and attendant winter injury. One of its major shortcomings is susceptibility to downy mildew and, to a lesser extent, powdery mildew. Consequently, it has seen little commercial success in eastern North America. It was once very popular in British Columbia where it was made into high-quality varietal wines.

Colobel (Seibel 8357). Colobel has seen little commercial success except for small plantings in New York State and Ontario, where it was used for blending to enhance colour because of its heavily pigmented juice. The quality of varietal wines is mediocre at best. Vines are very productive, but just not entirely cold hardy. The large clusters of blue-black berries are late ripening.

Verdelet (Seibel 9110) (Figure 4.1(e)). Verdelet achieved commercial success in Ontario in the 1970s when it was used for varietal wines. However, although vigorous and productive, its very large clusters (>300 g) can frequently lead to overcropping and compromised winter hardiness. This cultivar was also popular in British Columbia until the late 1980s. The large clusters are relatively loose and contain large, oval berries. Wines are usually neutral flavoured.

De Chaunac (Seibel 9549) (Figure 4.1(f)). De Chaunac was named for Bright's Wines (Ontario) winemaker and Director of Research, Adhemar de Chaunac.

Figure 4.1 Examples of Seibel hybrids: (a) Rosette (Seibel 1000), (b) Aurore (Seibel 5279), (c) Rougeon (Seibel 5898), (d) Chancellor (Seibel 7053), (e) Verdelet (Seibel 9110), (f) De Chaunac (Seibel 9549), (g) Chelois (Seibel 10878) and (h) Cascade (Seibel 13053).

It became the most widely planted French–American hybrid in Ontario and British Columbia, and it had limited commercial success in New York State and elsewhere in eastern North America. It is winter hardy, vigorous and very productive. The clusters are large (>300 g), conical and relatively loose with orbicular, highly pigmented berries. The combination of large clusters and high fruitfulness (often four clusters per shoot are observed) can unfortunately lead to overcropping and reduced vine size in addition to compromised fruit maturity. Cluster thinning is highly recommended, but because of its loss in popularity over the past two decades, the low prices paid by wineries prevent the use of cluster thinning and other cultural practices. Even when grown well, wine quality is at best mediocre. Other shortcomings include susceptibility to foliar powdery mildew and certain viruses such as tomato ringspot.

Chelois (Seibel 10878) (Figure 4.1(g)). Along with Rougeon and Chancellor, Chelois ranks among the very best of the Seibel hybrids from a standpoint of wine quality. It achieved some popularity in Ontario, British Columbia and New York State beginning in the 1970s, during which time some excellent varietal wines were made. In fact, even after establishment of VQA in 1988 in Ontario and British Columbia, Chelois and Rougeon continued to be planted in British Columbia. It is only moderately winter hardy, vigorous and productive, and it can display winter injury on cold sites. Clusters are relatively small (usually <200 g), cylindrical and tight, with medium-sized orbicular berries. Berry splitting and subsequent bunch rots have been observed. According to New York State recommendations, Chelois requires cluster thinning to prevent overcropping (Reisch et al., 1993).

Cascade (Seibel 13053) (Figure 4.1(h)). Cascade is a productive and moderately hardy cultivar that has seen limited commercial success in eastern North America. Clusters are medium to large and loose, with small orbicular berries, and they are early maturing. Bird damage is said to often be a problem. Wines are generally mediocre in quality, and they are light in colour and body with low acidity.

Francois Baco (1865–1947). Francois Baco was a professor of agriculture in the Armagnac region. He was able to produce some good hybrids after one or two generations; in fact, some of his F_1 hybrids are still commercially grown. In addition to producing phylloxera-resistant cultivars, he also had interest in selections that were resistant to black rot (*Guignardia bidwellii*). Some noteworthy ones include Baco noir (Baco I; Folle blanche × *V. riparia*, 1902) and Baco blanc (Baco 22A = Maurice Baco; Folle blanche × Noah, 1898).

Some descriptions of some of Baco's most significant contributions are as follows:

Baco noir (Baco I) (Figure 4.2(a)). This cultivar has been widely planted in Ontario, New York State, the midwestern United States and New Brunswick. Attributes include winter hardiness, high resistance to powdery and downy mildew and high vigour (often excessive) when grown on its own roots. Clusters are usually tight but are relatively large and cylindrical, with a mean weight of <200 g, containing small, highly pigmented blue berries. Wine quality can be excellent, although acidity can be excessive and tannins are usually low. Other issues can include susceptibility to nematode-borne viruses (Reisch et al., 1993).

Baco blanc (Baco 22A). Baco blanc has not been widely grown and has seen little commercial success. Vines are winter hardy, vigorous and productive. Clusters are large, cylindrical and tight with medium-sized orbicular berries. Wine quality is mediocre and neutral in flavour.

Georges Couderc (1850–1928). Georges Couderc was from the same town as Albert Seibel in the Ardèche region, in the southern Rhone Valley. Couderc is perhaps best known as a rootstock breeder but also released a few scion cultivars. These include Muscat de Moulin [C.299–35; C.603 (*vinifera, rupestris*) × Pedro Ximenez], which is

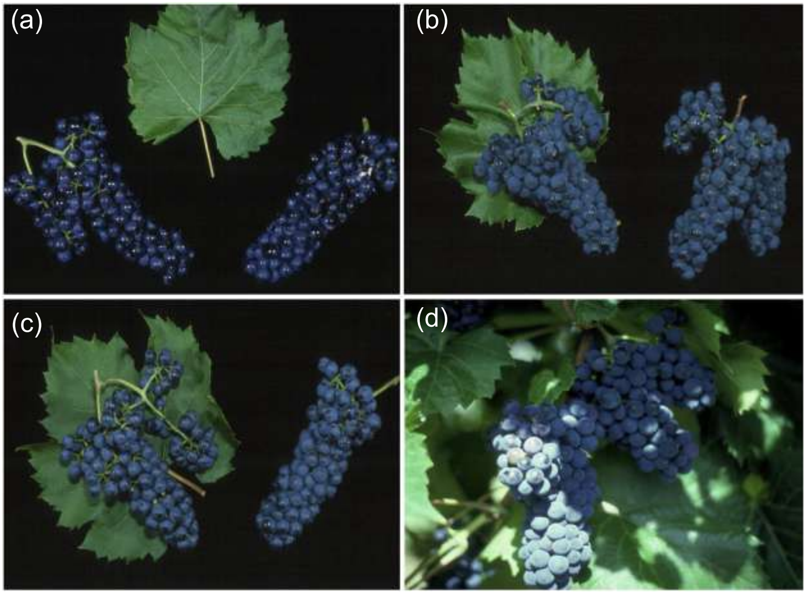


Figure 4.2 Examples of hybrids from the Baco and Kuhlmann breeding programmes: (a) Baco noir (Baco #1), (b) Maréchal Foch, (c) Lucie Kuhlmann and (d) Leon Millot.

often referred to as 'Couderc Muscat'. Couderc's rootstock cultivars are widely used worldwide and include C.3306, 3309, 1202 and 1613 (primarily *riparia/rupestris*).

Some descriptions of some of Couderc's most significant contributions are as follows:

Muscat de Moulin (C.299–35 = Couderc 19). Muscat de Moulin has not been widely grown despite its favourable attributes. It is relatively winter hardy and productive and produces wines with a clean, muscat flavour. It is perhaps best known as a parent in the Geneva hybrid cultivar Valvin Muscat (Muscat de Moulin × Muscat Ottonel; Reisch et al., 2006).

Eugene Kuhlmann (1858–1932). Eugene Kuhlmann was Director of the Oberlin Wine Institute in Alsace (1915–1926), which was founded by fellow grape breeder Christian Oberlin in 1897. Most of his hybrids had mainly *V. riparia* × *Vitis vinifera* background, and like Baco, there are several F_1 hybrids that are still grown commercially, primarily in eastern North America. Overall, Kuhlmann produced 21 red and 15 white cultivars. Noteworthy ones include Maréchal Foch [Millardet et de Grasset 101-14 (*V. riparia* × *V. rupestris*) × Goldriesling (Riesling × Courtillier Musqué)]; Maréchal Joffre [(*V. riparia* × *V. rupestris*) × Goldriesling]; Leon Millot [(*V. riparia* × *V. rupestris*) × Goldriesling]; and Lucie Kuhlmann [(*V. riparia* × *V. rupestris*) × Goldriesling] or {(*V. riparia* × *V. rupestris*) × [Oberlin 595 (Gamay × *V. riparia*) × Pinot noir]}. Kuhlmann was one of the only hybridizers to use Asian germplasm (*V. amurensis*).

Some descriptions of some of Kuhlmann's most significant contributions are as follows:

Maréchal Foch (Kuhlmann 188-2) (Figure 4.2(b)). This cultivar has been widely planted in Ontario, New York State, the midwestern United States, Nova Scotia and

British Columbia. Attributes include winter hardiness, high resistance to powdery and downy mildew and high vigour when grown on its own roots. New York State recommendations include use of rootstocks to maintain vine size (Reisch et al., 1993). Clusters are usually tight, with a mean weight of <100 g, containing small, highly pigmented blue berries. Wine quality can be excellent, although acidity can be excessive.

Lucie Kuhlmann (Kuhlmann 149-31) (Figure 4.2(c)). Lucie Kuhlmann has viticultural attributes that are essentially identical to those of Maréchal Foch. Commercial plantings have been rare.

Leon Millot (Kuhlmann 194-2) (Figure 4.2(d)). As with Lucie Kuhlmann, Leon Millot has attributes that are very similar to Maréchal Foch. There have been commercial plantings in Ontario and Nova Scotia, but they are uncommon.

Maréchal Joffre (Kuhlmann 187-1). As with the aforementioned cultivars, this cultivar has attributes that are essentially identical to Maréchal Foch. Although there have been commercial plantings, it has not attained the popularity of Maréchal Foch.

Bertille Seyve, pere (1864–1939). Bertille Seyve was from the Isère Department. He used many of Seibel's early hybrids as parents. The only cultivars from his programme that remain of interest are Le Commandant (BS 2862; S. 822 × S.872) and Le General (BS 5563; S.6905 × S.3445). Both of these were grown commercially in Ontario but did not see wide distribution.

Some descriptions of some of Bertille Seyve, *pere*'s most significant contributions are as follows:

Le Commandant (BS 2862). This cultivar was grown commercially in Ontario in limited quantities. It is productive, vigorous and winter hardy. Clusters are large, conical and tight, with large orbicular berries. Wine quality is mediocre, and it was consequently used exclusively as a blending component; no varietal products were ever produced to the author's knowledge.

Le General (BS 5563) (Figure 4.3(a)). As with Le Commandant, this cultivar was likewise grown commercially in Ontario in limited quantities. It is also productive, vigorous and winter hardy. Clusters are large, conical and tight, with large orbicular berries. Wine quality is at best mediocre, and it was used exclusively as a blending component; no commercial varietal products were ever produced to the author's knowledge.

Bertille Seyve, fils (1895–1959). Bertille Seyve, *fils* married the daughter of Victor Villard (another French grape breeder) in 1919 to form the Seyve-Villard breeding line in St. Vallier in the Drome region. As with Bertille Seyve, *pere*, he used many of Seibel's early hybrids. Noteworthy cultivars from this programme include Seyval blanc (S.V. 5276; S. 5656 × S. 4986), S.V. 23-512 (origin unknown), S.V. 5247 (S.4495 × S.4986) and Villard noir (S.V. 18-315; S.7053 × S.6905). Seyval blanc was a popular cultivar throughout eastern North America and is still grown commercially. Villard noir was also grown in Ontario and to a lesser extent elsewhere.

Some descriptions of some of Bertille Seyve *fil*'s most significant contributions are as follows:

S.V. 5247. Because of the popularity of its much more famous 'cousin' (Seyval blanc), S.V. 5247 has seen little commercial success. Vines are vigorous and productive. Clusters are large, conical and relatively loose with medium-sized orbicular berries. Wine quality is mediocre and neutral in flavour.

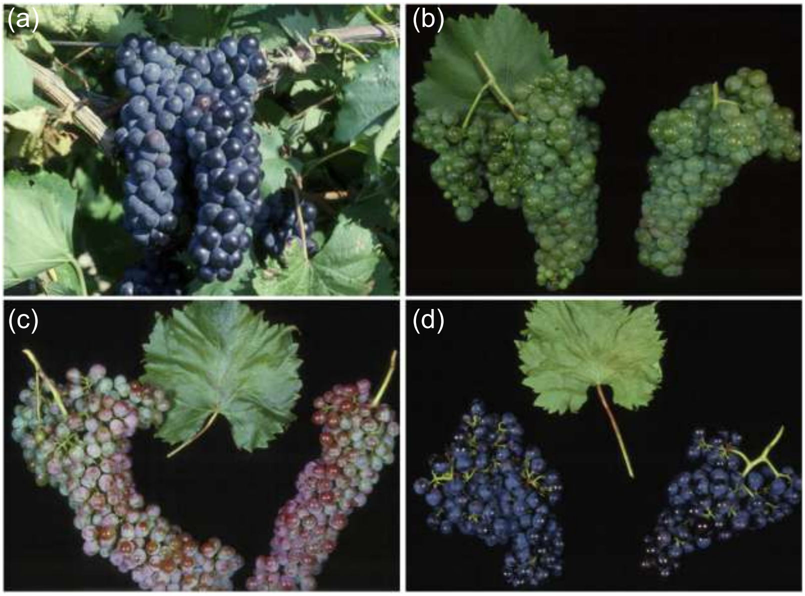


Figure 4.3 Hybrids from the Bertille Seyve, Seyve-Villard and Joannes Seyve programmes: (a) Le General (B.S. 2862), (b) Seyval blanc (S.V. 5276), (c) J.S. 23-416 and (d) Chambourcin (J.S. 26–205).

Seyval blanc (S.V. 5276) (Figure 4.3(b)). Seyval blanc became the most popular white French–American hybrid beginning in the 1970s and continued its popularity in eastern North America until the early 1990s. However, it has several shortcomings. Vines should be grafted to overcome phylloxera injury. Clusters can exceed 300 g; therefore, cluster thinning is highly recommended to maintain vine size. Clusters can be tight, and bunch rot can be common in wet seasons. Wines are of good quality – neutral with slight apple notes; some winemakers have used barrel fermentation and/or barrel ageing to produce products akin to Chardonnay. The Elmer Swensen hybrid cultivars *LaCrosse* and *St. Pepin* are white wine grapes derived from Seyval blanc.

Villard blanc (S.V. 12-375). Villard blanc has not been widely planted. It is a very productive, late-ripening grape, producing large, loose clusters of oval berries (Reisch et al., 1993). Wine quality is average. The fruit may be appropriate as a dessert grape. The Elmer Swenson hybrid Esprit is a seedling of Villard blanc.

Villard noir (S.V. 18-315). Villard noir had limited commercial success other than in Ontario, where varietal wines were produced for many years. Although wine quality was excellent, viticultural shortcomings limited its long-term success. These included low winter hardiness, susceptibility to phylloxera (it needs to be grafted) and a tendency to overcrop because of large clusters.

S.V. 23-512. Most of the commercial success with this selection is in Ontario, where it has been used for blending into inexpensive white wines. Vines are vigorous, productive and resistant to disease. Clusters are large and relatively tight, with large oval berries. It is normally resistant to bunch rots. Wines are typically neutral.

Joannes Seyve (1900–1966). Joannes Seyve, brother of Bertille Seyve, *fils*, was originally a biochemist and is perhaps best known as the breeder of Chambourcin (J.S. 26-205; origin unknown). This cultivar has found wide distribution throughout the eastern and the midwestern United States. He also introduced a white (J.S. 23-416; B.S. 4825 × S.7053), which is still grown commercially in Ontario. He began marketing these hybrids in 1945.

Some descriptions of some of Joannes Seyve's most significant contributions are as follows:

J.S. 23-416 (Figure 4.3(c)). As with S.V. 23-512, this selection has been grown commercially for many years in Ontario. It is also used for blending into inexpensive white wines. Vines are vigorous, productive and resistant to disease. Clusters are large and relatively tight, with large oval berries. It is normally resistant to bunch rots. Wines are typically neutral.

Chambourcin (J.S. 26-205) (Figure 4.3(d)). This cultivar has become the most prominent red wine cultivar in the midwestern United States (e.g. Ohio, Illinois and Indiana), where *V. vinifera* production is risky. It has had some commercial success in New York State but less so in Ontario. Vines are vigorous, productive and normally winter hardy. However, clusters are very large and can lead to overcropping and concomitant winter hardiness issues; consequently, cluster thinning is strongly recommended. The large clusters are loose and contain large, loose, highly pigmented berries. Chambourcin is late ripening and requires a long growing season to fully mature the fruit. It may produce a highly rated red wine when fruit fully matures.

Pierre Landot (1900–1942). Landot was from Ain, in the northern Rhone Valley, west of Geneva. Landot 4511 (Landot 244 × S.V. 12–375) is his best-known red hybrid. Landot 4511 was never widely grown commercially, but it has achieved importance as a parent in many crosses in the University of Minnesota breeding programme; for instance, it is a parent of Frontenac.

Some descriptions of some of Landot's most significant contributions are as follows:

Landot 4511 (Figure 4.4(a)). This selection is winter hardy, vigorous and productive. Clusters are medium-sized and loose, with orbicular berries. Wines are of good quality, although they are slightly herbaceous. There has not been much commercial success with this selection. It is perhaps most well known as the parent of Frontenac and other cultivars from the University of Minnesota programme.

Ferdinand Gaillard (1821–1905). Ferdinand Gaillard was from the central Rhone region and was President of the Lyon Horticultural Association. His programme was not as prolific as many of the others, but it produced hybrids that were widely used by other breeders. As an example, Gaillard 2 {Noah × [(Clinton × Black Hamburg) × Othello]} was used often by Seibel in his crosses.

Some descriptions of some of Gaillard's most significant contributions are as follows:

Gaillard 2 (Noah noir). This selection is winter hardy, vigorous and productive. Clusters are medium-sized and loose, with orbicular berries. Wines are of mediocre quality and slightly herbaceous, and they have some labrusca flavour. There has not been much, if any, commercial success with this selection. It is perhaps most well known as the parent of many of the crosses in Albert Seibel's programme.

J.-L. Vidal. Vidal worked in the Cognac area and was Director of the Fondation Fougerat à Bois-Charentes. One of his hybrids, Vidal blanc (Vidal 256), has achieved

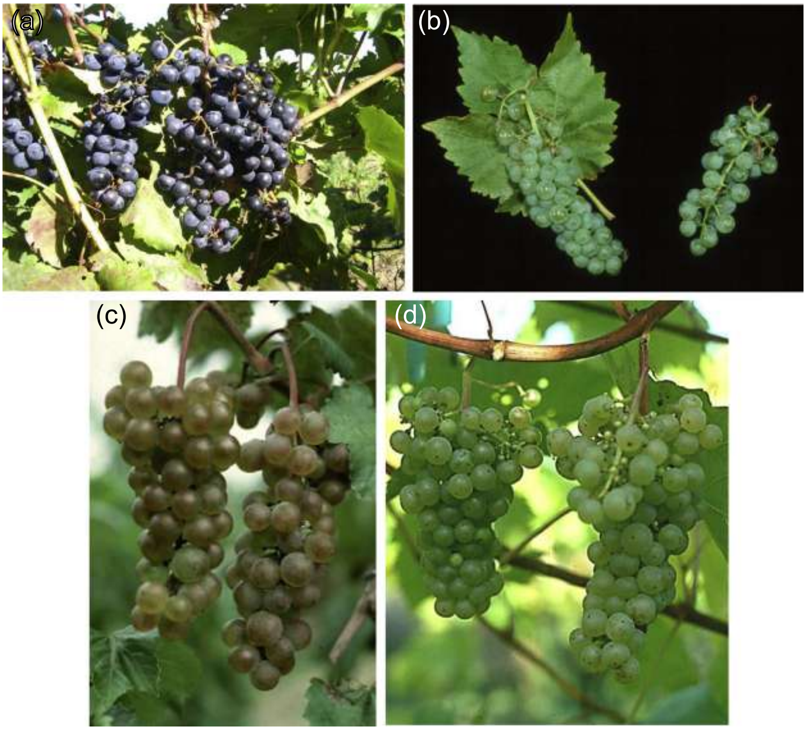


Figure 4.4 Examples of hybrids from the Landot, Vidal and Ravat programmes: (a) Landot 4511, (b) Vidal blanc (Vidal 256), (c) Ravat 34 and (d) Vignoles (Ravat 51).

popularity in Ontario, British Columbia, and in the United States in the Northeast and Midwest, where it is commonly made into icewines.

Some descriptions of some of Vidal's most significant contributions are as follows:

Vidal blanc (Figure 4.4(b)). This cultivar is perhaps second only to Seyval blanc and Vignoles in terms of its popularity in eastern North America. It is used for varietal white wines, in blends, and in dessert wines, particularly icewines. Vines are winter hardy, vigorous and productive. Clusters are large and cylindrical, with medium-sized orbicular berries. New York State recommendations include cluster thinning to prevent overcropping (Reisch et al., 1993).

J.F. Ravat (d. 1940). Ravat was a civil engineer in Saone et Loire, near the Burgundy region. One noteworthy cultivar from his programme, Vignoles (Ravat 51; S.6905 × Pinot de Courtin), is widely planted in the eastern and midwestern United States.

Some descriptions of some of Ravat's most significant contributions are as follows:

Ravat 34 (Figure 4.4(c)). This selection has not been widely grown commercially; therefore, commercial success is limited. However, it is recommended in New York State because of its attributes such as being early ripening and moderately vigorous and because of its productivity and winter hardiness. Wine quality is typically good. Reisch et al. (1993) indicate that yield trial results from Fredonia, NY, show excellent potential.

Vignoles (Ravat 51) (Figure 4.4(d)). Vignoles ranks among the best of the white French–American hybrids. It is vigorous on its own roots, late maturing and produces small, tight conical clusters with orbicular berries. Its cluster configuration causes it to be susceptible to sour rot and bunch rot. Acidity is generally high, but soluble solids are also high. It is widely planted in New York State, but its sour rot problems prevented it from being planted commercially in Ontario. It is frequently used for dessert wine production. The reported parentage (S.6905 × Pinot de Courtin) has been disputed by Bautista et al. (2008).

4.3 Naming the French hybrids

Some of Kuhlmann's material was named by Kuhlmann himself. Baco noir and Aurore were unofficial names in France. Chambourcin, Chelois (Seibel 10878) and Seyval blanc (S.V. 5276) were named in France. A group consisting of wine industry leaders from New York (Finger Lakes Wine Growers Association) named the following in 1970: Rosette, Rougeon, Chancellor, Verdelet, De Chaunac (originally Cameo), Cascade, and Vignoles. These names were confirmed by the Great Lakes Grape Nomenclature Committee in 1972. Many of these names were found on wine labels of 1972 vintages in Ontario varietal wines.

4.4 Conclusions

In addition to the thousands of French–American hybrids bred between ca. 1870 and 1950, there were also a great many rootstocks, particularly those from the Couderc breeding programme. *V. riparia* × *V. rupestris* rootstocks such as C.3306 and C.3309 are widely used worldwide. Since the 1960s, as the large acreages of hybrids were removed, the focus on cultivar improvement became that of clonal selection of *V. vinifera* (ENTAV, 1995). Of course, grape breeding continues in France, as does grape genetic research.

References

Bautista, J., Dangl, G.S., Yang, J., Reisch, B.I., Stover, E., 2008. Use of genetic markers to assess pedigrees of grape cultivars and breeding program selections. Am. J. Enol. Vitic. 59, 248–254.

Bowers, J.E., Bandman, E.B., Meredith, C.P., 1993. DNA fingerprint characterization of some wine grape cultivars. Am. J. Enol. Vitic. 44, 266–274.

Bowers, J.E., Boursiquot, J.M., This, P., Chu, K., Johansson, H., Meredith, C.P., 1999. Historical genetics: the parentage of Chardonnay, Gamay, and other wine grapes of northeastern France. Science 285, 1562–1565.

Bowers, J.E., Meredith, C.P., 1997. The parentage of a classic wine grape, Cabernet Sauvignon. Nat. Genet. 16, 84–87.

Cattell, H., Stauffer, H.L., 1978. The Wines of the East. I. The Hybrids. L & H Photojournalism, Lancaster, Pennsylvania.

ENTAV, 1995. Catalogue des Variétés et Clones de Vigne Cultivés en France. Ministère d'Agriculture de la Pêche et l'Alimentation, 357 pp.

Galet, P., 1956. Cépages et Vignobles de France, Tome. I. Les Vignes Américaines, Déhan, Montpellier.

Galet, P., 1979. A Practical Ampelography. Cornell University Press, Ithaca, NY.

Galet, P., 1998. Grape Varieties and Rootstock Varieties. Oenopluromedia, Chaintré, France.

Ibáñez, J., Muñoz-Organero, G., Hasna Zinelabidine, L., Teresa de Andrés, M., Cabello, F., Martínez-Zapater, J.M., 2012. Genetic origin of the grapevine cultivar Tempranillo. Am. J. Enol. Vitic. 63, 549–553.

Meredith, C.P., Bowers, J.E., Riaz, S., Handley, V., Bandman, E.B., Dangl, G.S., 1999. The identity and parentage of the variety known in California as Petite Sirah. Am. J. Enol. Vitic. 50, 236–242.

Myles, S., Boyko, A.R., Owens, C.L., Brown, P.J., Grassi, F., Aradhya, M.K., Prins, B., Reynolds, A., Chia, J.-M., Ware, D., Bustamante, C.D., Buckler, E.S., 2011. Genetic structure and domestication history of the grape. Proc. Nat. Acad. Sci. 108, 3530–3535.

Reisch, B.I., Luce, R.S., Bordelon, B., Henick-Kling, T., 2006. "Valvin Muscat"™ grape. New York's Food Life Sci. Bull. 161, 1–6.

Reisch, B.I., Pool, R.M., Peterson, D.V., Martens, M.-H., Henick-Kling, T., 1993. Wine and juice grape varieties for cool climates. Inf. Bull. 233 (Cornell Cooperative Extension).

US Department of Agriculture. 2011. http://www.nass.usda.gov/Statistics_by_State/New_York/Publications/Statistical_Reports/Fruit/grape.pdf.

Wagner, P.M., 1955. The French hybrids. Am. J. Enol. Vitic. 6, 10–17.

Grapevine breeding programmes in Germany

5

E. Ruehl[1], *J. Schmid*[1], *R. Eibach*[2], *R. Töpfer*[2]
[1]Geisenheim University, Geisenheim, Germany; [2]JKI Institute for Grapevine Breeding, Geilweilerhof, Germany

5.1 Introduction

Located at the northern border of viticulture, grape growing in Germany is restricted to the mildest areas in river valleys, such as the Rhine with its tributaries (e.g. Mosel, Main or Neckar), and to only a few early-ripening cultivars. Because of the restricted amount of suitable land, grapevines are grown without crop rotation, and soil-borne pests and diseases were and still are a problem. Since the Middle Ages, monasteries established themselves as centres of wine growing in most regions, and it is obvious that selection work was conducted to keep the material true to type, free of virus infections and well performing (Bassermann-Jordan, 1907). For most monasteries wine production was a major source of income. From there, vineyard workers distributed cuttings into their own or neighbouring vineyards, ensuring a high productivity in the surrounding villages. The secularization of church properties in 1802/1803 together with the introduction of new pests and diseases during the second half of the nineteenth century resulted in a decline of viticulture and marks the starting point of modern grapevine breeding and research at several places in Germany.

5.2 Clonal selection

5.2.1 Introduction (history)

Low yield, resulting from virus infections, was the main reason to commence clonal selection. The first activities for clonal selection date back to 1876, when the private breeder Gustav Adolf Froelich initiated clonal selection on Silvaner mainly for improving yield. Although the long-term average per hectare from 1763 to 1787 in the Mosel region was only 3280 L, it increased in 1963–1987 to 10,680 L (Schöffling und Stellmach, 1993). In the eighteenth and nineteenth century, if maintenance breeding was applied at all, mass selection was prevalent (Hörter, 1831; Laufner, 1987). The concept of single vine selections, introduced in 1886 by Froelich (1900), and its huge success created clonal selection activities in many research stations (Bauer, 1913, 1933; Ludowici, 1924; Seeliger, 1933) but also at private winery estates (Hofäcker, 2004).

Because virus diseases, in particular fanleaf, have a major impact on vine performance under the cooler German conditions, visual assessment and performance-based selection of clones gave good results. When viruses as causal agents of vine decline

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00005-3

were established, visual assessment was complemented by indexing of clonal mother vines since the 1970s and serological methods such as enzyme-linked immunoabsorbent assay in the mid-1980s. Since the early 1990s, all German clones are virus tested, and since 2013, all mother blocks are managed according to the European Union legislation (The Council of the European Union 14.02.2002; Commission Directive 23.06.2005).

5.2.2 Recent attempts (current situation)

This combined strategy proved successful, and already in the mid-1950s from most cultivars only clonal material was available and almost exclusively planted. On January 1, 2013 at the Bundessortenamt (Federal Variety Office), 130 scion cultivars with 675 clones were registered for 17 breeders (Table 5.1). As a matter of fact, the total number of breeders is even larger because the ‘Aktionsgemeinschaft zur Erhaltung von Rebsorten e.V’. consists of several clonal breeders. Of these 130 cultivars, 66 are fairly new registered cultivars with only one clone. Of the remaining 38 cultivars, altogether 609 clones were listed, and for major cultivars such as Riesling, Pinot noir and Müller-Thurgau, 117, 74 and 56 clones were listed, respectively. A certain number of them are phytosanitary lines and show no distinct performance difference; however, for example, in Pinot noir, genetic diversity between clones could be shown on a molecular level (Konradi et al., 2003; Blaich et al., 2007) and in regard to performance (Porten, 2001). This offers growers a large range of different clones with specific characteristics, such as upright shoot growth, loose clusters due to larger pedicels or smaller berries, different levels of *Botrytis* tolerance, titratable acidity, anthocyanins, tannins and flavour. With the cultivar Frühburgunder, a synonym to Pinot précoce noir, which is ampelographically identical to Pinot noir but ripens 2 weeks earlier, there are even different ripening times available. In this case, in Germany, the cultivar is regarded as distinctly different from Pinot noir and received its own name.

In such a large number of clones it is difficult to identify the right clone for a particular purpose; therefore, some breeders include descriptions of clonal characters in its name, such as ‘Classic’, ‘Super’ or ‘Charisma’ (Hofäcker, 2004) or using special numbers for certain characters. For example, Geisenheim University is using ‘1-’ at the beginning of clone numbers for those with loose clusters due to long pedicels; clone numbers starting with ‘20’ or more indicate types with small berries (Hofäcker, 2004; Schmid et al., 2009b).

In the past, the genetic variability in Riesling was regarded as small, but studies on many different clones have shown genetic diversity (Blaich et al., 2009) as well as differences in appearance and performance (e.g. yield, acidity, *Botrytis* tolerance) and even morphology (Rühl et al., 2009). In particular, Hochschule Geisenheim University is collecting and preserving novel plant material found in old vineyards and assessing the range of genetic diversity in Riesling, Pinot noir, Pinot gris and Pinot blanc accessions (Schmid et al., 2009b). There is hope that in a few years more and better characterized clones of these cultivars will be available to German growers.

Table 5.1 **Currently registered scion and rootstock cultivars and their breeders (numbers 1–18)* in Germany (2013)**

Variety name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Clones
Accent					1														1
Acolon		1																	1
Albalonga				1															1
Allegro					1														1
Angela											1								1
Arnsburger					1														1
Auxerrois			1		12					1									14
Bacchus										2									2
Baron			1																1
Big Bleu	1																		1
Birstaler Muskat							1												1
Blauburger													1						1
Blauer Frühburgunder					12								3						15
Blauer Limberger		3							8										12
Blauer Portugieser		1				10							2						13
Blauer Silvaner													1						1
Blauer Spätburgunder			19		32	1	10						12						74
Blauer Trollinger		3					10						5						18
Blauer Zweigelt													1						1
Bolero					1														1
Bronner			1																1
Cabernet Cantor			1																1
Cabernet Carbon			1																1
Cabernet Carol			1																1
Cabernet Cortis			1																1
Cabernet Cubin		1																	1
Cabernet Dorio		1																	1

Continued

Table 5.1 **Continued**

Variety name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Clones
Cabernet Dorsa		1																	1
Cabernet Franc					8														8
Cabernet Mitos		1																	1
Cabernet Sauvignon					1														1
Calandro												1							1
Chardonnay			2		10								13						25
Constanze											1								1
Dakapo					1														1
Deckrot			1																1
Domina													2						2
Dornfelder		1																	1
Dunkelfelder					5	1													6
Ehrenbreitsteiner					1														1
Ehrenfelser					5														5
Esther													1						1
Evita											1								1
Faberrebe						1													1
Fanny											1								1
Felicia											1								1
Findling													1						1
Franziska											1								1
Freisamer			1								1								1
Früher roter Malvasier													2						2
Gelber Muskateller		3																	3
Goldriesling									1										1
Grüner Silvaner		7				13							13						33
Hecker			1																1
Hegel		1																	1
Helfensteiner		1																	1
Helios			1																1

Heroldrebe		1																	1
Hibernal					1														1
Hölder		1																	1
Huxelrebe						1													1
Jakobsberger	1																		1
Johanniter			1																1
Juwel		1																	1
Kanzler						1													1
Kerner		1											1						2
Kernling													1						1
Lilla											1								1
Mariensteiner				1															1
Merlot					13														13
Merzling			1																1
Monarch			1																1
Morio Muskat													2						2
Müller-Thurgau	8		3		15	10							20						56
Müllerrebe		10					5												15
Muskat Ottonel			1		7											1			9
Muskat Trollinger							2												2
Neronet	1																		1
Nobling			3																3
Optima													1						1
Orion												1							1
Ortega				1															1
Osteiner					1														1
Palas		1																	1
Palatina							1												1
Perle				1															1
Phoenix												1							1

Continued

Table 5.1 Continued

Variety name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Clones
Piroso			1																1
Picurka																		1	1
Primera					1														1
Prinzipal					1														1
Prior			1																1
Reberger												1							1
Regent												1							1
Regner						1													1
Reichensteiner					2														2
Rhea																		1	1
Rheinfelder						1													1
Rieslaner													2						2
Rondo					6														6
Rotberger					8														8
Roter Elbling						5							1						6
Roter Gutedel			3																3
Roter Muskateller													1						1
Roter Traminer			2		9	6													17
Rubinet	1																		1
Ruländer			8		20								4						32
Ruling		1																	1
Saphira					1														1
Scheurebe						3							7						10
Schönburger					1														1
Serena					1														1
Sibera					1														1
Siegerrebe						1													1
Silcher		1																	1
Sirius												1							1
Solaris			1																1

Sophie											1								1
St. Laurent					5								1						6
Staufer												1							1
Sulmer		1																	1
Tauberschwarz		1																	1
Teréz													1						1
Villaris												1							1
Weiβer Burgunder			7		7	3							5						22
Weiβer Elbling						5							2						7
Weiβer Gutedel			3										5						8
Weiβer Riesling		9			68	18						6	15						116
Wildmuskat															1				1
Würzer						1													1
Sum of scion varieties	5	24	27	4	33	18	4	2	2	0	8	9	31	0	1	1	1	2	130
Sum of scion clones	12	53	68	4	259	82	27	2	9	0	8	14	129	0	1	1	1	2	672
Rootstocks																			0
5C Geisenheim					7														7
Kober125AA			1		5	2							1	1					10
Kober 5BB			2	1	7	2								1					13
Selektion Oppenheim 4			1	4	3	7								1					16
Binova						2													2
Börner					1														1
Cina						1													1
Rici						1													1
3309 Cooderc			1		2														3
Sori					2														2
Teleki 8B					6														6
101-14 Mgt					2														2
110 Richter					2														2

Continued

Table 5.1 Continued

Variety name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Clones
1103 Paulsen					2														2
161-49 Couderc					2														2
420 A Mgt					2														2
Sum rootstock varieties	0	0	4	2	13	6	0	0	0	0	0	0	1	3	0	0	0	0	17
Sum rootstock clones	0	0	5	5	43	15	0	0	0	0	0	0	1	3	0	0	0	0	72

*Breeders' address.

1. Erbe/Erbengemeinschaft Hermann Jäger Rheinstraβe 17, 55437 Ockenheim.
2. Staatliche Lehr- und Versuchsanstalt für Wein- und Obstbau Postfach 13 09, 74185 Weinsberg.
3. Staatliches Weinbauinstitut Merzhauser Straβe 119, 79100 Freiburg.
4. Land Bayern, vertreten durch Bayerische Landesanstalt für Weinbau und Gartenbau – Abt. Weinbau und Önologie – Herrnstraβe 8, 97209 Veitshiöhheim.
5. Hochschule Geisenheim Institut für Rebenzüchtung Eibinger Weg 1, 65366 Geisenheim.
6. Dienstleistungszentrum Ländlicher Raum (DLR) Rheinhessen-Nahe-Hunsrück – Dienstsitz Oppenheim - Postfach 11 65, 55272 Oppenheim.
7. Weinbauverband Württemberg e.V. Postfach 11 48, 74183 Weinsberg.
8. Volker Freytag Theodor-Heuss-Straße 78, 67435 Neustadt.
9. Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie – Abt. Gartenbau - Söbrigener Straβe 3 a, 01326 Dresden.
10. Genossenschaftskellerei Heilbronn-Erlenbach-Weinsberg eG Binswanger Straße, 74076 Heilbronn.
11. Jörg Wolf Alter Dürkheimerweg 7, 67098 Bad Dürkheim.
12. Julius Kühn-Institut, Bundesforschungsinstitut für Kulturpflanzen Erwin-Baur-Straße 27, 06484 Quedlinburg.
13. Aktionsgemeinschaft zur Erhaltung von Rebsorten e.V. im Dienstleistungszentrum Ländlicher Raum Rheinhessen-Nahe-Hunsrück Wormser Straβe 111, 55276 Oppenheim.
14. Arbeitsgemeinschaft Jäger, Mandler, Wennesheimer, bestehend aus: Weingut Jäger, Ockenheim; Heinrich Mandler, Wendelsheim und Fritz Wennesheimer, Worms- Abenheim (als Gesellschaft des bürgerlichen Rechts), Rheinstraβe 17, 55437 Ockenheim.
15. Weingut Amalienhof GbR, bestehend aus: Martin Strecker und Regine Böhringer, Heilbronn (als Gesellschaft des bürgerlichen Rechts) Lukas-Cranach-Weg 5, 74074 Heilbronn.
16. Klaus Fehlinger Ohligstraβe 19, 67593 Westhofen.
17. Wahler Reben GbR, bestehend aus: Hans Wahler und Thomas Wahler, Weinstadt, Wiesentalstraβe 58, 71384 Weinstadt-Schnait.
18. Friedrich Bäder (Inh. der Rebschule Villa Bäder) An der Bellerkirche, 55599 Eckelsheim.www.bundessortenamt.de.

5.2.3 Preserving genetic diversity in the light of climate change

There are two major challenges to clonal selection in Germany: climate change and the preservation of genetic diversity. A few years ago, the general assumption of climate change was warmer summers and milder winters in Central Europe, which sounds great for a Mediterranean crop such as grapevines. The summer of 2003 was taken as proof of this, but long, cold winters and rainy Septembers recently demonstrate that weather and climate do not follow our assumptions but stay variable and possibly will become even more fluctuating. Clonal selection takes at least 20 years, and despite all predictions nobody knows what the climate will be 20 years ahead.

Consequently, we have to consider several options and try to develop a range of different clones. Clones with high tolerance to bunch rot, average vigour, upright shoot growth, a low number of lateral shoots, average cropping level and good flavour will most likely not be a wrong approach, no matter what the climate will be like in the middle of this century. Rather difficult to predict is the right acid level in 30 or 40 years' time.

A prerequisite to select improved clones is the utilization of genetic diversity. Although with cross breeding a breeder can always create new variation by crossing two different cultivars, this is impossible for clones. Grapevines are largely heterozygous; therefore, a selfing will never conserve the cultivar, and introducing a single gene in a cultivar by conventional breeding techniques is also not possible. This could only be achieved by gene transfer, which is currently a taboo in Germany and Continental Europe. The only way to develop a clone with new characteristics is to find natural variants (mutants) within the cultivar.

New features of a plant originating from mutations occur always randomly and are not predictable. Nevertheless, in older cultivars, such as Pinot noir, Traminer or Riesling, small mutations have been preserved by vegetative propagation, accumulated over centuries and contribute to a genetic diversity within these cultivars. If the change was distinct, then new cultivars might have emerged (e.g. Pinot gris or Pinot blanc because berry colour mutants out of Pinot noir). That kind of genetic material is required by clonal selection for the development of new and 'better' clones. The question emerges where to find suitable vines.

The chances of finding it in normal vineyards are rather small, particularly in Germany, because since the mid-1950s almost only clones have been planted and chances of different types/sports are small. Better chances are old vineyards established with mass-selected or non-selected planting material. In a recent German vineyard register, ≈500 ha planted before 1950 are listed, well before the common use of clonal planting material. Public and private German clone breeders are using these remaining vineyards to identify and preserve unique genotypes. Thus far, Hochschule Geisenheim University has transferred more than 1000 accessions of Riesling and more than 1000 various Pinot cultivars into germplasm collections, in most cases even at different locations.

5.2.4 Future developments

As pointed out already, clonal selection is rather simple: You only have to find the right genotype and multiply it. The problem is how to find it. A Riesling vine in an old vineyard growing own-rooted in steep slopes on gravelly, shallow soils along the Mosel valley will certainly look different than a young grafted Riesling on a deep sandy loam in the Geisenheim breeding quarters. Currently, this only becomes obvious when cuttings of this old vine have been virus tested, grafted, planted in a germplasm collection and compared with other accessions and standard clones. Phenotyping clonal characteristics are difficult, unreliable and time-consuming.

Genetic markers correlating with traits could provide a shortcut. However, these kinds of markers are not yet available to analyse newly identified genotypes. Such a tool could not only help to focus on more relevant clone candidates in the breeding fields but it could also be used to utilize interesting genes in virus-infected clones. Until now, in phenotype assessment systems, virus-infected vines cannot be evaluated further because the influence of virus and genotype cannot be separated. Therefore, they are usually discarded.

With recent developments in molecular genetics and an increasing knowledge of grapevine genes, a system based on genetic markers, which are expected to become available in a few years, will become possible to assist in identifying valuable clone candidates in the last remaining non-clonal vineyards in Germany.

5.3 Cross-breeding

5.3.1 Introduction (history)

Grapevine cross-breeding in Germany dates back to the nineteenth century (summarized in Töpfer, 2008) when Sebastian Englerth, the owner of a winery at Würzburg, selected Bukettrebe around 1864. Breeding programmes in Germany commenced at the end of the nineteenth century, the period of dramatic changes regarding novel pests (phylloxera) and diseases (downy and powdery mildew) in Europe. Initial crosses were made using traditional wine grape cultivars. Continuous resistance breeding programmes are on track since 1925 to breed for downy mildew and powdery mildew resistance. Phylloxera resistance was a major aim for the first decades, but it proved to be a huge burden for scion breeding. The combination of all of the resistances and high wine quality as breeding goals was a shoot for the moon, and two lines of breeding developed: rootstock and scion breeding. As a consequence, phylloxera resistance as a breeding goal was abolished, when rootstocks proved to be a reliable alternative to combat the aphid.

In Germany, several public institutions were engaged in grapevine breeding (Table 5.1). Except for Geilweilerhof, which is funded by the federal government and belongs to the Julius Kuehn Institute (JKI), the federal research centre for cultivated plants, all other stations are funded by the states. The breeding activities that have been reduced in Germany during the last almost two decades are nowadays largely complementary, having their own focus (e.g. in Geisenheim) on particular cultivars for clonal selection and rootstock breeding based on *Vitis* species, especially *Vitis berlandieri*, or at Geilweilerhof on wine grape breeding using marker-assisted selection (MAS).

5.3.2 Traditional breeding

Wine grape-breeding programmes at the end of the nineteenth/beginning twentieth century consisted initially of crosses made between traditional wine grape cultivars.

At Geisenheim, Hermann Müller made crosses in 1882 that led to the well-known cultivar Müller-Thurgau, one of the most successful new selections. Other pioneers at the beginning of the twentieth century were breeders such as Georg Scheu from Alzey (e.g. cv. Scheurebe 1916,[1] Huxelrebe 1927), Peter Morio from Geilweilerhof (e.g. Domina 1927, Morio Muskat 1928, Bacchus 1933), Heinrich Birk from Geisenheim (e.g. Ehrenfelser 1929) and August Herold from Lauffen/Weinsberg (e.g. Kerner 1929), who later selected Dornfelder (1955), which is nowadays a very popular red wine cultivar in Germany. Common to all breeding activities is the long-lasting selection of a cultivar and a similarly long phase for market introduction. To summarize the nineteenth and early twentieth century wine grape breeding with traditional cultivars as parents, one can state that in Germany several excellent cultivars have been developed that entered the market and maintain an important market share: from ~100,000 ha in Germany, approximately one-third is used for cultivation of new breeds (Figure 5.1). However, from a genetic point of view, today we know that in traditional wine grape cultivars no resistance against powdery or downy mildew exists. For that reason, several breeding programmes switched early to resistance breeding.

5.3.3 Disease tolerance

5.3.3.1 Wine grape breeding

The problems in aiming at resistant grapevine cultivars became huge because of the complexity of resistance traits (powdery mildew and downy mildew) and in particular because of the complexity of wine quality traits. *Vitis vinifera* is known to confer wine quality but no mildew resistances. Thus, it was necessary to introgress resistance loci from the American or Asian gene pool having the burden that the offspring suffers from poor wine quality. German breeders took advantage of the work and plant material derived from American, but mainly from French, breeders. This breeding material faced tremendous difficulties.

The huge problem throughout European breeding programmes became the preconception of so-called 'hybrids'. Every crossing with an American or Asian *Vitis* species in the pedigree of one parent was considered as a 'hybrid' irrespective of the number for backcrosses with *V. vinifera* cultivars. The first cultivars derived from European breeding programmes surely suffered from poor wine quality when put onto the market because they were not all thoroughly tested. The poor image of hybrids was set and lasted until the end of the twentieth century. In addition to the hybrid bias, in switching from *V. vinifera* breeding to resistance breeding, the efficiency dropped at least by a factor of 10, making small breeding programmes more inefficient. Progenies were frequently too small to attain a good chance of finding superior genotypes.

These major developments put resistance breeding in a very bad environment throughout Europe. In Germany approximately 20 years ago, Professor Gerhardt Alleweldt and his team did pioneering work developing the cultivars Phoenix and in particular Regent. Phoenix was a cross from 1964 of Bacchus × Villard blanc, and Regent is a cross made in

[1] Year of crossing is indicated.

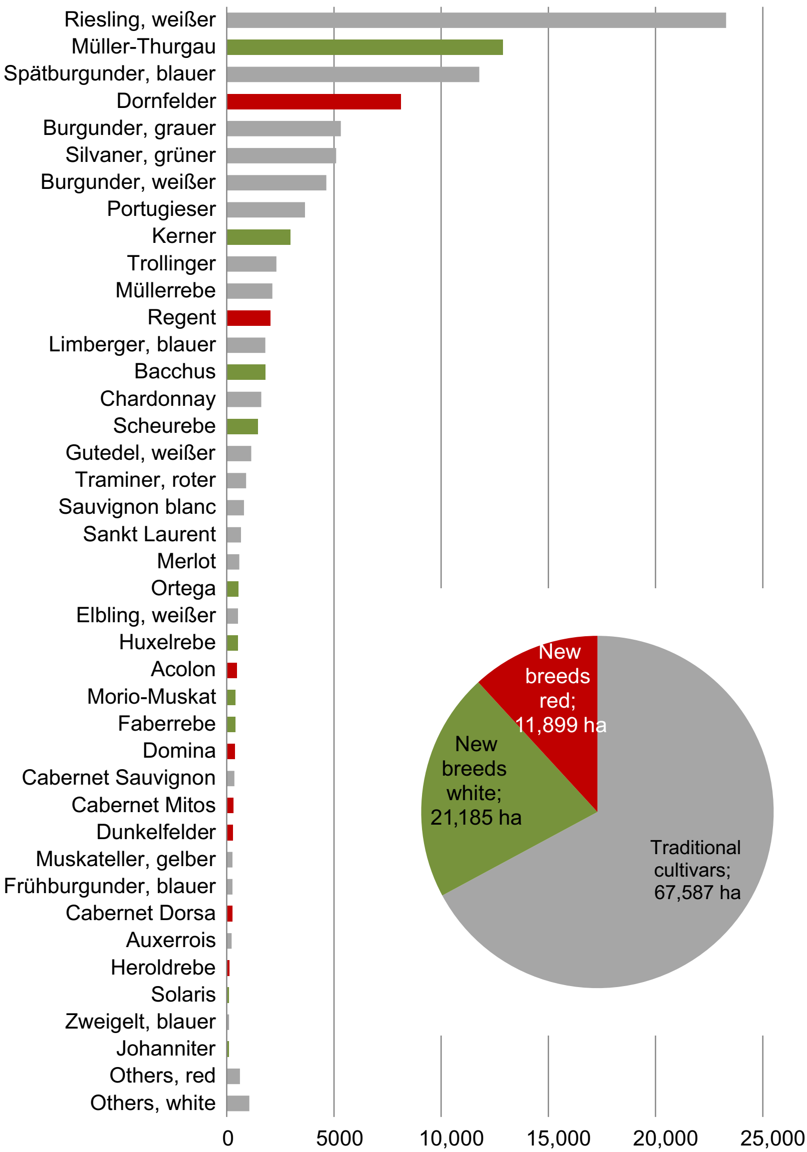


Figure 5.1 Total hectare area (2013) for those cultivars grown on more than 100 ha in Germany. Grey indicates traditional cultivars covering 67% of the growing area. New breeds share 21% for white cultivars and 12% for red cultivars, respectively.
Data according to Deutsches Weininstitut GmbH 2013.

1967 of Diana × Chambourcin. A major breakthrough for grapevine resistance breeding was achieved when these new cultivars became classified for quality wine production. Both cultivars were the first to be accepted by the wine growers for their high quality and good resistance. Other cultivars followed in Germany (Table 5.2), and today in Germany

Table 5.2 **Loci for downy and powdery mildew resistance found in modern German cultivars**

	Downy mildew loci					Powdery mildew loci		
	$Rpv3^2$	Rpv1	$Rpv3^1$	Rpv10	Rpv12	Ren3	Ren1	Run1
	Degree of resistance							
Cultivar	4	5	5	6	7	5	8	9
Phoenix	–	–	x	–	–	x	–	–
Orion	–	–	x	–	–	x	–	–
Staufer	–	–	x	–	–	x	–	–
Merzling	–	–	–	–	–	x	–	–
Sirius	–	–	x	–	–	x	–	–
Regent	–	–	x	–	–	x	–	–
Bronner	–	–	–	x	–	x	–	–
Hibernal	–	–	–	–	–	x	–	–
Rondo	–	–	–	x	–	–	–	–
Prinzipal	–	–	–	–	–	x	–	–
Johanniter	–	–	x		–	x	–	–
Saphira	–	–	–	–	–	x	–	–
Solaris	–	–	–	x	–	x	–	–
Helios	–	–	x	–	–	x	–	–
Cabernet Carbon	–	–	–	x	–	–	–	–
Cabernet Carol	–	–	–	x	–	x	–	–
Cabernet Cortis	–	–	–	x	–	x	–	–
Prior	–	–	x	–	–	x	–	–
Monarch	–	–	–	x	–	x	–	–
Bolero	–	–	–	–	–	x	–	–
Allegro	–	–	–	–	–	x	–	–
Accent	–	–	–	–	–	x	–	–
Villaris	–	–	x	–	–	x	–	–
Reberger	–	–	x	–	–	x	–	–
Calandro	–	–	x	–	–	x	–	–
Baron	–	–	–	x	–	–	–	–

The degree of resistance is indicated: 1 = no symptoms; 9 = severe symptoms.

the potential and necessity of grapevine resistance breeding is beyond question. Freiburg, Geilweilerhof and Geisenheim currently offer their new selections. They show high wine quality and a good resistance, but as always in breeding the better is the enemy of the good: new breeding strains and new technologies are approaching that result in further progress. Current new cultivars show an average reduction of plant protection requirement of approximately two-thirds. They are frequently carrying one major resistance locus (Table 5.2). Table 5.2 indicates two additional aspects: (1) the resistance needs to be broadened because only one powdery mildew resistance and two downy mildew resistances have been used and (2) the resistances used exhibit a medium degree of resistances.

5.3.4 Future developments

For nearly 10 years molecular markers have been available and are currently in use within breeding programmes. A list on www.vivc.de (data on breeding and genetics) indicates several genetic loci and correlating markers that are useful for monitoring resistance loci and their combination (pyramiding of resistance). Some of the loci are still at a stage of introgression (resistance against *Erysiphe necator* Run2, Ren2, Ren4, Ren6); others (Run1, Ren1, Ren3, Rpv1, Rpv3-1, Rpv3-2, Rpv10) are found in high-quality cultivars or elite breeding lines and can be used at an advanced breeding level (Table 5.2, VHR-3084-1-42 (Run1/Rpv1), Kishmish Vatkana (Ren1)). For the next-generation cultivars, pyramiding of some resistance loci should be the prerequisite. It will be a matter of choices if the combination of two or of three resistance loci should be the goal. As long as we do not understand the mechanisms of resistance of the loci to be pyramided, the best guess is to combine, for example, up to three loci from diverse origins to achieve durability as good as possible. However, breeding is always a compromise on the time scale: the optimal genotype remains in the future.

The combination of the six resistances indicated above on five loci would currently be ideal. On the other hand it has to be considered that combining increasing numbers of loci requires increasing sizes of populations. But population sizes may be restricted due to technical reasons. As a strategy, we propose to develop locus-specific homozygous (LSH) lines. Technically this could be achieved quite easily by selfing breeding lines exhibiting a range of desired resistance loci. But success of this strategy might be limited, due to the high inbreeding depression in grapevine. Therefore it is more promising to cross elite lines with no close kingship, both parents exhibiting a set of the same resistance loci. By applying marker-assisted selection (MAS) lines homozygous for the target resistance loci can be identified. Using these LSH lines for further crossings, the entire offspring will carry the full set of resistance loci.

5.4 Rootstock breeding

5.4.1 Phylloxera in Germany

Similar to most other European countries, the use of rootstocks in Germany is linked to the introduction of phylloxera (*Daktulosphaira vitifoliae* [*Viteus vitifoliae*]) in the middle of the nineteenth century. In contrast to most other European countries, the spread of the pest was slow because of strict quarantine measures and unfavourable conditions. The first introduction occurred in 1866 to the Botanical Garden of Bonn; phylloxera only reached the viticultural territory in 1881 in the Ahr region, about 50 km away (Schmid et al., 2009b). At the beginning, people believed they could combat phylloxera with various quarantine and physical or chemical treatments. Legislation efforts included restrictions in trade with grape material and prohibition of the planting of American vines and rootstocks (Schaller, 1912).

5.4.2 History of rootstock breeding (until today)

Despite banning American rootstocks and hybrids, German research stations were ordered by the government to commence rootstock breeding. At Geisenheim, rootstock breeding commenced in 1880 with *Vitis riparia* seeds that were sent from New England, where the species grows in abundance. However, the problem soon became obvious; in 1884–1886, yellow leaves and poor growth, due to lime-induced iron chlorosis, showed that those seedlings were not suitable (Schmid et al., 2009b).

Many soils in North America are free of lime, whereas most European vineyards are on calcareous soils. Lime-induced iron chlorosis became – apart from phylloxera – the major challenge of rootstock breeding. Some seedlings of *V. riparia* were less susceptible and became the first rootstocks (e.g. Riparia#1 Geisenheim). Because *V. vinifera*, the indigenous species of Europe was lime tolerant, the idea of crossing the domesticated European grape with American species was also followed up, resulting in a commercial rootstock Schiava Grossa (Trollinger, Black Hamburg) × Riparia 26 Geisenheim (26G), which was in some areas still used until the 1990s despite its rather limited phylloxera tolerance.

It was the introduction of *V. berlandieri*, indigenous to the calcareous mountains of Central Texas that brought the solution. For Germany, it was very much the effort of the Hungarian wine grower Sigmund Teleki from Villány and his family. In 1896, he got ~10 kg of seeds sent from the French nursery of Euryale Rességuier that were crosses (open pollinations) of *V. berlandieri* (Manty, 2005). He planted the ≈40,000 seeds and graded the seedlings according to their appearance with letters and numbers. Numbers 1–3 looked like *V. berlandieri* types, but they were not continued because of their poor rooting. Groups 4–9 were *V. berlandieri* × *V. riparia* types. Groups 4–6 looked more like *V. riparia* and 7–9 more like *V. berlandieri*. Group 10 represented *V. berlandieri* × *V. rupestris* types. To further distinguish groups, he used the letters ‘A’ and ‘B’. ‘A’ stands for glabrous shoots and more *V. riparia* appearance whereas ‘B’ describes pubescent shoots and more a *V. berlandieri* look. In one group there might well have been more than one promising genotype. Three different rootstocks are until today still called Teleki 5A and with Teleki 8B even five genetically different cultivars exist in various European countries (Manty, 2005).

Between 1902 and 1904, Sigmund Teleki gave 10 of his best selections to the Austrian viticulture inspector Franz Kober. Kober refined Teleki’s system by dividing plants in four different groups: A–D. Group A has bronze shoot-tips and reddish pubescent shoots; Group B plants have bronze shoot-tips and reddish, but glabrous, shoots. Group C has vines with green shoot-tips and green pubescent shoots, reddish on the sun-exposed side. Group D comprises plants with green shoot-tips, green, glabrous shoots and a reddish node. From these four groups and ~100 plants, Kober selected the most robust and vigorous ones and marked them with double letters (Manty, 2005). That marks the origin of rootstock cultivar names such as Kober 5BB or Kober 125AA.

In 1922, Alexander Teleki continued the work of his father Sigmund, with focus on Teleki 5A and Teleki 5C. At a visit to the breeding fields in Hungary a few years later, Heinrich Birk, the head of the breeding station at Geisenheim, was impressed by this work and was given cuttings of some particularly good-looking vines. Heinrich Birk continued the selection work at Geisenheim, which resulted in the cultivar 5C Geisenheim, released in 1936.

In 1912, the director of the research station in Oppenheim, Heinrich Fuhr, imported some of Teleki's selections from Hungary. He worked with Teleki #4 and in 1919 selected out of these plants the selections SO4 (Selection Oppenheim #4), SO5 and SO8. SO4 was regarded as the best, and multiplication commenced after 1922. The effort of the Teleki family and Franz Kober resulted in the rootstock cultivars SO4, 5C, 8B, 5BB, 125AA and Binova, a sport of SO4 with hermaphrodite flowers instead of the usual male ones. These rootstocks are today the most common ones in Germany and many other wine regions around the world. This highlights the ingenuity of Sigmund Teleki's approach.

The idea of a complete resistance, by American colleagues often referred to as 'immunity', is tempting, but until the 1930s this kind of resistance was only know from *Muscadinia rotundifolia*, a species from the southeastern United States with a different number of chromosomes and therefore difficult to incorporate in breeding programmes. However, in the late 1930s, Carl Börner detected a hypersensitive reaction against phylloxera in *Vitis cinerea* Arnold (Börner, 1943). The species itself is difficult to root and needs a long growing season; therefore *V. cinerea* selections could not be used as rootstocks themselves. Börner consequently crossed them with other species and had the first 146 hybrids planted in 1943 at a calcareous site near Neustadt. In the 1950s, Helmut Becker and Hans Brückbauer continued Carl Börner's selection work. Some of the hybrids came with Becker to Geisenheim when he became head of the breeding institute in 1964; the rest remained at Neustadt. In 1989, the Bundessortenamt (Federal Variety Office) granted plant cultivar rights to the Geisenheim breeding institute for the cultivar Börner, the first commercial rootstock cultivar with a complete resistance to phylloxera. A few years later, two cultivars from Neustadt (Cina and Rici) followed.

5.4.3 Future developments

Despite the huge successes of rootstock breeding during the twentieth century, some problems still remain. One is the small genetic basis of our major rootstock cultivars. Approximately 10 cultivars grow on 90% of vineyards worldwide. Possibly 50% are planted, with Teleki/Kober selections coming only from one seedling population (Teleki). A new emerging pest or disease could be devastating. More genetic diversity would certainly reduce such a risk. On the other hand, there are many grape-growing regions and sites in the world with different climates and different soils. It is highly unlikely that the currently used few rootstock cultivars meet all demands of these different sites, where they have been planted.

The cultivar Börner is the living proof that complete phylloxera resistance is achievable in a commercial rootstock. Therefore, the breeding institute at Geisenheim started in 1993 with a rootstock breeding programme on the basis of the complete phylloxera resistance mechanism of *V. cinerea* Arnold. Meanwhile, the first of these hybrids have demonstrated that they are of commercial value with some giving superior results on some trial sites. Time will tell if these new rootstock hybrids will succeed in the wine industry.

There is another underutilized grape species in rootstock breeding – *V. berlandieri*. Despite its high lime tolerance, only a few plants have been used in breeding programmes. It is highly unlikely that they represent the whole genetic range of the species. To utilize more of the genetic basis of this species, Peter Cousins (U.S. Department of Agriculture, Geneva) along with Joachim Schmid and Frank Manty (Geisenheim) collected *V. berlandieri* seeds from the wild in Central Texas in 2005 (Schmid et al., 2009a). Today, more than 3000 seedlings are growing at Geisenheim and are currently evaluated for their phenotypic and genetic variability. First results show a wide range of different characteristics and that they differ from the *V. berlandieri* plants used in rootstock breeding so far.

It is definitely too early for conclusions, but a large range of genetically diverse material is essential for a successful breeding programme, and combining all of these characteristics should provide the genetic material for new rootstock hybrids to overcome the challenges of climate change and provide a sound basis for viticulture in the second half of the twenty-first century.

5.5 Individual breeding programmes and institutes

5.5.1 Hochschule Geisenheim University, Institute for Grape Breeding, Geisenheim

Grape breeding at Geisenheim commenced in the 1880s with scion (Müller-Thurgau) and rootstock breeding. In 1927, the institute became a department on its own and Heinrich Birk the first head. His aims were cross-breeding for early Riesling-like cultivars and phylloxera-tolerant rootstocks. Between 1964 and 1990, Helmut Becker headed the institute. He increased cross-breeding activities, focusing more on disease tolerance, and he introduced – with the help of Professor Vilém Kraus from Lednice – *Vitis amurensis*, for its frost and downy mildew tolerance into scion breeding. At the same time he developed some of Carl Börner's rootstock hybrids further and accordingly named the first commercial cultivar 'Börner'. He also introduced large-scale virus testing in German grapevine maintenance breeding and clonal selection. Since 1991, Ernst Rühl has headed the institute, shifting activities more to cross-breeding of rootstocks with complete phylloxera resistance and clonal selection of traditional German cultivars. A prerequisite for the task is the preservation of those cultivars' intra-varietal variation in germplasm collections. The cross-breeding of scion cultivars was scaled down substantially because this is still the focus of other German breeding stations. Examples of Geisenheim cultivars are pictured in Figure 5.2.

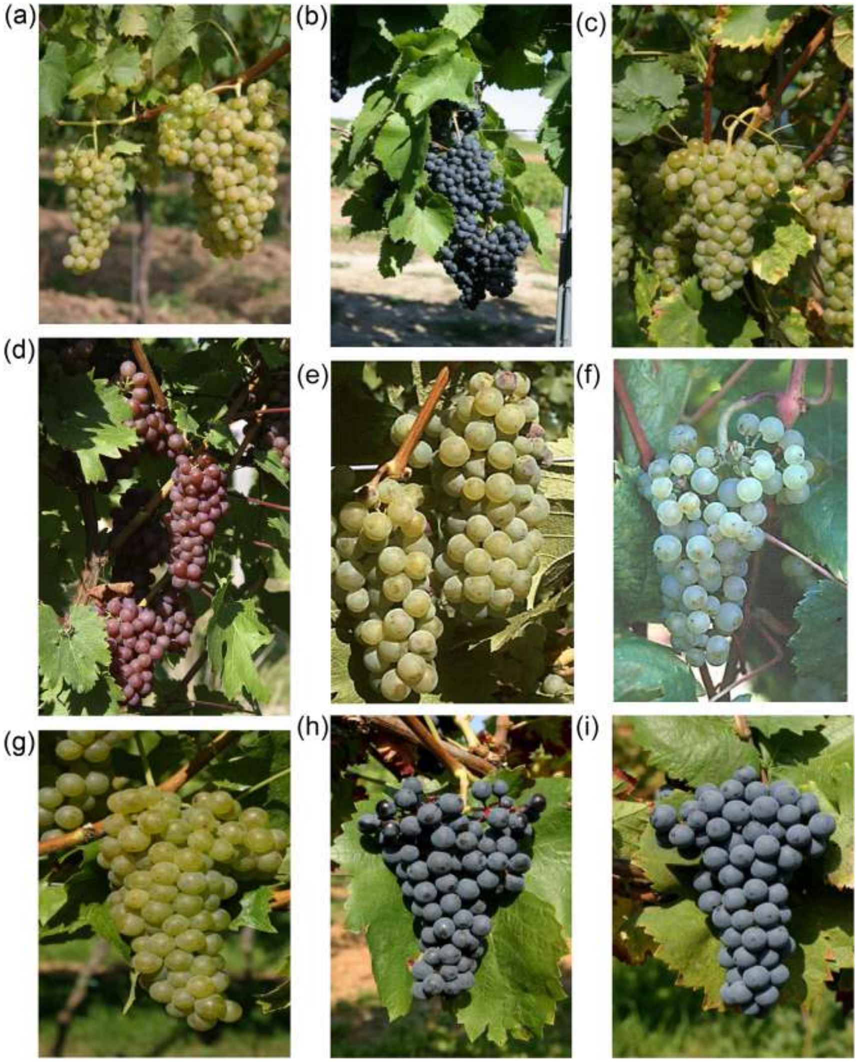


Figure 5.2 Examples of cultivars from various German breeding programmes, From Geisenheim: (a) Müller-Thurgau, (b) Rondo, (c) Saphira and (d) Schönburger. From Geilweilerhof: (e) Bacchus, (f) Aris, (g) Felicia, (h) Reberger and (i) Regent.

Traditional cultivars (clonal selection):

White: Riesling, Müller-Thurgau, Pinot gris, Pinot blanc, Chardonnay, Auxerrois, Muskat Ottonel, Gewürztraminer.

Red: Pinot noir, St. Laurent, Merlot, Cabernet Franc, Cabernet Sauvignon.

New Geisenheim cultivars:

White: Schönburger, Reichensteiner, Ehrenfelser, Arnsburger, Saphira,[1] Hibernal,[1] Prinzipal,[1] Sibera,[1] Serena,[1] Primera[1]
([1]tolerant to downy and/or powdery mildew).

Red: Dunkelfelder,[2] Dakapo,[2] Rondo,[1] Bolero,[1] Allegro,[1] Accent[1, 2]
([1]tolerant to downy and/or powdery mildew; [2]Teinturier type).

Rootstock cultivars:

Kober 5BB, SO4, Kober 125AA, 5C Geisenheim, Teleki 8B, Börner, 161-49 Couderc, 3309 Couderc, Sori, 101-14 Mgt, 420 A Mgt, 110 Richter, 1103 Paulsen.

5.5.2 JKI, Institute for Grapevine Breeding Geilweilerhof

The property of Geilweilerhof, today the JKI, Institute for Grapevine Breeding Geilweilerhof, can be traced back to an estate of a former monastery of the Zisterzienser monks and was first documented in 1184. It can be assumed that viticulture has been practiced at Geilweilerhof for centuries. However, the first grapevine breeding activities were initiated by Peter Morio, who grew the first grapevine seedlings in 1926. He was active as a grape breeder at Geilweilerhof for more than 25 years, until 1952. Included in his activities were cultivars that are still being grown nowadays, such as Morio Muskat, Bacchus, Optima or Domina. Nearly contemporaneous to the breeding work of Morio, a department for grape breeding was founded far away at the Kaiser-Wilhelm Institute in Müncheberg (near Berlin) under the supervision of Erwin Baur, 1933. His student and later his assistant, Bernhard Husfeld, became responsible for grapevine breeding and focused his programme exclusively on resistance breeding. After World War II, Professor Husfeld moved to Geilweilerhof and continued his resistance breeding activities. With cultivars such as Aris and Siegfriedrebe created by Husfeld, he for the first time proved that high quality and good resistance can be combined in new cultivars, a postulate that at that time was doubted even among scientists. His successor, Gerhard Alleweldt, was head of the institute from 1970 up until 1995. He focused breeding activities even more stringently on the combination of fungus resistance and wine quality. The resistant red cultivar Regent of Alleweldt represents another milestone in the history of resistance breeding. Since its registration in 1996 in Germany, the total area increased to more than 2000 ha, indicating a broad acceptance from growers and consumers. In retrospect, it is undoubtedly Gerhard Alleweldt during his period as head of the institute who made significant contributions to remove the prejudices against resistance breeding and to pave the way for today's acceptance of cultivars derived from resistance breeding. Since 1995, the breeding programme at Geilweilerhof was continued along the paths of Husfeld and Alleweldt while molecular diagnostic tools were introduced into practical breeding. Making use of a tremendously increased knowledge worldwide about grapevine genetics and stacking of resistances, multiple resistances against one disease became a major goal. First selected lines with multiple resistance loci against powdery mildew and downy mildew are at the door for extended field testing. Examples of Geilweilerhof cultivars are pictured in Figure 5.2.

New scion cultivars:

White: Aris,[1] Morio Muskat, Bacchus, Optima, Phoenix,[1] Sirius,[1] Orion,[1] Villaris,[1] Staufer,[1] Felcia[1] ([1]tolerant to downy and powdery mildew).

Red: Domina, Regent,[1] Reberger,[1] Calandro[1]
([1]tolerant to downy and powdery mildew).

5.5.3 Rheinland-Pfalz – Dienstleistungszentrum Ländlicher Raum Rheinhessen Nahe Hunsrück – Rural Service Centre Rheinhessen Hunsrück Nahe, Oppenheim

Rootstock breeding commenced at Oppenheim in 1912, when Director Fuhr of the School of Viticulture Oppenheim received hybrids from the collection of the Hungarian breeder Sigmund Teleki. Out of this population over the next decades, the rootstocks SO4 and Binova, a hermaphrodite sport of SO4, were developed. Maintenance breeding of Kober 5BB is another objective at Oppenheim. At Neustadt, another Rural Service Centre of the State, maintenance breeding is conducted for the rootstocks Kober 125AA and two *V. cinerea* crosses originating from Carl Börner's work, Cina and Rici.

Cross-breeding of scion cultivars commenced in 1909 at Alzey under the leadership of Georg Scheu. Over the next decades, he developed cultivars such as Scheurebe, Faberrebe, Siegerrebe, Huxelrebe, Würzer, Regner and Kanzler. Georg Scheu was succeeded by Dr H. Breider and in 1972 by Dr Otmar Bauer. In 1997, Dr Werner Hofäcker followed as head of the breeding station at Alzey. In the following years, the breeding station Alzey was amalgamated with the Rural Service Centre Oppenheim, which became in charge of all breeding activities of the state. Examples of Alzey cultivars are pictured in Figure 5.3.

Traditional cultivars (clonal selection):

White: Riesling, Silvaner, Müller-Thurgau, Elbling, Pinot blanc.

Red: Pinot noir, Portugieser, Dunkelfelder.

New scion cultivars (all white):

Scheurebe, Huxelrebe, Faberrebe, Würzer, Siegerrebe, Kanzler, Regner, Rheinfelder[1] ([1]tolerant to downy and powdery mildew).

Rootstocks:

SO4, Binova, Kober 5BB, Kober 125AA, Cina, Rici.

5.5.4 Bayerische Landesanstalt für Weinbau und Gartenbau – Bavarian State Institute for Viticulture and Horticulture, Veitshoechheim

Grape breeding in Bavaria was founded in 1912. The first breeders, August Dern and August Ziegler, focused on cross-breeding to produce new cultivars for the Franconian wine-growing region by mainly using the cultivars Silvaner and Müller-Thurgau as parents. From 1950 to 1970, Professor Hans Breider headed the grape-breeding department at the Bavarian State Institute for Viticulture and Horticulture, Veitshoechheim. He succeeded in creating new white wine cultivars and started to cross-breed for new rootstocks. This was continued by his successor, Professor Klaus Wahl. In addition to cross-breeding, clonal selection of typical Franconian cultivars as well as conservation of old cultivars and their genetic range was performed. In 2002, cross-breeding ceased to focus on the development of Silvaner clones, better adapted to the need of Franconian growers. Examples of Wurzburg cultivars are pictured in Figure 5.3.

Traditional cultivars (clonal selection):

White: Silvaner, Müller-Thurgau.

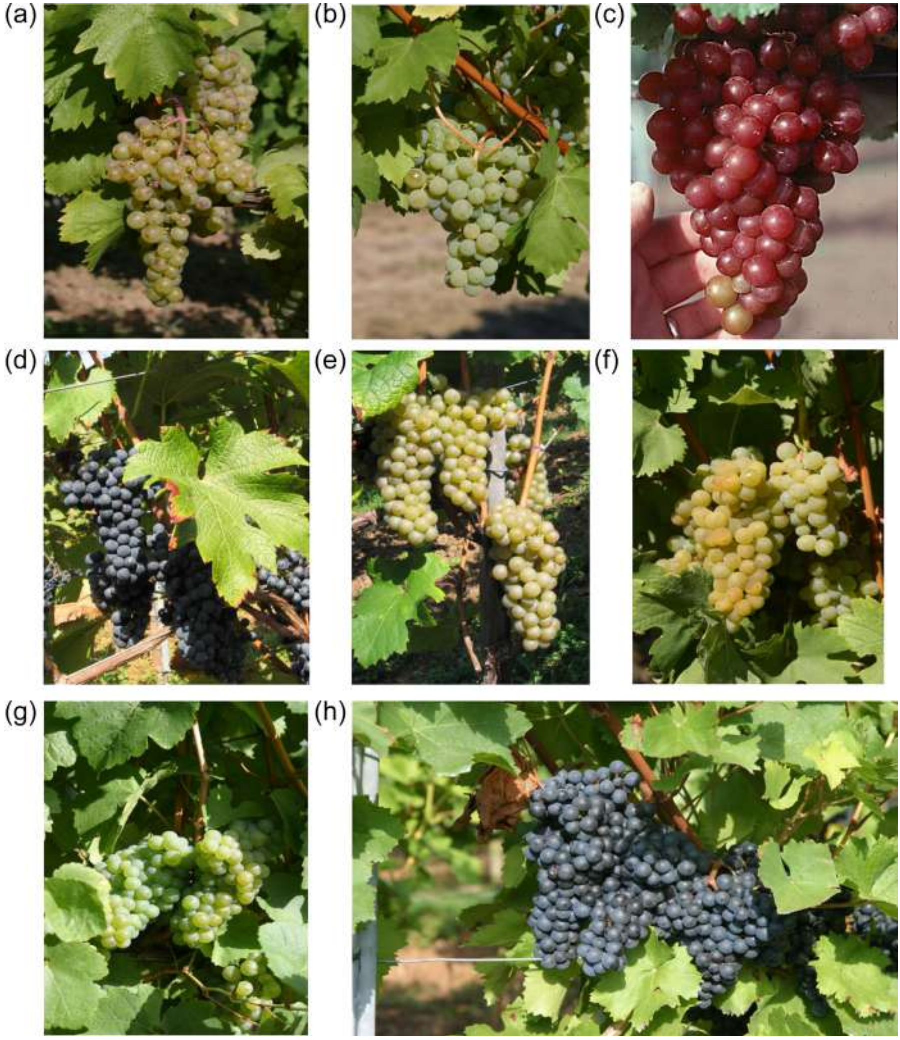


Figure 5.3 Examples of cultivars from various German breeding programmes. From Oppenheim (Alzey): (a) Huxelrebe, (b) Scheurebe, (c) Siegerrebe. From Freiburg: (d) Cabernet Cortis and (e) Solaris. From Veitshoechheim (Wurzburg): (f) Ortega, (g) Rieslaner; Weinsberg and (h) Acolon.

New Veitshoechheim cultivars:
White: Rieslaner, Ortega, Albalonga, Perle, Fontanara, Mariensteiner, Osiris, Montagna, Muscabona, Cantaro.
Rootstock cultivars (clonal selection):
Kober 5BB, SO4.
New rootstock cultivars:
Sorisil, B 62-20-40, B 62-20-192.

5.5.5 LVWO Staatliche Lehr – und Versuchsanstalt für Wein – und Obstbau – Department for Grape Breeding, Weinsberg

LVWO Weinsberg (close to Heilbronn in Württemberg) was established in 1868 as the first school for viticulture in Germany. The institute for grape breeding was established in 1907 as an independent institution. In 1947, the grape-breeding institute was integrated into the organization of LVWO. From the beginning, cross-breeding of new cultivars and clonal selection of traditional cultivars were the main objectives of LVWO grape breeding. The first head of the institute was Ludwig Mittmann (1908–1928). He focused on improving the performance of typical Württemberg cultivars via clonal selection. Between 1928 and 1964, August Herold was head of the institute. August Herold is one of the most renowned German grape breeders. He did some of the most successful German crosses (e.g. Dornfelder and Kerner). Helmut Schleip followed as head of the department from 1964 until 1974. He aimed to systematize cross-breeding at LVWO and is a breeder of some of the more recent LVWO cultivars such as Cabernet Cubin and Sauvignon Gryn. From 1974 to 2012, Bernd H. Hill led the department. He initiated the resistance cross-breeding programme at LVWO and launched the above-named cultivars into commercial cultivation. In 2013 Jürgen Sturm became head of the breeding department. An example of a Weinsberg cultivar is pictured in Figure 5.3.

Traditional cultivars (clonal selection):

White: White Riesling, Gelber Muskateller (Muscat à petit grains blancs), Grüner Silvaner.

Red: Pinot noir, Pinot Meunier, Blauer Limberger, Blauer Trollinger (Schiava Grossa), Blauer Portugieser.

New Weinsberg cultivars:

White: Hölder, Juwel, Kerner, Sauvignon Cita, Sauvignon Gryn, Sauvignon Sary, Silcher.

Red: Acolon, Cabernet Cubin, Cabernet Dorio, Cabernet Dorsa, Cabernet Mitos,[1] Dornfelder, Hegel, Helfensteiner, Heroldrebe, Palas[1] ([1]Teinturier type).

Rootstock cultivars (clonal selection):

Kober 5BB

5.5.6 Staatliches Weinbauinstitut Freiburg – State Institut for Viticulture Freiburg

Breeding activities in Freiburg commenced with Dr Karl Müller, breeding the cultivar Freisamer in 1916. In 1920, Karl Müller became the first director of the newly founded 'Badische Weinbauinstitut'. Grapevine breeding for disease resistance was one of the objectives of the new institute. Between 1937 and 1972, Dr Johannes Zimmermann was in charge of grape breeding at Freiburg and largely focused on resistance to downy and powdery mildew. This work was continued by Dr Norbert Becker between 1972 and 2000. He further expanded breeding for disease resistance, resulting in many disease-tolerant cultivars with good wine quality as well. Since 2001, Dr Volker Jörger has headed the institute, which is still focused on breeding of disease-tolerant cultivars. Another objective is clonal selection of traditional scion cultivars and rootstocks. Examples of Freiburg cultivars are pictured in Figure 5.3.

White wine cultivars:
Freisamer, Nobling, Merzling,[1] Johanniter,[1] Bronner,[1] Solaris,[1] Helios,[1] Muscaris,[1] Sauvignin gris.[1]
Red wine cultivars:
Deckrot, Prior,[1] Baron,[1] Monarch,[1] Cabernet Cortis,[1] Cabernet Carbon,[1] Cabernet Cantor,[1] Cabernet Carol,[1] Piroso[1] ([1]tolerant to downy and powdery mildew).

5.6 Private grape breeders in Germany

The success of Gustav Froelich with his first Silvaner clone triggered breeding activities in most institutes, but also in some private wineries. Most of those breeders are today organized in the 'Aktionsgemeinschaft zur Erhaltung von Rebsorten e.V. im Dienstleistungszentrum ländlicher Raum Rheinhessen Nahe Hunsrück Oppenheim'. The Aktionsgemeinschaft is registered breeder of 31 scion and one rootstock cultivar with 130 clones in total. The 'Weinbauverband Württemberg' (Württemberg Grape Growers Association) is looking after four locally important cultivars with 27 clones in total. Jörg Wolf, a nurseryman at Bad Dürkheim, maintains eight Hungarian table grape cultivars as ornamental cultivars. The nursery Volker Freytag maintains Swiss cultivars bred by Valentin Blattner. The Erbengemeinschaft Hermann Jäger is in charge of four new disease-tolerant cultivars and eight Müller-Thurgau clones.

Traditional cultivars (clonal selection):
White: Riesling, Müller-Thurgau, Pinot gris, Pinot blanc, Chardonnay, Auxerrois, Muskat Ottonel, Gewürztraminer, Bacchus, Findling, Kerner, Kernling, Morio Muskat, Optima, Rieslaner, Roter Elbling, Weiβer Elbling, Roter Muskateller, Teréz, Weiβer Gutedel.
Red: Pinot noir, Blauer Portugieser, Blauer Trollinger, Muskat Trollinger, Blauer Zweigelt, Domina.

5.7 Concluding remarks

Over the past 150 years, German grapevine breeding has played an important part in German viticulture in many ways. At the beginning, the emphasis was mostly on clonal selection to combat virus diseases, which are devastating in the cool German conditions. This battle against virus disease was conducted not only by several newly established public institutes but (also) by many private breeders. This has led to many different clones of traditional varieties and a high phytosanitary level in most vineyards, despite the presence of virus-transmitting nematodes in some regions. Climate change is a new challenge for clonal selection and the development of new better, adapted clones. Large germplasm collections of clonal material are a prerequisite and are currently established by German breeders to ensure large genetic diversity in traditional cultivars.

Already in the nineteenth century the idea of new grape varieties with new characters emerged, resulting in the variety Müller-Thurgau, and triggered cross-breeding activities in many places and a considerable number of new varieties (e.g. Scheurebe, Siegerrebe, Morio Muskat, Bacchus, Kerner, Dornfelder and Ehrenfelser). From the mid-1930s, cross-breeding commenced, focusing on disease-tolerant varieties, and led to many new cultivars (e.g. Regent), which are reaching increasing importance in viticulture, not only in Germany but also in many neighbouring countries. Disease-tolerant German varieties are growing in Denmark, Sweden, Norway, Netherland, Poland, Czech Republic, England and Ireland, where they often provided the basis of biologic wine production. New molecular techniques will further improve cross-breeding and lead to new varieties with a higher degree of disease resistance.

Although Germany was not hit hard by phylloxera, German rootstock breeding has played an important role not only for Germany. Varieties such as SO4, 5C Geisenheim or Kober 5BB clone 13 Gm are used worldwide, and with Börner Germany introduced the first completely phylloxera-resistant rootstock. Rootstock breeding in the future will increasingly focus on the challenges of climate change (e.g. drought and iron chlorosis on wet limy soils). German breeding institutes host large germplasm collections not only of *V. vinifera* cultivars, but also of American species (e.g. *V. berlandieri* and *V. cinerea*), which are a prerequisite for the development of new and better adapted rootstocks.

References

Bassermann-Jordan, F., 1907. Geschichte des Weinbaus, 3 Bände. Keller Verlag, Frankfurt a.M.
Bauer, A., 1913. Über Rebenzuchtwahl. Landwirtschaftliche Blätter, 121, pp. 103–105.
Baur, E., 1933. Der heutige Stand der Rebenzüchtung in Deutschland. Der Züchter 5, 73–77.
Blaich, R., Benjak, A., Hoffmann, P., Forneck, A., 2009. Untersuchung zur Existenz und zum Ausmaß genetischer Variation traditioneller Rebsorten im Hinblick auf die Erhaltung genetischer Ressourcen. DNA Strukturanalysen mittels Markertechniken. Bundesamt für Landwirtschaft und Ernährung, Bonn (Forschungsprojekt, 514–33.52/04HS022). Online verfügbar unter. http://download.ble.de/04HS022.pdf.
Blaich, R., Konradi, J., Ruhl, E., Forneck, A., 2007. Assessing genetic variation among pinot noir (*Vitis vinifera* L.) clones with AFLP markers. Am. J. Enol. Vitic. 58 (4), 526–529. Online verfügbar unter. http://www.ajevonline.org/cgi/content/abstract/58/4/526.
Börner, C., 1943. Die ersten reblausimmunen Rebenkreuzungen. Angewandte Botanik 25, 126–143.
Commission Directive, 23.06.2005. Commission directive 2005/43/EC of 23 June 2005-amending the annexes to council directive 68/193/EEC on the marketing of material for the vegetative propagation of the vine. Commission directive 2005/43/EC. Off. J. Eur. Union L164, 37–45.
Fröhlich, G.A., 1900. Zur Hybridisation der Reben und der Auswahl von Zuchtreben. Weinbau und Weinhandel, 18, pp. 230–231.
Hofäcker, W., 2004. Die Deutschen Rebklone. (Oppenheim).
Hörter, J., 1831. Die besten Setzreben im Bezug auf nöthige Reduktion der in Deutschland angebauten Traubensorten. Coblenz, Hergt.
Konradi, J., Forneck, A., Blaich, R., 2003. DNA-untersuchung Spätburgunder-Frühburgunder. Eine Bande macht den Unterschied. Das deutsche Weinmagazin, 24, pp. 13–15.
Laufner, R., 1987. 200 Jahre Qualitätsweinbau an Mosel-Saar-Ruwer. Die Weinbauverordnung des Trierer Kurfürsten Clemens Wenzeslaus 1787. Verkehrsamt der Stadt Trier, Trier.
Ludowici, A., 1924. Die Schule der Rebzucht. Ulmer-Verlag, Stuttgart.

Manty, F., 2005. Hintergründe zur Entstehung der Bezeichnungen der Unterlagenselektionen von Sigmund Teleki und Franz Kober. Deutsches Weinbau-Jahrbuch 2006, 57, pp. 159–164.

Porten, M., 2001. Der richtige Spätburgunder-klon. Das deutsche Weinmagazin, 18, pp. 38–40 42.

Rühl, E.H., Konrad, H., Schönhals, E.M., 2009. Untersuchung zur Existenz und zum Ausmaß genetischer Variation traditioneller Rebsorten im Hinblick auf die Erhaltung genetischer Ressourcen. Erfassung der physiologischen Kennzahlen der Klone. Bundesanstalt für Landwirtschaft und Ernährung, Bonn, (Forschungsprojekt, 514–33.52/04HS021). Online available at http://download.ble.de/04HS021.pdf.

Schaller, A., 1912. Reblaus Gesetze. Sammlung der im Königreich Preußen geltenden Reichs- und landesgesetzlicher Vorschriften und sonstiger Anordnungen zur Verhütung der Einschleppung und Weiterverbreitung der Reblaus sowie Bekämpfung derselben. Reblausgesetz von 1905. Verlagsbuchhandlung Paul Parey, Berlin.

Schmid, J., Manty, F., Cousins, P., 2009a. Collecting Vitis berlandieri from native habitat sites. Acta Horticulturae, 827, pp. 151–153.

Schmid, J., Manty, F., Lindner, B., 2009b. Geisenheimer Rebsorten und Klone. Forschungsanstalt Geisenheim, Geisenheim, (Geisenheimer Berichte 67).

Schöffling, H., Stellmach, G., 1993. Klon-Züchtung bei Weinreben in Deutschland. Waldkircher Verlag.

Seeliger, R., 1933. Der Neue Weinbau. Parey-Verlag, Berlin.

Töpfer, R., 2008. Grapevine protection against fungi and phylloxera. In: Die Entwicklung der Pflanzenzüchtung in Deutschland (1908–2008). 100 Jahre GFP e.V. - eine Dokumentation. Vorträge für Pflanzenzüchtung, Germany 75, 475–483. ISSN/ISBN: 0723-7812.

The Council of the European Union, 14.02.2002. Council directive 2002/11/EC of 14 February 2002-amending directive 68/193/EEC on the marketing of material for the vegetative propagation of the vine and repealing directive 74/649/EEC. Council directive 2002/11/EC. Off. J. Eur. Comm. L53, 20–27.

Grapevine breeding in Hungary

6

E. Hajdu
Corvinus University of Budapest, Budapest, Hungary

6.1 Introduction

Horticulture and viticulture have always been major activities within agriculture in Hungary. Climatic and soil conditions are favourable in our country. Variety is a very important factor in this culture because its genetic- and bio-potential can be used the most economically. Plant breeding began with the cross-breeding of plough land plants in 1863. However, this activity was banned in England (1819), in Germany (1849), in France (1850) and later in all of Europe (Fabricius, 1921). Vine breeding in France had begun even earlier and it was credited to L. Bouschet (Hegedűs et al., 1966; Tomcsányi, 1969). The breeding of new rootstock, table and wine grape varieties began in the last third of the nineteenth century. The insect phylloxera (*Dactulosphairae vitifoliae* Fitch.), which was brought into Europe from America, and fungal diseases (*Uncinula necator* (Schw.) Burr., *Plasmopara viticola* (Berk. et Curt.) Berl. et de Toni) urged Hungarian breeders to breed resistant varieties.

Researchers and breeders have likewise been motivated to breed new varieties and use them in viticulture either because of disasters (epidemics, global warming, etc.) in viticulture or by changed consumer demands. For example, when the large socialist state farms were established in the 1960s, vine training systems changed from low training with covering to high cordon without covering. At that time, cold-sensitive varieties were replaced by cold-resistant ones, particularly in low-lying areas. Every third year there are winter frosts with temperatures of −21 °C or below in 30% of our vineyards. New vine varieties were produced by crossing whereas the old varieties were improved by clonal selection. Both methods were applied to breeding rootstock, table and wine grape varieties.

Nowadays, because of environmental pollution, the consumption of 'organic' products has become more preferable, for which resistant varieties (Pilzwiderstansfähige Rebsorten; PIWI) are indispensable. Consumers demand table grape varieties with bigger clusters and berries, finer aromas and of deeper and nicer colour than the previously crossed ones.

6.2 Rootstock breeding

During the phylloxera epidemic, Laliman and Bazille in France recognized the sensitivity of Eurasian vine varieties to phylloxera. When they were grafted into phylloxera-resistant rootstocks, phylloxera damage stopped (Kozma, 1966). This heralded the beginning of rootstock breeding. Planchon, Viala and Millardet from France organized expeditions to North America to explore American wild species (*Vitis berlandieri* Planch., *Vitis riparia* Michx., *Vitis rupestris* Scheele, *Vitis cinerea* Engel, etc.), which

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00006-5

are resistant to phylloxera. The French businessmen took a large quantity of cuttings of these *Vitis* species from America to France. However, it soon turned out that the adaptability of the imported *Vitis* species to the European ecological conditions was difficult. Mainly, the dry and calcareous soils were unfavourable for them. Therefore, the French breeders tried to reduce the negative characters of the American wild species by hybridizing with Eurasian (*Vitis vinifera* L.) varieties.

At the beginning of rootstock breeding, it was the French, and later the Italian experts, who led the way. However, within a short time, Hungarian rootstock breeders gained high respect among them. Phylloxera in Hungary was observed first in Pancsova (today part of Serbia) in 1875. Zsigmond Teleki (1854–1910) worked as a wine merchant in Würzburg (Germany) during this period. He regularly travelled around Europe, and he saw the destruction caused by phylloxera in wine regions. He soon realized the importance of rootstock breeding. First, he planted rootstocks (Riparia portalis, Rupestris du Lot, Aramon × Rupestris G.1 (AXR1), Mourvedre × Rupestris 1202, etc.) on his own farm (5 ha) and grafted buds of wine grape varieties into them. The soil of his vineyard was very rich in lime; therefore, these rootstocks could not bring the expected results. He wanted to import new rootstocks again from France, but at that time, the import of propagation materials was prohibited because of the epidemic of black rot disease (Teleki, 1900, 1901, 1902, 1906).

He decided to produce new rootstock varieties from seeds. He was 27 years old when he came back from Würzburg to Villány to breed rootstocks. He travelled to France and brought home 10 kg of hybrid seeds (~40,000 seeds) from Euryalc Resseguier, a vine-grower in Alénya (Pyrenees). He sowed the seeds, and then he selected and evaluated 3000 seedlings. These plants were grouped according to shoot pubescence: Group A was non-pubescent and Group B was pubescent. The genotype of these groups differed from one another. When he crossed the seedlings of groups together, he produced a stock that was genetically mixed (Bakonyi et al., 1996b; Bakonyi and Kocsis, 2004; Csepregi and Zilai, 1989; Hajdu and Bakonyi, 2006; Schmid et al., 2009). He selected his seedlings according to their resistance to phylloxera, lime, vine size and affinity between the rootstock and the scions. Many foreign and national experts and visitors studied his results, which became known worldwide in a short time. Several rootstock breeders used the propagation materials of his rootstock hybrids for their own experiments. Among them were Fuhr (Oppenheim/Germany), Birk (Geisenheim/Germany) and Kober (Klosterneuburg/Austria) (Hegedűs et al., 1966). The propagation materials that they used were genetically rich; therefore, they were suitable for further selection (Table 6.1).

Teleki's rootstock seedlings were very valuable, and they helped to stop the advent of phylloxera in Europe, which had caused serious economic damage. Those who first received his rootstock selections treated them as clones. When they were tested, it was apparent that there were big differences between them; therefore, they were subsequently considered not as clones but instead as individual varieties.

Teleki rootstocks in order of their release are Teleki-Fuhr SO4, Teleki-Kober 5BB, Teleki 5C, Teleki-Kober 125 AA, Teleki 8B and Teleki 10 A (Table 6.1) (Csepregi and Zilai, 1955). From 1920 on, these varieties spread around the whole world. After his death, his sons (Andor and Sándor Teleki) continued to value and spread the new

Table 6.1 Clones selected from Teleki's rootstock hybrids

Place of selection (breeder)	Basic material	Clones
Germany		
Naumburg (Börner)	Teleki-Kober 5BB	59, 64, 68 B
Oppenheim (Fuhr)	Teleki '4A'	SO4, SO8
Freiburg (Becker)	Teleki-Kober 5BB	Fr. 148
Geisenheim (Birk)	Teleki 5C	Gm.6, Gm.10
Weinsberg (Götz)	Teleki-Kober 5BB	Weit.48
France		
Barr/Alsace	Teleki 9B	Barr 503, Barr 520
Italy		
Ferrari	Teleki 8B	Ferrari 8B
Conegliano (Cosmo)	Teleki 8B	Cosmo 2, Cosmo 10
Austria		
Wienerneustadt		Wi148, Wi155, Wi160, Wi296
Switzerland		
Wädenswil	Teleki 5C	Wädenswil 5C
Romania		
Blaj	Teleki-Kober 5BB	Cr.2, Cr.26.
	Teleki 8B	Cr.71
Dragosani	Teleki 8B	Dragosani 31, Dragosani 57

Bakonyi and Kocsis (2004).

rootstock hybrids. Phylloxera urged all experts to plant only by grafting in the wine regions of Europe (Teleki, 1910, 1927; Teleki and Teleki, 1927, 1928, 1936).

Decades passed, and during this time, nurseries and vine growers gained much experience with rootstocks. Meanwhile, other researchers were engaged in breeding in the Ampelology Institute of Budapest, but their experiments failed (Szabó-Jilek, 1970). From 1970 on, Károly Bakonyi opened a new period in the history of Hungarian rootstock breeding at the Agricultural University of Keszthely.

6.2.1 Identification of Teleki hybrids

Teleki was involved in two major fields of study. He left not only world-famous rootstock varieties but (also) a rich and excellent gene source for posterity. In the course of his research and collection activities, Bakonyi founded a rootstock variety collection in Keszthely. He collected rootstocks from foreign and national variety collections, neglected vineyards and vines creeping on tree trunks along the banks of ditches. His aims were to determine and identify these unknown potential rootstocks to make the work of the brilliant Hungarian rootstock breeder, Zsigmond Teleki, complete. Teleki's rootstock varieties collected and described by Bakonyi are as follows: Teleki-Bakonyi

G.K.1; G.K.9; G.K.10; G.K.62; G.K.67; G.K.68; G.K.69; G.K.70; G.K.72. These rediscovered rootstock hybrids of Teleki will probably not play an important role in viticulture but they might be used for breeding in the future (Bakonyi et al., 1996a, 1997; Bakonyi and Bakonyi, 2002).

6.2.2 Breeding new rootstock varieties

Bakonyi not only selected clones and bred wine grape varieties but (also) bred new rootstock varieties using Teleki's rootstocks as gene sources. The new rootstock Georgikon 28 (Teleki-Kober five BB × *V. vinifera* L. pollen mixture) was released from his valuable hybrids. This variety also received international variety protection (license). As Georgikon 28 comes from crossed American × Eurasian species (as are Chasselas × Berlandieri 41 B and Fercal), its root formation is very good. In addition, its scar and affinity with the stock is better and its lime resistance is higher than that of American × American hybrids. The two components of grafting (rootstock + scion) can thicken together; therefore, their symbiosis is also better than that of the American × American hybrids. His valuable hybrids are Georgikon 46, Georgikon 61, Georgikon 103 and Georgikon 251 (Bakonyi and Kocsis, 2006).

6.3 Breeding table grape varieties

After the Industrial Revolution, rail traffic started in several places of Europe and news agencies became more active, which resulted in better communication between nations. The development of capitalism in Hungary promoted the export and import of grapes for domestic consumption and the import of vine varieties in the nineteenth century. At that time, vine varieties grown in the vineyards of Hungary were mixed and not true to variety. Among them, only those varieties that had the finest grapes were marketable for consumption (e.g. Mézes fehér, Kövidinka, later Gohér, Kecskecsöcsű, Romonya). From the end of the eighteenth century, Chasselas and its variants from Western Europe (Hajdu, 2000) replaced these old vine varieties. In 1870, vine regions were formed to grow table grapes (Buda, Nagymaros, later Gyöngyös, Ménes, Beregszász, Novi Sad, Bácsalmás, Versec). Table grapes were popular, but the climate of the Carpathian basin with severe winters is not ideal for table grape growing in mass production. Table grape varieties are more sensitive to winter frosts than wine grape varieties. People were demanding more and more of these high-quality table grapes. At the same time, the development of nutritional science had a positive effect on the consumption of fresh grapes.

By the end of the 1800s, the collection of vine varieties was very fashionable among educated people, who spoke foreign languages and loved horticulture. Ferenc Entz established the first rich vine variety collection in Buda (Budapest) already before 1848. His collection was highly admired in Hungary. Educated and well-informed farmers competed with each other and took pride in their vine variety collections. The other famous and rich vine variety collection belonged to János Mathiász, a vine breeder in Szőllőske (Kosice; in present Slovakia). He had 231 vine varieties (among them 163 table grape varieties), and he published a list of the names and prices of his varieties. In addition to these two big collections, several smaller collections can be mentioned, among others the ones belonging to Ferenc Schams (Sashegy in Budapest), Demeter Görög (Grinzing in Vienna) and Gottfried Rotestein (Bratislava, in present Slovakia).

6.3.1 Private vine breeding

At the end of the nineteenth century, private breeders started to breed table grape varieties. In Kosice, in 1901, József Mathiász bred the first table grape hybrid Darányi Ignác Muskotály. His brother, a lawyer, János Mathiász (1838–1921), played a pioneering role in vine breeding in Hungary. His work was very successful, and his varieties spread throughout the whole world. Before he started his breeding activity, he had moved from Kosice to Kecskemét (Katonatelep), taking his collection with him. He wanted to protect his valuable variety collection against phylloxera. There is sandy soil in Katonatelep that is not suitable for the spread of phylloxera; therefore, he could safely work. His collection was very rich in genotypes and suitable as a gene source for cross-breeding. His first hybrid with large clusters was Ezeréves Magyarország Emléke. He used its gene material for further crosses.

Csaba gyöngye, the world's earliest ripening muscat-flavoured hybrid today, was bred by Adolf Stark (Domonkos, 1889, 1900). Stark introduced another important variety, Kossuth Szőlő. Mathiász made several crosses with Csaba gyöngye to transmit the muscat flavour and early ripening to his hybrids. In the hybrid families, it was given the name Szőlőskertek Királynője Muskotály (1916) (Figure 6.1). It was highly successful in Europe. Stark's contemporary and rival was Angelo Pirovano from Italy, the breeder of the variety Italia.

Adolf Stark's most noteworthy table grape varieties include Mathiász Jánosné Muskotály (1902), Szauter Gusztávné (1902), Cegléd Szépe (1903), Munkátsy József

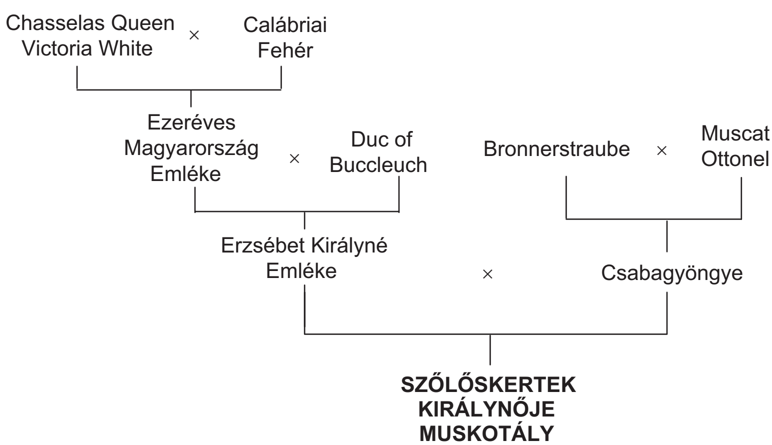


Figure 6.1 Pedigree of the resistant table grape variety SZŐLŐSKERTEK KIRÁLYNŐJE MUSKOTÁLY.

Muskotály (1903), Tompa Mihály (1904), Thallóczy Lajos Muskotály(1911) and Szőlőskertek Királynője Muskotály (1916) (Váry, 1940). In addition to these, he had a very extensive variety collection of genotypes from which he bred his table grape varieties. Vine breeders worldwide used his varieties as genetic sources for their own crosses. His descendants continued the successful and excellent work of Mathiász.

Kocsis Pál (1884–1967) began his first crosses in Kecskemét in 1915. His aim was to breed table grape varieties that were resistant to drought and suitable for growing in sandy soil. His table grape varieties included Attila (1917), Gloria Hungariae (1929), Irsai Olivér (1930) and Kocsis Irma (1929). He was awarded the Kossuth Prize – an outstanding recognition in Hungary – for his successful work. Vine growers have known his varieties since 1930 (Kocsis, 1958, 1963). One of his most valuable varieties is Irsai Olivér, which ripens very early (in the middle of August) and has a muscat flavour. Today, Irsai Olivér is used as a wine grape variety and its wine is exceptional. He also bred several hybrids. He named some of his most interesting hybrids after the members of his family, his acquaintances and historical persons. Some of them received imaginary names (Füri, 1977). The varieties of Mathiász and Kocsis are still in use. There are nearly 120 hybrids.

Several other private grape breeders are worthy of mention. Poczik Ferenc bred the variety Pannónia Kincse from Mathiász's hybrids in Budakeszi in 1942 (Németh, 1975). This is one of the most valuable Hungarian table grape varieties with huge clusters and berries of whitish-yellow colour. It is an easily marketable product. Szűcs József worked in Szentendre. He bred the varieties Izbégi Muskotály, Korai Ropogós, Kőhegyi Láng, Kőhegyi Zamatos and Mócsai Mariska. However, these varieties have already lost their importance. Ábrahám Béla became known for his table grape variety Marosi Mária, but it can be found only in variety collections today. Lubik István improved vine varieties by cross-breeding in Bölcske. His table grape varieties include Anita and Lubik Piros. The maternal parent of both varieties is Rosa Menna di Vacca. Both have been released. They have big clusters, large rose-coloured berries and they ripen early (in the second half of August) (Hajdu, 2012).

6.3.2 Grape breeding in state institutes

After World War II, agricultural production and research took place within the framework of large-scale socialist agriculture in accordance with the Five Year Plans. The breeding of table grape varieties began within the programme of the Ministry of Agriculture and with its financial assistance at the beginning of the 1960s. This breeding programme was directed by Sándor Szegedi at the Research Institute for Viticulture and Enology in Kecskemét, by Professor Pál Kozma at the Department of Viticulture, by professors István Tamássy and István Koleda in the Faculty of Plant Breeding and Heredity of the University of Horticulture in Budapest and by Károly Bakonyi at the University of Agriculture in Keszthely. Initially, the breeders worked with *V. vinifera* L. varieties. From their hybrid populations, intraspecific table grape varieties were selected. The following varieties were named and released: In Kecskemét, Anna, Boglárka, Csilla, Emőke, Éva, Favorit, Kósa, Melinda, Narancsízű and Téli Muskotály (Szegedi, 1968); in Budapest, Kozma Pálné Muskotály and in Keszthely, Helikon Szépe. In addition to being valuable and marketable, these varieties can be grown very well. They are propagated and grown mainly in hobby gardens.

The resistance-breeding programme was another programme of high priority. Natural disasters such as phylloxera, the epidemic of fungal diseases, environmental pollution, climate change, winter frosts, etc., caused the breeders to breed table grape varieties that were resistant to abiotic and biotic stress effects. These varieties do not need spraying at all, or if so, to a lesser extent than *V. vinifera*. Because table grapes are eaten fresh, it is very important that the clusters should not include any chemical residues. Hungarian breeders were pioneers and were unprecedented in this work. However, in the beginning (in the 1970s), breeders had to fight for the acceptance of the resistant varieties. Today, these resistant varieties, called PIWI varieties, are already indispensable in the production of organic products. Luckily, PIWI table grape varieties are very popular now in domestic and international markets. They are highly resistant to fungal diseases (*Plasmopara viticola* (Berk. et Curt) Berl. et de Toni; *Botrytis cinerea* Pers.) and they are not sensitive to winter frosts. They have various shapes, colours and flavour in the period of ripening, and they are of high quality (Table 6.2).

Table 6.2 **National variety list of 2012 (new varieties)**

Name of variety	Year of qualification
1. Rootstock varieties	
Georgikon 28	2005
Teleki 5C	1983
Teleki-Fuhr S.O.4	1998
Teleki-Kober 125AA	1998
Teleki Kober 5BB	1983
2. Intraspecific hybrids	
White wine grape varieties	
Csabagyöngye	1956
Cserszegi fűszeres	1982
Ezerfürtű	1973
Generosa	2004
Gesztus	2004
Irsai Olivér	1959
Jubileum 75	1974
Kabar	2005
Karát	1982
Korona	2002
Nektár	1994
Pátria	2002
Pelso	2005
Rozália	2002
Rózsakő	2003
Szirén	2005

Continued

Table 6.2 Continued

Name of variety	Year of qualification
Trilla	2005
Vulcanus	2003
Zefír	1983
Zengő	1982
Zenit	1976
Zeus	1994
Zéta	1990
Zervin	2012
Red wine grape varieties	
Bíborfrankos	2009
Bíbor Kadarka	1974
Kármin	1974
Turán	1985
Table grape varieties	
Anita	1993
Anna	2012
Attila	1963
Boglárka	1979
Cegléd Szépe K.73	1978
Csilla	2012
Emőke	2012
Éva	2012
Favorit	1968
Kósa	2000
Kozma Pálné Muskotály	1984
Lubik piros	2009
Mathiász Jánosné Muskotály	1956
Melinda	2003
Millenium	2012
Narancsízű	2000
Nóra	2012
Pannónia Kincse	1959
Szőlőskertek Királynője m.	1956
Téli Muskotály	1973
3. Interspecific hybrids	
White wine grape varieties	
Aletta	2009
Bianca	1982
Csillám	1997
Göcseji Zamatos	2005
Kunleány	1975
Odysseus	2004
Orpheus	2003

Continued

Table 6.2 **Continued**

Name of variety	Year of qualification
Pölöskei Muskotály	1979
Refrén	2005
Viktor	2009
Viktória gyöngye	1995
Zalagyöngye	1970
Taurus	2004
Red wine grape varieties	
Duna gyöngye	1995
Korai Bíbor	2004
Medina	1984
Nero	1993
Pannon Frankos	2004
Table grape varieties	
Borostyán	2006
Csépi Muskotály	2006
Esther	2003
Fanny	2003
Lidi	2008
Palatina	1996
Pegazus	2006
Teréz	1995

The breeders successfully used French–American hybrids (Seyve-Villard 12-375) and the Asian wild species (*V. amurensis* Rupr.) as resistance gene sources. György Kriszten bred the first trihybrids in Hungary, which carry the genes of at least three wild species (*V. vinifera* L., *V. amurensis* Rupr. and French–American hybrids) (Kriszten, 1990). Figure 6.1 shows the pedigree of the most valuable table grapes. The qualified PIWI table grape varieties are as follows: in Kecskemét, Esther, Fanny, Lidi, Pölöskei Muskotály and Teréz; in Budapest, Palatina (Kozma, 1961); and in Keszthely, Borostyán, Csépi Muskotály and Pegazus. There are now several interspecific hybrids under evaluation in Kecskemét and in Keszthely.

6.4 The breeding of wine grape varieties

Although table grape varieties were the results of purposeful crosses from the very beginning, the breeding of wine grape varieties goes back to earlier times. It started with the activities aimed at the maintenance of varieties (selection). These activities were inextricably linked with cultivation. There were two methods of purposeful breeding. One of them was improving the quality and safety of the crop production of the Eurasian varieties (*V. vinifera* L. *convarietas pontica*), which were grown on a huge area of the country, by crossing them with other Eurasian varieties (*V. vinifera* L. *convarietas occidentalis*), resulting in intraspecific hybrids. The other method was breeding resistant varieties by using several *Vitis* species as gene sources (interspecific hybrids).

6.4.1 Hybridization of the Eurasian varieties

At the beginning of the nineteenth century, private breeders made hybrid populations for table grapes, from which several grape varieties originated. These included the hybrids of Mathiász (Kecskemét Virága (1904)), hybrids of Kocsis (Kecskeméti Rizling (1915), Balaton Kincse (1917) and Bernáth János (1917)) and hybrids of the brothers András and Béla Ábrahám (Kunvér (1937), Jászvér (1940) and Ördögvér (1941)). However, these hybrids were not qualified and were not widely planted (Kapás, 1969).

Hungarian native vine varieties (*Hungarica*) (e.g. Ezerjó, Furmint, Hárslevelű, Kadarka, Kövidinka, Mézes Fehér, Pozsonyi Fehér) were grown extensively and were dominant in the wine-growing regions. They yielded large crops, but the quality of wine was objectionable in several vintages and their wine was not marketable. Their vines were typically trained to a low cordon system with short spurs, and they were covered with soil in winter. In the 1950s, the large socialist co-operative farms were established where the high cordon training system and agricultural machines were used in vineyards. The trunks of the old vine varieties froze on the high cordons; therefore, their yield was unstable. It became necessary to grow cold-resistant varieties that could ripen by the end of September in the Carpathian basin, and their wines were marketable. Viticultural co-operatives imported and planted international varieties such as Chardonnay, Cabernet franc, Cabernet Sauvignon, Pinot blanc, Riesling, etc.

The organized breeding programme began at the stations of the Research Institute for Viticulture and Enology in Badacsony, Eger, Kecskemét, Pécs and Tarcal in 1948. The Ministry of Agriculture assisted this programme. Vines were bred at the University of Horticulture in Budapest and at the University of Agriculture in Keszthely. Their breeding results can be seen in Table 6.3.

6.4.2 Cross-breeding of PIWI varieties

Resistance breeding is a very important branch of breeding. Hungarian breeders were pioneers in this field, and their results have been recognized all over the world. Breeders began purposefully breeding the resistant varieties already in the 1950s. The first resistant hybrids showed good improvement with respect to resistance to fungal diseases (downy mildew, powdery mildew, Botrytis) and winter frost (Table 6.3). They were trying to convince the winemakers of the country of the advantages of the resistant wine grape varieties. However, the oenologists argued against these varieties, saying that the quality of wine made from resistant varieties was much lower than that of the wine produced from *V. vinifera*. At that time, only wooden barrels were used in winemaking, and these created oxidative conditions for wine. We know today that the wine from resistant varieties needs reductive conditions.

In the resistance-breeding programme, wild species were used as gene sources, such as *V. amurensis* and French–American hybrids (Seibel and Seyve-Villard hybrids)

Table 6.3 Level of disease resistance of the Hungarian resistant vine varieties on sandy soil, Kecskemét, 2000–2012

Variety	Degree of resistance (0–9)			
	Downy mildew on leaf	Powdery mildew on leaf	Grey rot on berries	Frost (−21 °C) in buds
White wine varieties				
Aletta[a]	7	6	7	9
Bianca	8	7	8	8
Csillám	6	5	6	6
Göcseji Zamatos	5	4	5	5
Kunleány	8	4	8	8
Odysseus	8	6	7	7
Orpheus	7	6	8	8
Pölöskei Muskotály	7	6	8	3
Refrén	7	5	8	7
Viktor[a]	7	6	6	7
Viktória gyöngye	7	6	8	8
Zalagyöngye	6	4	7	6
Taurus	8	7	8	7
Red wine varieties				
Duna gyöngye	5	6	6	7
Korai Bíbor	7	5	6	6
Medina	5	6	7	5
Nero	6	5	7	6
Pannon frankos	7	6	7	8
Table grape varieties				
Borostyán[a]	7	6	7	5
Csépi Muskotály[a]	6	5	6	6
Esther	6	5	6	4
Fanny	5	4	8	6
Lidi	7	4	6	5
Palatina	6	5	7	5
Pegazus[a]	7	6	7	7
Teréz	7	6	8	5

Key: 0 = sensitive; 9 = resistant.
[a]Trial place in Helvécia.

(Figures 6.2 and 6.3; Kozma, 2002). These gene sources allowed the hereditary transmission of resistance to biotic and abiotic stress effects into the hybrids (Csizmazia et al., 1994). The resistant wine grape variety Viktor (Figure 6.3) is also a trihybrid bred by Csizmazia (in Eger) and by Kosztrikin (in Novocserkaszk/Russia).

In the beginning, breeders applied simple crosses, reciprocal crosses and the back-cross method. On the basis of the segregation of different characteristics, they could follow their inheritance. In the 1990s, the development of molecular markers such as

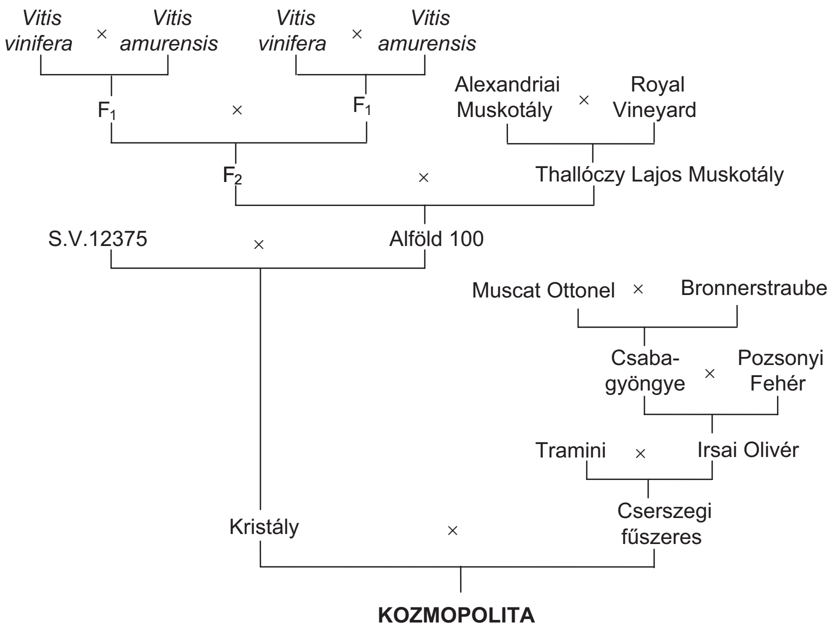


Figure 6.2 Origin of the white wine grape variety Kozmopolita.
Kozma (2002).

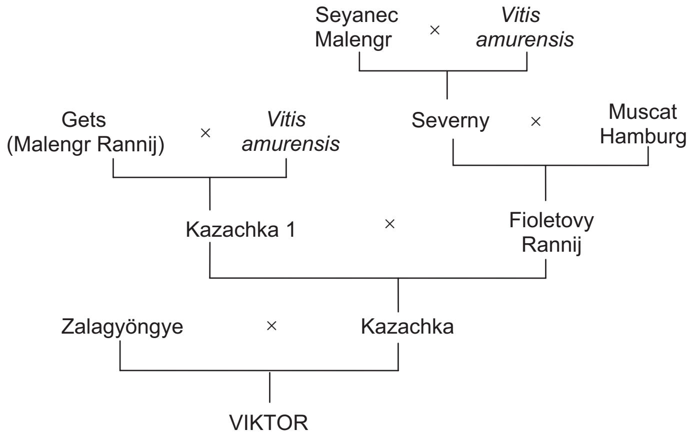


Figure 6.3 Origin of the white wine grape variety Viktor.
Csizmazia et al. (1994).

RFLP, RAPD, AFLP, SSR, ISTR, SCAR, etc. made plant breeding more successful. Isozymes and molecular markers help breeders to find hereditary variations in hybrid populations. To select the desired genotypes, these techniques allow them to assess the genetic structure of the population and to protect their own varieties (Hajósné Novák, 1999). There are laboratories (at Szent István University of Gödöllő, at Corvinus University of Budapest) where the genetic analysis of grapevines is possible.

Table 6.4 Resistance of *Vitis* species to *Agrobacterium vitis* on stems

Number of clones and individuals	Sign of bacteria on stems			
	AT-1	AB-3	S-4	S-1
Vitis amurensis selections				
P-1	–			–
P-3	–			–
P-u	–			
29	+	+	+	
27	+	+		
30	+	+		
31	–			
34	–			–
48	+	+	+	
50	+	+	–	
58	+	+		
66	–	–	–	
115	–	–		
122	+	+		
S.III.32/24	–	+	–	
Vitis piasetzkii	–			
Vitis flexuosa	–	–		

+ indicates tumour on contamination places; – indicates no tumour on contamination places.
Korbuly (2002).

Polyploidy and induced mutation were considered successful techniques in producing genotypes with good agronomic characteristics, but they did not produce the expected results. Plant breeders crossed diploid grape plants with autotetraploid ones to produce seedless triploids, but their experiment failed (Németh, 1968; Szegedi, 1975). In this experiment, they applied colchicine to produce a higher ploidy level, but they had no success. We obtained the best results by using traditional methods to induce variability at first and then to select the best plants. The real evaluation of genetic variability involves the reliability of characterization based on protein, particularly at the DNA level.

Gene pyramidation is a successful crossing technique in which breeders build positive characteritics into a genotype from generation to generation to form horizontal and vertical resistance while maintaining good wine quality. *Agrobacterium vitis* (Smith and Town. (Conn.)) causes great damage in all wine regions, particularly on the Hungarian Plain. Chemical protection against this pathogen is unknown up to this day, but resistance breeding could probably be a solution. European varieties are all susceptible to *Agrobacterium* strains, but wild *Vitis* species could be used as sources of resistance.

In the 1980s, the breeders at the University of Horticulture in Budapest found specimens showing resistance after artificial infection in several East-Asian species, among them in *V. amurensis* Rupr. (Table 6.4). The resistance of the individuals to *Agrobacterium* varies within species. Some genotypes are susceptible whereas others are resistant to several strains (e.g. *V. amurensis* 66). The mode of inheritance of resistance is very important in cross-breeding. Therefore, several hybrid combinations of *V. amurensis* were bred to test the manifestation of resistance. On the basis of the results, it was established that there was resistance to a bacterium strain that showed a monogenic dominant mode of inheritance. It was later found that in addition to race-specific resistance, there was also resistance to all of the strains, presumably to all of the species used in the test (Korbuly, 2002).

6.5 Clonal selection

Gustav A. Froelich (1847–1912) first introduced a new selection method applied on the white wine variety Sylvaner in Edenkoben, Germany in 1876 (Schöffling and Stellmach, 2003). His followers later gained worldwide fame with the clones selected in Germany.

In Hungary, the Ministry of Agriculture supported the selection of a vine as a state-organized activity after World War II. Grapevine stocks, which were cultivated in their natural surroundings in the same area (in the Carpathian basin) for centuries, tended to change in morphology and other characteristics because of selective pressure. A specific vineyard block would become heterogeneous, with one variant (i.e. clone) becoming weak and susceptible to diseases and with the other maintaining its original characteristics. However, there were clones that showed positive changes. These changes are expressed phenotypically, and if they are fixed in the genotype and manifested through generations of clones, then they could be very valuable clones. During centuries, the old vineyards of traditional varieties (e.g. Furmint, Hárslevelű, Kadarka, Kékfrankos, Kövidinka, Olasz rizling) deteriorated, and the plant material of those vineyards became variable. This was probably due to genetic (mutations) and/or plant health problems. Plantations such as these needed selection. It can be proven by several steps of clonal selection whether the positive properties are expressed as morphological or other characteristics of a clone or whether they are caused by modifications or changes in the genotype (mutation).

Three selection methods were used in the country: mass, clonal type and individual (clone) selections. Because grapevines can be vegetatively multiplied, the selected clones can be maintained by vegetative propagation. Goethe (1887) considered the bud to be the smallest mutable plant part suitable for propagation. One hundred years later, in 1989, Bouquet stated that it was the cell that can also be a somaclone and can be transformed into an in vitro plant (Hajdu, 1993, 2002). However, selection can restrict and maintain the polymorphism of a vine. The following subsections present the selection methods that are used in Hungary.

6.5.1 Mass selection

Breeders study the production of vine stocks for years in vineyards. The propagation material is collected from all of the positive stocks. This method is rapid enough, and considerable progress can be made in the selection. Pál Kozma, Head of the Selection Centre of Vine and Fruit in Budapest, used mass selection for the most important vine varieties in 1957. They became widespread in the whole country (Kozma, 1957). The propagation materials of the selected vine stocks were used for large-scale planting during the Second Five Year Plan.

6.5.2 Clone-type selection

This method involves grouping the vine stocks according to one or more important characteristics (e.g. flower type). These groups are then propagated together. When this method is applied, advance selection is essential for the unselected basic stock staff. Clone-type selection is more efficient than mass selection. Kozma (1951) worked out this method for the varieties Furmint and Kadarka on the basis of flowering biology in 1948.

6.5.3 Individual (clone) selection

The Hungarians adapted this method from Germany, where it had been applied successfully. Németh (1958) developed an individual method consisting of four steps; Luntz (1990) later reduced the number of steps to three. Individual selection is still very popular. It is used at the Research Institute for Viticulture and Enology, at its Research Stations (Badacsony, Eger, Kecskemét, Pécs, Tarcal) and at the University of Agriculture in Keszthely in parallel with genetic and plant sanitary selection. The pathogen-free mother stocks, from which the pathogen-free 'mother field' is produced, come from the propagation material of selected clones. The pathogen immunization of vine against *Agrobacterium* and viruses is conducted at the Research Institute for Viticulture and Enology in Kecskemét.

6.5.3.1 Vine clones selected and released in Hungary (Table 6.5)

In Badacsony:	Olasz rizling B.5, B.5/8, B.14, B.14/14, B.20, B.20/7, B.20/16; Rajnai Rizling B.7; Szürkebarát B.10, B.10/5, B.10/10.
In Eger:	Bianca E.66, Chardonnay E.98, Fehér tramini E.73, Leányka E.99; Cabernet franc E.11, Cabernet Sauvignon E.153, E.183, Kékfrankos E.48, E 63, Kékoportó E.42, Nero E.722, Turán E.723, Zweigelt E.11.
In Kecskemét:	Cegléd szépe K.73, Pannónia kincse K.56; Irsai Olivér K.11, Hárslevelű K.9, Kövidinka K.8; Virus-free clones: Chasselas blanc Kt.46, Chasselas rouge Kt.15, Furmint Kt.4, Olasz rizling Kt.8, Ottonel Muskotály Kt.16, Pinot blanc Kt.19, Piros tramini Kt.2, Rajnai rizling Kt.3, Sauvignon blanc Kt.10, Szürkebarát Kt.1, Zöld Veltelíni Kt.14, Kadarka Kt.3, Kt.4, Kékfrankos Kt.1, Kt.3, Kékoportó Kt.1, Merlot Kt.9.
In Pécs:	Cifandli P.123, Furmint P.14, P.26, P.27, P.51, Hárslevelű P.41, Olasz rizling P.2, P.10, Piros tramini P.13, Sauvignon blanc P.1, P.25, P.130, Zengő P.122, Zenit P.104; Kadarka P.9, Merlot P.102, Pinot noir P.1.
In Tarcal	Furmint T.92, T.85, Hárslevelű T.311, 1007
In Keszthely	Chasselas blanc K.16, Chasselas rouge K.18, Rizlingszílváni K.3, Olasz rizling 'Nemes'.

Altogether, there are 50 released clones of 30 varieties and 17 released virus-free clones of 15 varieties.

Table 6.5 **National variety list of 2012 (released clones)**

Variety	Clone numbers
White wine varieties	
Chardonnay	Bb.75/1, Bb.96/1, Bb.116/1; E.98
Chasselas rouge	Bb.61/1; G.K.18; Kt.15
Chasselas blanc	Bb.60/1; G.K.16; Kt.46
Tramini white	E.73
Furmint	Kt.4; P.14, P.26, P.27, P.51; T.85, T.92
Hárslevelű	1007; K.9; P.41; T.311
Irsai Olivér	K.11
Kövidinka	K.8
Leányka	E.99
Muscat Ottonel	Kt.16
Müller-Thurgau	Bb.650/1; G.K.3
Nektár	G.K.71
Olasz rizling	B.5, B.5/8, B.14, B.14/14, B.20, B.20/7, B.20/16; G.K.1, G.K.18, G.K.37; Kt.8; P.2, P.10
Pinot blanc	Bb.54/1, Bb.55/4; Kt.19
Pinot gris	B.10, B.10/5, B.10/10; Bb.52/1; Kt.1
Piros tramini	Bb.47/1, Bb.48/1; Kt.2; P.13
Rajnai rizling	B.7; Bb.49/1; Kt.3
Rozália	G.K.1
Sauvignon blanc	Bb.297/1; Kt.10; P.1, P.25, P.130
Zengő	P.122
Zenit	P.104
Zöld veltelíni	Kt.14
Red wine grape varieties	
Cabernet franc	E.11
Cabernet Sauvignon	Bb.15/1; E.153, E.183
Kadarka	Kt.3, Kt.4; P.9
Kékfrankos	E.48, E.63; Kt.1, Kt.3
Kékoportó	E.42; Kt.1
Merlot	Bb.348/1; Kt.9; P.102
Nero	E.722
Pinot noir	Bb.113/1, Bb.162/1; P.1
Turán	E.723
Zweigelt	E.11
Table grape varieties	
Cegléd Szépe	K.73
Pannónia Kincse	K.56
Virus-free rootstocks	
Fercal	K.25
Teleki 5C	Gm.6-K.64, Gm.10-K.74, K.20, Wed.-K.103
Teleki-Fuhr S.O.4	K.133
Teleki-Kober 125AA-	K.147
Teleki-Kober 5BB	Cr.2-K.18, K.21, Wie.48-K.5

Place of selection: B=Badacsony; Bb=Balatonboglár; E=Eger; G.K.=Keszthely; Kt and K=Kecskemét; P=Pécs; T=Tarcal.

6.6 Maintenance and use of varieties

A new variety or clone is valuable only if it is propagated and maintained. Therefore, one has to propagate it and to introduce it in viticulture as soon as possible. New varieties and clones get from breeders to vine growers through several steps.

First, the breeders prepare and announce their new varieties and clones for registration and for state qualification at the National Food Chain Safety Office (NFCSO) in Budapest. They are registered by the office. After the acceptance of the application, this office starts testing (DUS, VCU) the announced varieties and clones in comparative trials. The office then presents the results of the examinations with its proposal to the National Council for the Registration of Agricultural Varieties. The Minister of Agriculture appoints the chairman and the secretary of the council, whereas the chairman of the council appoints the members of the council. State-registered varieties (Table 6.2) are entered into the National Variety List (*Law No. CXXXI/1996 and the Ministry of Agriculture decree No. 88/1997* (*XI.28*)*FM*). Grape varieties can only be propagated after state registration.

Meanwhile, the breeder or owner of the new varieties/clones has to ensure that the propagation material is free of pathogens. This activity is performed at the Research Institute for Viticulture and Enology in Kecskemét, Hungary. The most frequently used multiplication methods in Hungary are green and wood grafting on rootstocks for heavy soils and layering, own-rooted cuttings or in vitro plants for sandy soils. The in vitro propagation of a grapevine from the fragmented shoot apex is a possibility to produce pathogen-free propagation materials (Haydu, 2002). A mother block is established from the pathogen-free propagation material where the varieties and clones are stored. This 'pre-basis' mother field is kept under rigorous phytosanitary control every year. The original pathogen-free trunks (five trunks per variety) are kept in a plastic greenhouse. The pathogen-free grafts or the rooted plants have high biological value; therefore, their growing is profitable (Tóth, 2002).

The NFCSO supervises and justifies not only the basic mother fields but (also) vine propagation in the whole country. Breeders (variety owners) check their bred material in the mother field every third year. The grower or user pays a royalty to the variety owner for the purchased rooted nursery plant of the grape variety that has been state registered or authorized for provisional multiplication. In Hungary, according to Law No. CXXI/1997, a vine variety can be planted as a recommended or additional variety in a given wine region.

The use of varieties has been adjusted to the market requirements. In Hungary, the ratio of white and red wine grape varieties is continuously changing (white wine: 70–75%, red wine: 25–30%) depending on the consumer demand (Tables 6.6 and 6.7). Breeders endeavour to propagate their own varieties. Table 6.6 presents the planting area of the most widespread wine grape varieties, categorized by *convarietas* (Proles). Table 6.7 lists all wine grape varieties grown commercially in Hungary.

Table 6.6 **Variety groups in Hungarian vineyards**

Variety group	Variety relation of vineyards (%)			
	1965	1995	2005	2012
Vitis vinifera L. *convarietas*				
occidentalis	22.8	43.5	44.1	44.5
orientalis	8.6	19.9	16.3	8.0
pontica	55.0	10.6	20.7	28.5
Hybrids				
Intraspecific	0	19.9	12.0	8.8
Interspecific (PIWI)	0	6.1	6.9	10.2
Direct producer	13.6	0	0	0
Total	100.0	100.0	100.0	100.0

Table 6.7 **Planting area of vine varieties in Hungary (ha) 2012**

Variety	Land area (ha)
1. Wine grape varieties	67,699
Olasz rizling	4585
Furmint	4274
Zalagyöngye	**3297**
Cserszegi fűszeres	3531
Chardonnay	2777
Müller-Thurgau	2092
Ezerjó	2568
Arany sárfehér	1222
Chasselas	1707
Zöld veltelíni	1535
Kunleány	1248
Rajnai rizling	1344
Hárslevelű	1597
Muscat Ottonel	1256
Pinot gris	1596
Irsai Olivér	985
Bianca	1185
Kövidinka	974
Leányka	817
Királyleányka	860
Lakhegyi mézes	361
Juhfark	176
Sauvignon blanc	867
Muscat Lunel	708
Zenit	555
Aletta	449
Ezerfürtű	423
Zengő	276

Continued

Table 6.7 Continued

Variety	Land area (ha)
Pinot blanc	217
Jubileum 75	176
Villard blanc	167
Viktória gyöngye	135
Csabagyöngye	97
Zéta	92
Pölöskei Muskotály	90
Piros szlanka	80
Generosa	65
Karát	53
Zefír	51
Kövérszőlő	44
Kéknyelű	42
Mátrai muskotály	27
Cirfandli	25
Csillám	22
Nektár	22
Rózsakő	20
Göcseji Zamatos	17
Zeus	17
Kabar	15
Remainder	729
Total white varieties	**46,204**
Red wine grape varieties	
Kékfrankos	8084
Cabernet Sauvignon	2886
Zweigelt	2217
Merlot	1938
Cabernet franc	1345
Kékoportó	1250
Pinot noir	1075
Blauburger	452
Turán	178
Syrah	160
Medina	157
Bíborkadarka	143
Duna gyöngye	63
Kármin	43
Nero	38
Rubintos	18
Pannon frankos	9
Remainder	672
Total red varieties	**20,728**
Grand total	**66,932**

6.7 Ampelography

The bred new vine varieties and selected clones are mostly unknown to growers; therefore, it is very important to review them. Ampelographies describe the morphology, viticultural, wine, growing and market values of new vine varieties and clones. Several valuable books of ampelography have been published in Hungary in the last 120 years. Among them, some of the most important ones in chronological order are found in the Appendix.

6.8 Hungarian grape breeders

János Mathiász (1838–1921) (Figure 6.4(a)). Mathiász was the first successful vine breeder in Hungary and the founder of a breeding school. After his legal and economic studies, he began to deal with viticulture near Kassa, which is now a town in Slovakia. He had one of the richest variety collections in the country. At the time of the phylloxera epidemic, he rescued his valuable varieties to the sandy soils in Kecskemét. Mathiász used the varieties Chasselas, Calabria white and Muscat types as gene sources in his crosses. He wanted to develop early-ripening table grape varieties with large clusters and berries and excellent muscat flavour. He propagated his varieties himself and published their name and price list. He took part in several national and international exhibitions. Mathiász was highly appreciated and rewarded wherever he went. Several of his varieties (Csaba gyöngye, Szőlőskertek Királynője Muskotály) are widely used as gene sources. The Experimental Station of the Research Institute for Viticulture and Enology in Kecskemét was named after him (Mathiász Telep). His table grape varieties include Cegléd Szépe, Ezeréves Magyarország Emléke, Mathiász Jánosné Muskotály and Szőlőskertek Királynője Muskotály, all of which are grown widely, mainly in hobby gardens.

Zsigmond Teleki (1854–1910) (Figure 6.4(b)). Teleki was an excellent breeder of rootstocks at the time of phylloxera infestation. He established stock plantations of *V. riparia*, Rupestris du Lot, Solonis and Aramon×Rupestris in Villány to produce rootstock wood and grafts. However, his attempt to produce rootstock failed in the limy soils of Hungary. Phylloxera-resistant, lime-tolerant rootstocks were needed. He was thought to have found the solution in *V. berlandieri* from Resseguir. Approximately 40,000 seeds were sown and 10 types were selected. He made new attempts in 1900. His rootstock varieties included Teleki 5C, Teleki-Fuhr SO4, Teleki-Kober 125 AA and Teleki-Kober 5BB. The lime tolerance of these hybrids proved to be excellent. He pioneered work in the fight against phylloxera.

Pál Kocsis (1884–1967) (Figure 6.4(c)). Originally, Kocsis wanted to be a painter, but he instead became a viticulturist. He was an autodidact, an empirical vine breeder, a disciple of Zsigmond Hankovszky and a fruit breeder in Kecskemét. After 1923, he continued the work of János Mathiász. In 1922, he presented his own varieties at the Exhibition of Viticulture and Enology in Budapest. He also published a variety list. He was a member of the board of a state wine storehouse and a viticultural expert in

Figure 6.4 Hungarian grape breeders: (a) Janos Mathiász, (b) Zsigmond Teleki, (c) Pál Kocsis, (d) Márton Németh, (e) Ferenc Király, (f) Darab József Csizmazia, (g) Pál Kozma, (h) Sándor Szegedi, (i) Károly Bakonyi, (j) György Kriszten, (k) András Kurucz and (l) István Koleda.

Ágasegyháza (near Kecskemét). He was an excellent specialist and received numerous visitors. He worked out a special senescence method to bring about early fruiting in seedlings. He named his varieties after his family members and famous people. He selected 150 valuable hybrids and crossed varieties found on sandy soils (e.g. Mathász Jánosné Muskotály) aiming to produce varieties adaptable to sandy soils. Most of his hybrids are in collections. His released varieties include Attila, Glória Hungariae, Irsai Olivér and Kocsis Irma. Among them, Irsai Olivér is one of the most popular white wine varieties with muscat aroma and is grown on several thousand hectares. He was awarded the Kossuth Prize.

Márton Németh (1910–1986) (Figure 6.4(d)). Dr Németh was a horticultural engineer, a vine breeder, an ampelographer, a senior research fellow at the Research Institute for Viticulture and Enology in Pécs and Head of the Experimental Station. He was a well-qualified, talented scientist. He established a model variety collection. He summed up his ample knowledge of vines in his ampelographic works. His books *Identification of Wine Grape Varieties* and *Ampelographic Album* (1967, 1970, 1975), illustrated with colourful paintings and containing detailed descriptions, won international fame. He dealt with selection breeding and clones. In 1958, he worked out a four-step clone selection method. He introduced the varieties Aligoté, Bouvier, Királyleányka, Merlot, Pinot blanc and Pintes into Hungary. He also played an active part in variety maintenance and production evaluation. His results were published in books and journals. His released clones include Furmint P.51, Hárslevelű P.41, Kadarka P.9, Pinot noir M.2, Olasz rizling P.2 and Olasz rizling P.10.

Ferenc Király (1911–1982) (Figure 6.4(e)). Dr Király was an agricultural engineer, a viticulturist and a breeder as well as a senior research fellow at the stations of the Research Institute for Viticulture and Enology in Pécs, Badacsony, Mór and Eger. He conducted agricultural experiments to improve vine production (cultural methods, nutrient supply and reconstruction of spoil banks). He taught at the Agricultural College in Gyöngyös. He was especially successful in vine breeding. He bred varieties that can be found in large areas of Hungary (Hungaricums) by means of selection and cross-breeding. He used *V. vinifera* L. varieties (Bouvier, Ezerjó, Furmint) as gene sources to get early-ripening wine grape varieties with high sugar content, wine taste and acids. His most successful combination was Ezerjó × Bouvier. His released clones include Királyfurmint and Olasz rizling B.20, and his released varieties include Zefír, Zengő, Zenit, Zéta, Zeus and Zervin.

Darab József Csizmazia (1918–) (Figure 6.4(f)). Dr Csizmazia was an agricultural engineer. From 1948 on, he worked in the Research Institute for Viticulture and Enology in Budapest and in Eger until his retirement. He was Head of the Vine Breeding Department and the leader of the breeding programme. He has a thorough knowledge of the special literature. With his good command of German, he has contributed to the promotion of Hungarian results abroad. He has established and maintained connections abroad to collect gene sources. His work involved breeding resistant, early-ripening vine varieties and wine grape varieties that are rich in colouring matters. In Hungary, he has done pioneering work in resistance breeding; in finding and using resistance gene sources; in organizing cross-combinations; in developing varieties; in evaluating new hybrids and in recognizing, popularizing, propagating and managing new resistant vine varieties at home and abroad. With his concept of resistance, he was far ahead of his time.

He used Franco–American hybrids (Seyve-Villard 12-375, Seyve-Villard 12-286) as resistance gene sources. He aimed at increasing the winter hardiness of buds, bud fertility, early fruit and wood ripening; the resistance to fungal diseases (powdery and downy mildew, grey mould); and quality. His resistant varieties are world famous. His breeding materials include several promising ones. In addition to that, he has also worked actively for the future of mankind. He has been awarded the Fleischmann and Mathiász prizes. He has a remarkable stamp collection of vine varieties and wineries. His released varieties include the *V. vinifera* hybrid, Turán. His resistant (PIWI) varieties include Aletta, Bianca, Göcseji Zamatos, Medina, Nero, Viktor and Zalagyöngye.

Pál Kozma (1920–) (Figure 6.4(g)). Kozma is an agricultural engineer, and he was a teacher at a special secondary school for viticulture and oenology in Tarcal and Kecskemét/Miklóstelep from 1947 to 1949. From 1949 until his retirement in 1990, he worked at the University of Horticulture in Budapest. From 1950 on, he was Dean of the Faculty of Viticulture. In 1960, he was appointed professor; in 1957–1965, he was Rector; in 1965–1971, he was Vice-Rector; and in 1977–1983, he was Rector of the university. In addition to his organizing and managing activities, he was deeply engaged in viticulture. He studied the flower biology of grapevines under different ecological conditions in several wine regions (Furmint, Kadarka, Szőlőskertek Királynője Muskotály, etc.). He profited from his results in his selection work. He worked out a clone-type selection method, which has been patented. He set up the Propagation Supervisory Board to support national selection. In the second half of his career, he published variety studies and variety descriptions. He developed approximately 600 hybrid families by crosses, and he set up the breeding strategies. In his wine and table grape varieties, he combined yield reliability with early-ripening and quality traits. He achieved remarkable results in resistance breeding. He wrote numerous books and scientific articles dealing with vine physiology and breeding results, including *Vine Breeding* (1951), *Table Grapes* (1961) and *The Flower-Biological Basics of Vine Fertility* (1963). Since 1973, he has been an ordinary member of the Academy of Sciences. He takes an active part in public life. His released clone is Kadarka Kt.3. His released varieties include the table grapes Kozma Pálné Muskotály and Palatina (PIWI). His released wine grape varieties (PIWI) include Csillám and Viktória Gyöngye Duna Gyöngye, and his Eurasian varieties include Bíborkadarka, Mátrai Muskotály and Rubintos.

Sándor Szegedi (1921–1986) (Figure 6.4(h)). Szegedi was an agricultural engineer, Director and later Scientific Director of the Research Institute for Viticulture and Enology in Kecskemét from 1972 to 1977; a vine breeder; and a Mathiász prize winner. His work included study of the vine root system, intensive propagation experiments and organization of the research institute. As a vine breeder, he conducted clone selection, hybridization, mutation breeding (polyploidy) and resistance breeding of table grape varieties. He maintained and enriched the variety collection in Kecskemét (Katonatelep), which was founded by Johann Mathiász. This variety collection was his gene source for cross-breeding. His targets were in the breeding: to breed a variety collection, within varieties, which ripen from August up to middle of October, with big cluster and berries, nice colour, rich tests. In the last part of his life he preferred resistance breeding to breed resistant table grape varieties. The resistance source was Seyve Villard 12-735 E.2. His table grape varieties are popular and widespread. His released table grape varieties include the Eurasian hybrids Anna, Boglárka, Csilla, Emőke, Éva, Favorit, Kósa, Melinda, Narancsízű, Nóra and Téli Muskotály. His resistant hybrids include Esther, Fanny, Lidi, Pölöskei Muskotály and Teréz.

Károly Bakonyi (1921–2010) (Figure 6.4(i)). Dr Bakonyi was a horticultural engineer and a vine breeder. From 1947 onward, he was an agricultural crew leader, a technician and a practical course leader at the Horticultural Faculty of the University of Agriculture in Keszthely. He dealt with figs and *Pelargonium* from 1947 to 1950 under the supervision of Árpád Jeszenszky. He started vine breeding in 1949 using the variety Olasz rizling, which is grown extensively near Lake Balaton and everywhere in Hungary. He started the selection of Müller-Thurgau, Chasselas and Teleki rootstock varieties in the 1970s using clone selection methods. At the end of the 1950s, he began cross-selection to breed early, savoury and resistant varieties. For this purpose, he established a variety collection consisting of 165 varieties. He used few, but he very carefully thought up combinations with great success. Out of the *V. vinifera* L. varieties, he used Irsai Olivér, Red Traminer, Ezerjó, Olasz rizling, Juhfark and Pinot gris as gene sources. From among his new varieties, Cserszegi Fűszeres is grown on more than 3000 ha. The crosses of rootstock varieties began in 1970. At that time, early-ripening rootstock varieties of vigorous growth, with good affinity, good rooting ability and lime and drought tolerance were in demand. In his crosses, *V. vinifera* L. varieties were used to increase rooting and lime tolerance. His variety candidate was Helikon Szépe. His long, assiduous and successful breeding activity was honoured by numerous rewards (e.g. Magyar Gyula Grand Prix and the Fleischmann Rudolf prize). He has a long list of publications. His released clones include Chasselas blanc K.16, Chasselas rouge K.18, Olasz rizling GK.1 and Müller-Thurgau K.2, K.3. His released wine grape varieties include Cserszegi Fűszeres, Korona, Nektár, Pátria, Rozália and Pelso. His released rootstock is Georgikon 28.

György Kriszten (1923–2003) (Figure 6.4(j)). Dr Kriszten was a horticultural engineer, a senior research fellow, faculty dean and a grape breeder. He was an assistant lecturer at the Department of Viticulture at the Horticultural University of Budapest. He later became a lecturer at the Department of Horticulture of the Agricultural University in Gödöllő. For a few years, he worked as a researcher in the Research Institute for Viticulture and Enology in Tarcal. He then worked at the College of Horticulture in Gyöngyös. He began his breeding work in Tarcal with the clonal selection of the varieties Furmint and Hárslevelű. He crossed the old traditional varieties of Tokaj-Hegyalja (Gohér, Kövérszőlő). He domesticated the grape vine variety Királyleányka jointly with Márton Németh. In the early 1970s, the aim of his crosses was to produce resistant hybrids. He was the first in Hungary to cross three *Vitis* species (*V. amurensis* Rupr., *V. vinifera* L. and French–American hybrid S.V. 12-375). His hybrid candidates were C.43 (Crystal) and C.50 (Toldi) with a high resistance level to downy mildew, powdery mildew, rot and winter frost. Before his retirement, he bred some resistant and seedless hybrids.

András Kurucz (1924–1976) (Figure 6.4(k)). Kurucz was a horticultural engineer, a senior research fellow in the Research Institute for Viticulture and Enology in Kecskemét and a vine breeder. In addition to irrigation and the intensive propagation of vine, he was interested in vine breeding. He dealt with the development of Eurasian-based intraspecific hybrids. He wanted to improve yield reliability and the quality of the old varieties (Hungarica) extensively grown between the Danube and the Tisza rivers. He was successful in combining the maternal varieties of Ezerjó, Hárslevelű, Kadarka and Kövidinka with the paternal varieties of Red Traminer and Pinot gris. He bred wine grape varieties and established model stock plantations of the most promising hybrids. He was the first in Hungary to use microvinification to evaluate the winery values of the variety candidates. He worked with his colleague, István Kwaysser. They made considerable genetic progress in bud fertility, early ripening, the sugar and acid contents of berries and the resistance to rot; they improved the colouring matter and wine quality in red wine varieties. His varieties are grown on several hundred hectares in the country. He left a valuable hybrid population legacy. Several interesting variety candidates have been selected from it. His released wine grape varieties include Ezerfürtű, Jubileum 75, Karát and Kármin.

István Koleda (1926–2001) (Figure 6.4(l)). Dr Koleda was a horticultural engineer with a Ph.D. in agricultural sciences. After leaving horticultural secondary school, he continued his studies in the Soviet Union and he graduated from university there. He was deeply engaged in plant genetics. He worked at the Department of Plant Heredity and Breeding of the University of Horticulture in Budapest. In addition to teaching, he dealt with plant breeding under the direction of Faculty Dean, István Tamássy. His breeding strategy was based on his theoretical knowledge. His aim was to increase frost tolerance and to foster a short growing period, early ripening and resistance to downy mildew. For this purpose, he used *V. amurensis* as a gene source. He crossed it with *V. vinifera* varieties. The hybrids were tested for frost tolerance in climate chambers. He studied the inheritance of the characters with special respect to frost and disease resistance. He has left an extraordinary rich gene material behind in his hybrid families. The evaluation of his hybrids is still going on. His released variety is Kunleány.

József Füri (1932–1988) (Figure 6.5(a)). Dr Füri was a horticultural engineer, a senior research fellow in the Research Institute for Viticulture and Enology in Kecskemét and head of the department. He devoted his life to viticulture. In addition to technological research (cultural and pruning methods, water and nutrient regimes, irrigation), he adapted new propagation methods to propagate clones and new varieties. He was an active vine breeder. He was a disciple of Pál Kocsis, whose varieties and hybrids are described in the book *The Giant of the Sand* (1977) by Sándor Illés. First, he dealt with the production, transport, storage and marketing of table grapes. He started clone selection in 1957. He evaluated his clones in randomized trials of multiple replications. It was he who began the resistance breeding of table grapes in Kecskemét. He learned the method from Jozsef D. Csizmazia in Eger. He selected his hybrids under field conditions for resistance to fungal diseases. Because of his foreign connections, he renewed and extended his variety collection consisting of varieties of Mathiász, Kocsis and Szegedi. His released clones include Cegléd Szépe K.73, Irsai

Figure 6.5 Hungarian grape breeders: (a) József Furi, (b) Ottokár Luntz, (c) László Nagy, (d) Ervin Kiss, (e) Edit Hajdu, (f) Pál Kozma Jr, (g) János Korbuly and (h) László Kócsis.

Olivér K.11 and Hárslevelű K.9, and his released resistant wine grape variety (PIWI) is Refrén.

Ottokár Luntz (1930–2001) (Figure 6.5(b)). Dr Luntz was an agricultural engineer, a senior research fellow and department head as well as a breeder and a variety maintainer. He started his breeding career in Budapest at the Board of Wood Propagation Supervision where he worked with Professor Pál Kozma on the clone-type selection of vine including the selection of wine grape varieties that are extensively grown in the country (Ezerjó, Kékfrankos, Kékoportó). He later supervised stock plantations in the National Institute for Agricultural Quality Control. He started a new period in the history of the Research Institute for Viticulture and Enology. He worked in Budapest from 1971 on and then in Kecskemét in 1982–1990, until his retirement. He organized virus-tested stock plantations composed of varieties and clones bred in or adapted for the whole country; he established a virus-free stock plantation network on nearly 100 acres and supervised the propagation of the new varieties and clones. He was a member of the Variety Qualification Council as well as a member of official wine judging boards. He was also a co-breeder of several released varieties and clones. His released clones include Kékoportó Kt.1 and Kékfrankos Kt.2. Varieties and clones adapted from abroad include Blauburger, Kerner, Zweigelt, Müller-Thurgau D.100, Zöld Veltelini 133, Chasselas blanc Fr. 38-95 and Chasselas rouge Fr. 36-28.

László Sz. Nagy (1934–) (Figure 6.5(c)). Dr Nagy is an agricultural engineer, a teacher, an associate professor and a vine breeder. After graduation, he worked as teacher and research worker in the Faculty of Viticulture at the University of Horticulture in Budapest. He dealt with technological trials, variety descriptions and cultural and winery quality evaluations as well as with breeding. In the beginning, he worked with Professor Kozma. Since his retirement, he has been working independently, dealing mostly with breeding and evaluating resistant hybrids. He is regularly invited by the National Institute for Agricultural Quality Control to take part in the work of the Qualification Committee. He takes an active part in variety evaluations and wine tasting. From among his materials, his seedless individuals deserve special attention. He is the co-breeder of the released wine grape varieties Csillám, Mátrai Muskotály, Viktória Gyöngye and Duna Gyöngye and the table grape varieties Kozma Pálné Muskotály and Palatina. His own released table grape variety is Millennium.

Ervin Kiss (1935–) (Figure 6.5(d)). Kiss is a horticultural engineer, a senior research fellow and head of a research station. After graduating in 1958, he worked as a trainee first on the state farm of Tokaj-Hegyalja, then at the Research Institute for Viticulture and Enology in Mór/Csókakő (in 1959–1960). From 1960 to 1995, he worked for the Research Institute for Viticulture and Enology in Badacsony at Lake Balaton. He is a member of several professional organizations. Because of his versatility, he has been a very active participant in viticultural research, including cultural technologies (cultural and pruning methods, the control of weeds, mulching, etc.) and the quality evaluation of wine grape varieties. He is an excellent wine taster. He has worked for decades mostly as an independent vine breeder on the selection breeding of varieties grown in the region around Lake Balaton. He played an important role in the evaluation of hybrids when working with the vine breeder, Ferenc Király. He made his breeding results known in his lectures and in several publications. His released clones are Olasz rizling B.5, B.14 and B.20 and their subclones Pinot gris B.10 and Rajnai rizling B.7. He is a co-breeder of the released new varieties Zefir Zengő, Zenit, Zéta, Zervin, Pintes Rózsakő and Vulcanus.

Edit Hajdu (1949–) (Figure 6.5(e)). Dr Hajdu is a horticultural engineer, a special engineer for breeding, a senior research fellow, department head, a vine breeder and a Mathiász János and Fleischmann Rudolf prize winner. After graduation (1972), she started to work in the Research Institute for Viticulture and Enology in Kecskemét. She first worked with Sándor Szegedi on table grape breeding using crosses and polyploidy and variety quality research. Succeeding József Füri, she continued the clone selection of table grape and wine grape varieties. Succeeding András Kurucz, she then carried on the cross-selection of wine grape varieties. She worked on the clone selection of Muscat Ottonel, Chardonnay, Kadarka and Rajnai Rizling. The maintenance of the gene bank with 1500 genotypes has been one of her responsibilities in Kecskemét. She leads micro-vinification trials. She takes part in wine tastings organized in different wine regions of Hungary. Since 1994, she has been working as a viticultural research leader. She aims at developing varieties giving reliable yield (frost tolerant, rot resistant) and high-quality wine (*V. vinifera* L. hybrids). In Kecskemét, she is in charge of evaluating her predecessors' breeding materials. With her breeding team, she evaluates 30,000 seedlings, 450 micro-clones and 75 middle plots. She analyses the heredity of characters in hybrid populations. She conducts national variety trials and develops variety collections. She does her best to promote the introduction of the resistant varieties in viticulture. She is writing the ampelography of the new vine varieties. Her scientific results have been published in articles and books.

She is a co-breeder of the released clones Irsai Olivér K.11 and Hárslevelű K.9 as well as several virus-free rootstock clones. Her own clones are Kövidinka K.8 and Pannónia Kincse K.56. Her released table grape varieties are Anna, Csilla, Emőke, Éva, Melinda and Nóra; among them are the PIWI varieties Esther, Fanny and Lidi. Her own released white wine grape varieties are Generosa, Gesztus, Szirén and Trilla.

Pál Kozma Jr (1952–) (Figure 6.5(f)). Dr Kozma is a horticultural engineer, a special engineer in breeding, an associate professor, a senior fellow researcher, department head, director, vine breeder and a Fleischmann Rudolf Prize winner. After graduating, he worked as an assistant lecturer in the Faculty of Plant Breeding and Genetics in Budapest. He taught genetics and heredity. He dealt with vine breeding under the guidance of Professor Koleda. From 1977 onward, he worked in the Research Institute for Viticulture and Enology in Kecskemét, then in Eger and later as director in Pécs. He assisted Sándor Szegedi with breeding table grapes. As head of the department, he was responsible for organizing research activities and for resistance breeding. He renewed the variety collection of the Institute in Kecskemét (Katonatelep), and he expanded it mostly with Russian varieties. He joined the rootstock breeding and phylloxera-resistance breeding programmes in Keszthely. From 1980 onward, he was also involved in crossing resistant wine grape varieties in co-operation with Russian, Yugoslavian and Czech partners (Kisinov, Novocherkassk, Novi Sad, Lednice). He has developed numerous hybrid families using several vine species (*V. vinifera* L., *V. amurensis* Rupr., *V. rotundifolia* L. and French–American hybrids). He worked intensively on the clonal selection of Kadarka. He was a co-breeder of the following released varieties: Csilla, Esther, Fanny and Kósa Georgikon 28. His released clones are Olasz rizling SK.54; Furmint P.26, P.27 and P.51; Red traminer P.13; Merlot P.102; Sauvignon blanc P.1, P.25 and P.130; Zengő P.122; and Zenit P.104. His variety Kozmopolita (in co-operation with Novi Sad) was released in Yugoslavia. Several of his resistant hybrids are before qualification. In addition to cross-breeding, he deals with gene analysis. His primary aim now is to breed varieties that are resistant to powdery mildew. For this purpose, he is working on a pyramidal programme.

János Korbuly (1954–) (Figure 6.5(g)). Dr Korbuly is a horticultural engineer, a vine breeder and department head. After graduating, he started teaching and conducting research in the Faculty of Plant Breeding and Heredity of the University of Horticulture in Budapest. He acquired his knowledge of plant genetics and the heritability of characteristics under the guidance of István Koleda. His experience proved to be useful when he later started to work independently. He took part in the evaluation of hybrid families bred within the faculty. Since 1980, he has been planning his cross-combinations himself. He has developed and evaluated nearly 25,000 seedlings. He aims at increasing the resistance to fungal diseases and frost. He uses the species *V. amurensis* Rupr. and its hybrids as gene sources. He is a co-breeder of several hybrids; some of them are under qualification. His released resistant (PIWI) white wine varieties include Odysseus, Orpheus and Taurus. His released resistant (PIWI) red wine varieties include Korai Bíbor and Pannon Frankos, and his released resistant (PIWI) table grape varieties include Csépi Muskotály, Borostyán and Pegazus.

László Kocsis (1963–) (Figure 6.5(h)). Kocsis was born in Zalaegerszeg in 1963. He is an agricultural and horticultural engineer. He has been a lecturer in the Department of Horticulture of the Georgikon Faculty in Keszthely since 1988. His fields of research are viticulture and grape breeding, especially rootstocks. He got involved in grapevine breeding and conducted research in this field in the second half of the 1980s. In the beginning, he was involved in the evaluation of grape rootstock seedling populations; later on, he participated in cross-breeding and clone selection of white wine and red wine varieties. He inspired the seedless table grape-breeding programme at the beginning of the 1990s with his concept of breeding a seedless variety imported from Israel. He started his own grape rootstock breeding programme in the Georgikon Faculty in 1998 aiming to increase lime and drought tolerance, meanwhile keeping phylloxera resistance at a high level. He started the clone selection of the Italian Riesling and Cserszegi Fűszeres. He launched a new breeding programme in 2003 with the main goal to obtain aroma-rich white wine grapes that are resistant to downy and powdery mildew and provide high crop security. He is also a private breeder, owner of the private company The Fruit of Göcsej. His new candidate varieties are on trial in several wine regions of Hungary. Thus far, he has been a co-breeder of the following state-certified varieties: Georgikon 28 rootstock, Berl. × Rip. Teleki 5C GK40 rootstock clone; Korona, Pelso white wine cultivars, Olasz rizling GK18 and GK37 white wine clones. He is a co-breeder of a new red wine cultivar called Messiás, which has been notified for state recognition.

References

Bakonyi, K., Bakonyi, L., Kocsis, L., 1996a. Alanynemesítés magyarországon. (Rootstock breeding in Hungary). Kertészet és Szőlészet 45 (47), 19.

Bakonyi, K., Bakonyi, L., Kocsis, L., 1996b. Teleki-féle alanyfajták sorsa. (Fortune of rootstock varieties of Teleki). Kertészet és Szőlészet 45 (48), 21–22.

Bakonyi, K., Bakonyi, L., Kocsis, L., 1997. Hungary's Rootstock Breeding Pioneer. Celebrating Zsigmond Teleki. Wine Growing, California.

Bakonyi, K., Bakonyi, L., 2002. History and results of rootstock breeding in Hungary. Int. J. Hort. Sci. 8 (1), 47–50.

Bakonyi, K., Kocsis, L., 2004. Teleki Zsigmond Élete és Munkássága. (Life and Activity of Sigismund Teleki). VE. Georgikon Mezőgazdasági Kar, Keszthely, 64 pp.

Bakonyi, K., Kocsis, L., 2006. Két Évszázad Az Oktatás és a Kutatás Szolgálatában. (Two Centuries in Service of Education and Research). P.E. Georgikon Mezőgazdasági Kar., Keszthely, 119 pp.

Csepregi, P., Zilai, J., 1955. Szőlőfajtáink (Ampelográfia). (Our Vine Varieties (Ampelography)). Mezőgazdasági Kiadó, Budapest, 386 pp.

Csepregi, P., Zilai, J., 1989. Szőlőfajta-Ismeret és Használat. (Knowledge and Use of Vine Varieties). Mezőgazdasági Kiadó 508, 396–403.

Csizmazia, J., Romenda, R., Holló, R., Misik, S., 1994. Breeding of new resistant, polyvitis trihybrid grape varieties in Eger. In: Proc. Int. Vit. Symp. on Grape Breeding, Yalta, pp. 159–165.

Domonkos, J., 1889. Kossuth szőlő. (Kossuth vine variety). Gyümölcsészeti és Konyhakerti Füzetek 10, 258–260.

Domonkos, J., 1900. Csaba Gyöngye. (Pearl of Csaba). Gazdasági lapok, Budapest, 852 pp.

Fabricius, E., 1921. A magyar növénynemesítés. (Hungarian plant breeding). Pátria Irodalmi Vállalat és Nyomdai Rtl 316, 164–179.

Füri, J., 1977. Kocsis Pál szőlőfajtáinak és hibridjeinek rövid leírása. (A short description of Paul Paul Kocsis's vine varieties and hybrids). pp. 151–185. In: Sándor, I. (Ed.), A Homok Óriása. Kocsis Pál Életregénye. (Giant of Sandy. Biographical Novel of Paul Kocsis). Mezőgazdasági Könyvkiadó, Budapest, 186 pp.

Goethe, H., 1887. Handbuch der Ampelographie. 2. Aufl. Verlagsbuchhandlung Paul Parey, Berlin. vol. 539, pp. 55–87.

Hajdu, E., 1993. Szőlőfajták Klónszelekciója. (Clonal Selection of Vine Varieties). Kandidátusi értekezés, MTA. vol. 192, 5 pp.

Hajdu, E., 2000. A csemegeszőlő-nemesítés története Magyarországon. (History of table grape varieties in Hungary). Milleneumi szőlős-boroskönyv. A Szőlő és Bor Magyarországon. Agroinform 459, 213–221.

Hajdu, E., Bakonyi, K., 2006. A szőlőalany-nemesítés és eredményei hazánkban. (Results of rootstock breeding in our country). Kertgazdaság 38 (3), 25–32.

Hajdu, E., 2002. Magyar Szőlőfajták (Hungarian Vine Varieties). Mezőgazda Kiadó, Budapest, vol. 258, pp. 27–221.

Hajdu, E., 2012. Magyar Szőlőfajták. (Hungarian Vine Varieties). Mezőgazdasági Kiadó, Budapest, 464pp.

Hajósné Novák, M., 1999. Genetikai Variabilitás a Növénynemesítésben. (Genetic Variability in Plant Breeding). Szőlészeti Mezőgazda Kiadó, Budapest, 142pp.

Haydu, Z., 2002. Experiences on the research and the practical application of micropropagation of grapevine (*Vitis* spp.) in Hungary. Int. J. Hort. Sci. 8 (1), 65–68.

Hegedűs, Á., Kozma, P., Németh, M., 1966. A szőlő (The vine). Akadémiai Kiadó, Budapest, vol. 325, pp. 183–193.

Kapás, S., 1969. Magyar Növénynemesítés. (Hungarian Plant Breeding). Akadémia Kiadó, Budapest, 758 pp.

Kocsis, P., 1958. Újabb szőlőfajták. (Renewed vine varieties). Kutatóintézet Évkönyve 11, 327–334.

Kocsis, P., 1963. Újabb Szőlőfajták és Szőlőfajtajelöltek. (Renewed Vine Varieties and Candidates). Szőlészeti Kutatóintézet Évkönyve, 12, 125–132.

Korbuly, J., 2002. Invaluable traits of *Vitis amurensis* (Rupr.) for grapevine resistance breeding. Int. J. Hort. Sci. 8 (1), 51–56.

Kozma, P., 1951. A Szőlő Nemesítése. (Breeding of the Vine). Mezőgazdasági Kiadó. 268, 87.

Kozma, P., 1957. Így Szelektáljuk a Kadarkát. (The Way to Select the Kadarka.) FM. Egyetem Nyomda, Budapest, 36pp.

Kozma, P., 1961. A Csemegeszőlő. (The Table Grape). Mezőgazdasági Kiadó, Budapest, 453 pp.

Kozma, P., 1966. A Szőlő Nemesítése. (Breeding of the Vine), pp. 183–193. In: Hegedűs, Á., Kozma, P., Németh, M. (Eds.), A Szőlő Akadémia Kiadó, Budapest, 325 pp.

Kozma Jr., P., 2002. Goals and methods in grape resistance breeding in Hungary. Int. J. Hort. Sci. 8 (1), 41–46.

Kriszten, G., 1990. A szőlő keresztezéses nemesítésében végzett munkáim. (My works in hybridization of vine). Szőlőtermesztés és Borászat 12 (3–4), 26–28.

Luntz, O., 1990. A klónszelekció hazai helyzete és eredményei. (National situation and results of clonal selection). Szőlőtermesztés és Borászat 12 (1–2), 2–7.

Németh, M., 1958. A szőlő klónszelekciós nemesítéséről. (About clonal selection of the vine). Agrártudomány 43–49.

Németh, M., 1968. Az Olasz rizling alfajtái tekintettel a tetraploidokra. (Subcultivar of vine variety Olasz rizling considering tetraploidy). Az Országos Szőlészeti és Borászati Kutató Intézet Évkönyve 13, 159–190.

Németh, M., 1975. Ampelográfiai Album. Alany-, Direkt Termő és Csemegeszőlő-Fajták. (Ampelography Album. Rootstock, Direct-Producer and Grape Varieties). Mezőgazdasági Kiadó, Budapest, 358 pp.

Schmid, J., Manty, F., Lindner, B., 2009. Geisenheimer rebsorten und klone. (Geisenheim grape varieties and clones). Geisenheimer Berichte 67 (156), 124–133.

Schöffling, H., Stellmach, G., 2003. Klon-Züchtung bei Weinreben in Deutschland. (Clonal Selection of Winegrapes in Germany). Waldkirchen Verlag, Waldkirch. 818 pp.

Szegedi, S., 1968. A szőlőnemesítés eredményei az Országos Szőlészeti és Borászati Kutatóintézet 70 éves 'Mathász János' kísérleti telepén. (Results of grape breeding in 70 year-old Mathiász János Research Station of the National Research Institute for Viticulture and Enology). Az Országos Szőlészeti és Borászati Kutató Intézet Évkönyve 13, 201–227.

Szabó-Jilek, J., 1970. (manuscript). 70 év a Szőlészeti és Borászati Kutató Intézet Múltjából (1898–1968). (70 Years from Past of the Research Institute for Viticulture and Enology (1898–1968)), vol. 80. SZBKI, Budapest, pp. 55–56.

Szegedi, S., 1975. Poliploid Nemesítés és Indukált Tetraploid *Vitis vinifera* L. Fajták Katonatelepen. (Polyploid Breeding and Induced Tetraploidy in *Vitis vinifera* L. Varieties in Katonatelep), vol. 447. Szőlészet és Borászat, Budapest.

Tomcsányi, P., 1969. Gyümölcs- és szőlőnemesítés. 4. A szőlő nemesítése. (Fruit- and vine breeding 4. Breeding of the vine). pp. 660–690. In: Kapás Sándor: Magyar Növénynemesítés. Akadémia Kiadó, Budapest. 758 pp.

Teleki, Z., 1900. Berlandieri. Borászati Lapok, Budapest, 40 pp.

Teleki, Z., 1901. Berlandieri Fajtákról. (About the *Berlandieri*-Varieties). Borászati Lapok, Budapest, 36 pp.

Teleki, Z., 1902. Az Amerikai Alanyvesszők Helyes Megválasztása Pécsett. (Correct selection of American rootstock canes in Pécs).

Teleki, Z., 1906. Az Amerikai Alanyfajokról. (About the American Rootstock Species). Borászati lapok, Budapest, 33 pp.

Teleki, A., 1910. Néhány Szó a Teleki-féle Riparia X Berlandieriről. (Some Words about the *Riparia* X *Berlandieri* Hybrids of Teleki). Borászati Lapok, Budapest, 18 pp.

Teleki, A., 1927. Der Moderne Weinbau. Die Rekonstruktion der Weingarten. Wien und Leipzig.

Teleki, A., Teleki, S., 1927. Vita a Berlandieri × Riparia Teleki 5. Számú Elnevezése Körül (Discussion around nomenclature of *Berlandieri × Riparia* Teleki 5). Borászati Lapok, Budapest, 4 pp.

Teleki, A., Teleki, S., 1927, 1928, 1936. A Szőlő Felújítása (1.2.3 Kiadás). (Renovation of Viticulture (1.2.3 Issue), Budapest.

Tóth, I., 2002. Development of varietal use in Hungary. Int. J. Hort. Sci. 8 (1), 69–73.

Váry, I., 1940. Mathiász jános. pp. 61–88. In: Kecskemét Th. Város Kiadása. 240 pp.

Appendix: Hungarian ampelographies in chronological order

Andrasovszky, J., 1926. Ampelográfiai (Ampelographic studies). Amp. Int. Évkönyve 8, 107–134.

Csepregi, P., Zilai, J., 1955. Szőlőfajtáink (Ampelográfia) (Our Vine Varieties (Ampelography)). Mezőgazdasági Kiadó, Budapest, 386 pp.

Csepregi, P., Zilai, J., 1973. Szőlőfajtáink (Our Vine Varieties). Mezőgazdasági Kiadó, Budapest, 271 pp.

Csepregi, P., Zilai, J., 1989. Szőlőfajta-Ismeret és Használat. (Knowledge and Use of Vine Varieties). Mezőgazdasági Kiadó, Budapest, 508 pp.

Hajdu, E., Ésik, A., 2001. Új Magyar Szőlőfajták. (New Hungarian Vine Varieties). Mezőgazda Kiadó, Budapest, 170 pp.

Hajdu, E., 2002. Magyar Szőlőfajták. (Hungarian Vine Varieties). Mezőgazda Kiadó, Budapest, 258pp.

Hajdu, E., 2012. Magyar Szőlőfajták (Hungarian Vine Varieties). Mezőgazda Kiadó, Budapest, 464 pp.

Katona, Z., 1951. Szőlőfajtaismeret (Knowledge of Vine Variety). Egyetemi Jegyzet, Budapest,

Kosinszky, V., 1948. Fajtaismeret (Knowledge of Variety).

Kozma, P., 1961. In: A Csemegeszőlő (The Table Grape), pp. 303–402. Mezőgazdasági Kiadó, Budapest, 453pp.

Molnár, I., 1897. Szőlőművelés és Borászat Kézikönyve (Handbook of Viticulture and Enology).

Németh, M., 1966. Fontosabb Szőlőfajták (The Most Important Vine Varieties), pp. 221–257. In: Hegedűs, Á., Kozma, P., Németh, M., Szőlő, A. (Eds.), Akadémia Kiadó, Budapest. 325 pp.

Németh, M., 1967. Borszőlőfajták Határozókulcsa (Key to Determining Wine Grape Varieties). Mezőgazdasági Kiadó, Budapest, 240pp.

Németh, M., 1970. Ampelográfiai Album Termesztett Borszőlőfajták 2. (Ampelographic Album. Grown Wine Grape Varieties 2). Mezőgazdasági Kiadó, Budapest, 272 pp.

Németh, M., 1974. Régi Magyar Szőlőfajták (Old Hungarian Vine Varieties). Mezőgazdasági Kiadó, Budapest.

Németh, M., 1975. Ampelográfiai Album. Alany-, Direkt Termő és Csemegeszőlő-Fajták (Ampelographic Album. Rootstock-, Direct Producer and Table Grape Varieties). Mezőgazdasági Kiadó, Budapest, 358 pp.

Pettenkoffer, S., 1930. Szőlőművelés (Viticulture). pp. 47–130. Pátria Irod. Váll. és Nyomdai RTV, 431 pp.

Grapevine breeding programs in Italy

7

L. Bavaresco[1,2], *M. Gardiman*[1], *L. Brancadoro*[3], *L. Espen*[3], *O. Failla*[3], *A. Scienza*[3], *S. Vezzulli*[4], *L. Zulini*[4], *R. Velasco*[4], *M. Stefanini*[4], *G. Di Gaspero*[5,6], *R. Testolin*[5,6]
[1]CRA-Centro di Ricerca per la Viticoltura (CRA-VIT), Conegliano, Italy; [2]Istituto di Frutti-Viticoltura, Università Cattolica S. Cuore, Piacenza, Italy; [3]Università degli Studi, Milano, Italy; [4]Research and Innovation Centre, Fondazione Edmund Mach, San Michele all'Adige, Italy; [5]University of Udine, Udine, Italy; [6]Istituto di Genomica Applicata, Udine, Italy

7.1 Introduction

Grape breeding (crossing and hybridization) has been actively conducted in Italy since the end of 1800. In the Vitis International Variety Catalogue (VIVC, www.vivc.de), more than 800 varieties obtained by Italian breeders are listed. Most are table grapes, but there are several wine varieties and rootstocks (Table 7.1). Among the most prolific Italian breeders worth mentioning are Alberto Pirovano (released 273 varieties – more than 120 table grapes), Federico Paulsen (95), Giovanni Dalmasso (93), Antonio Ruggeri (80), Clemente Grimaldi (70), Bruno Bruni (64), Vincenzo Prosperi (40) and Italo Cosmo (23) (VIVC – Vitis International Variety Catalogue, www.vivc.de). Despite the high number of crosses produced, only a few of them have commercial importance. Table 7.2 lists the rootstock and wine varieties registered in the Italian National Catalogue of Grapevine Varieties.

7.1.1 Major Italian rootstock breeders

Historically, special attention has been devoted to rootstock breeding, which has been a priority since the arrival and spread of phylloxera, which was first found in 1879 at Lecco and Agrate (Milan Province). The government took a long series of initiatives for the cultivation and use of American species and supplied cuttings and seeds, along with subsidies, to winegrowers. In addition, the government issued strict rules for the propagation of the vine, founded the first American vine nurseries (1881) and sent young graduates to Montpellier (France) to attend training courses (Fregoni and Bavaresco, 1986; Di Lorenzo and Sottile, 2000).

In July of 1885, the governmental grape nursery of Palermo was established, where **Federico Paulsen** (1861–1943) started in 1889 the hybridization of American species, looking for new hybrid rootstocks not only resistant to the pest but also suitable to the soils and climate of Sicily. Paulsen mainly used as the parent *Vitis berlandieri* for its resistance to limestone (i.e. high pH), adaptation to drought environments and for the

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00007-7

Table 7.1 The number of grape varieties obtained by Italian breeders

Use	Variety no.
Table grape	225
Rootstock	173
Wine grape	105
Wine grape/table grape	20
Not specified	315
Total	838

VIVC – Vitis International Variety Catalogue, www.vivc.de.

potential of its root system, which allows easy development even in heavy soils, as those typical of Sicily. The most famous rootstocks are *V. berlandieri* × *Vitis rupestris* hybrids nos. 775, 779 and 1103, obtained between 1894 and 1897.

In the same period, **Antonio Ruggeri** (1859–1915), Director of the Royal Experimental Vineyards of Spadafora – Milazzo (Messina – Sicily), began another breeding program (starting from 1895) that produced the hybrid 140 Ruggeri (*V. berlandieri* × *V. rupestris*), one of the most drought-tolerant rootstocks. Other hybrids in the group (*V. berlandieri* × *Vitis riparia*) obtained by Ruggeri are nos. 225, 240 and 300, which are less known and widespread.

Although the most impressive results were achieved in Sicily, the whole country was involved in the post-phylloxera viticulture reconstruction. Other scientists contributed to the production of new rootstocks, such as **Domizio Cavazza** (between 1888 and 1891) at the School of Viticulture and Oenology in Alba, several agronomists at the School of Avellino, **Clemente Grimaldi** (1882) in Modica, **Ercole Silva** (since 1893) and **Girolamo Persi** in Asti, **Corrado Montoneri** in Noto, **Angelo Longo** in Velletri, and **Giuseppe Rebora** in Novi Ligure. Other breeders worked at the nurseries of Acqui, Cagliari, Macon, Nicastro and Palmi and at the Schools of Viticulture and Oenology of Cagliari, Conegliano, Catania, etc. (Fregoni and Bavaresco, 1986).

In the first decade of the twentieth century, Alberto Pirovano (1884–1973), a famous breeder of fine table grape varieties, obtained two interesting new rootstocks by crossing Castel 15-612 and Rupestris du Lot: Gagliardo and Golia. The first is more similar to *V. riparia* and is suitable for deep and fresh soil whereas the second is quite similar to *V. rupestris* by being extremely vigorous and tolerant to drought.

Vincenzo Prosperi (1875–1955) was interested mainly in the production of new table grape varieties, but during his stay at the Royal Nursery of American Vines in Barletta (1903–1924) he devoted himself to the creation of hybrid rootstocks suited to the climatic conditions of Puglia. After the production of thousands of new vines and a comparative study pursued for nearly 30 years, the result of his work was the release of the hybrids 16-108 and 16-113 (*V. riparia* × *V. rupestris*), 17-118 (*V. riparia* × *V. berlandieri*) and 11-71 and 11-73 [*V. berlandieri* × (*V. riparia* × *V. rupestris*)].

After World War II, **Bruno Pastena**, Director of the Governmental Nursery of American Vines from 1968 to 1973, released the Pastena hybrids nos. 1 (1147P × 420A), 2 (1447P × 775P), 3 (1447P × 779P) and 4 (1447P × 140Ru). **Italo Cosmo** (1905–1980)

Table 7.2 **List of rootstock and wine varieties obtained by Italian breeding programs registered in the Italian National Catalogue of Grapevine Varieties (2014)**

Variety	VIVC number	Pedigree[a]	Breeder	Colour	Use	Year of crossing	Year of registration in the national catalogue
1045 Paulsen	9018	Berlandieri Resseguier 2 × Ganzin 1	F. Paulsen		R	1896	1971
1103 Paulsen	9023	Berlandieri Resseguier 2 × Rupestris du Lot	F. Paulsen		R	1895	1971
140 Ruggeri	10351	Berlandieri Resseguier 2 × Rupestris	A. Ruggeri		R	1896	1971
1447 Paulsen	9037	Berlandieri Resseguier 2 × Rupestris Martin	F. Paulsen		R	1896	1971
225 Ruggeri	10362	Berlandieri × Riparia	A. Ruggeri		R	1895	1971
775 Paulsen	9007	Berlandieri Resseguier 2 × Rupestris du Lot	F. Paulsen		R	1894	1971
779 Paulsen	9008	Berlandieri Resseguier 2 × Rupestris du Lot	F. Paulsen		R	1894	1971
Albarossa	239	Chatus × Barbera	G. Dalmasso	N	W	1938	1977
Bric	1677	Barbera × Nebbiolo	G. Dalmasso	N	W	1937	1977
Bruni 54	1721	Aleatico × Lacrima	B. Bruni	N	W	1936	1971
Bussanello	1914	Riesling Italico × Furmint	G. Dalmasso	B	W		1977
Celtica	23017	Riesling Italico × Chardonnay	M. Fregoni, A. Vercesi	B	W	1989	2010
Cornarea	2839	Barbera × Chatus	G. Dalmasso	N	W	1936	1977
Cosmo 10	2870	Berlandieri × Riparia	I. Cosmo		R	1931	1971
Cosmo 2	2866	Berlandieri × Riparia	I. Cosmo		R	1931	1971
Cove’	2808	Harslevelue × Harslevelue	G. Dalmasso	B	W	1936	1977
Ervi	17654	Barbera × Croatina	M. Fregoni	N	W	1970	1999

Continued

Table 7.2 Continued

Variety	VIVC number	Pedigree[a]	Breeder	Colour	Use	Year of crossing	Year of registration in the national catalogue
Fedit 51	4069	Garganega × Malvasia del Chianti	FEDIT	B	W	1951	1976
Fertilia	4112	Merlot × Raboso Veronese	I. Cosmo	N	W	1960s	1976
Flavis	4144	Verdiso × Riesling Italico	I. Cosmo	B	W	1960s	1976
Fubiano	4275	Furmint × Trebbiano	G. Dalmasso	B	W	1936	1977
Goldtraminer	10081	Garganega × Traminer	R. Rigotti	B	W	1947	2002
Golia	4886	Castel 156-12 × Rupestris du Lot	A. Pirovano		R	1913	1971
Gosen	10090	Carmenere × Teroldego	R. Rigotti	N	W	1950	2002
Iasma Eco 1	(–)	Teroldego × Lagrein	FEM	N	W	1993–1994	2014
Iasma Eco 2	(–)	Teroldego × Lagrein	FEM	N	W	1993–1994	2014
Iasma Eco 3	(–)	Moscato Ottonel × Malvasia Bianca Aromatica	FEM	B	W	1993–1994	2014
Iasma Eco 4	(–)	Moscato Ottonel × Malvasia Bianca Aromatica	FEM	B	W	1993–1994	2014
Italica	5584	Verdiso × Riesling it.	I. Cosmo	B	W	1950	1976
M1	(–)	106/8 × Resseguier No. 1	University of Milan		R	End of 1980s	2014
M2	(–)	Teleki 8B × 333 E.M.	University of Milan		R	End of 1980s	2014
M3	(–)	R 27 × Teleki 5C	University of Milan		R	End of 1980s	2014
M4	(–)	41B × Resseguier No. 1	University of Milan		R	End of 1980s	2014

Manzoni 2.15	7359	Cabernet franc × Glera (formerly known as Prosecco)	L. Manzoni	N	W	1924–1930	1970
Manzoni bianco	7360	Riesling Renano × Pinot blanc	L. Manzoni	B	W	1930–1935	1978
Manzoni moscato	22897	Raboso Veronese × Moscato d'Amburgo	L. Manzoni	B	W	1930–1935	2003
Manzoni rosa	7357	Traminer × Trebbiano Toscano	L. Manzoni	Rs	W	1924–1928	2003
Merlese	22990	Merlot × Sangiovese	C. Intrieri	N	W	1983	2007
Nebbiera	8416	Chatus × Barbera	G. Dalmasso	N	W	1936	1977
Nigra	8554	Merlot × Barbera	I. Cosmo	N	W	1950	1976
Passau	8965	Dolcetto × Chatus	G. Dalmasso	N	W	1936	1977
Pliniana	23032	Riesling Italico × Pinot nero	M. Fregoni, A. Vercesi	N	W	1989	2010
Prodest	9720	Merlot × Barbera	I. Cosmo	N	W	1960s	1976
Rebo	9961	Merlot × Teroldego	R. Rigotti	N	W	1948	1978
S. Martino	10671	Chatus × Dolcetto	G. Dalmasso	N	W	1936	1977
S. Michele	10672	Chatus × Barbera	G. Dalmasso	N	W	1936	1977
Sennen	10087	Merlot × Teroldego	R. Rigotti	N	W	1948	2002
Sirio	11832	Verdiso × Maddalena Reale	G. Dalmasso	B	W	1938	1977
Soperga	12083	Chatus × Barbera	G. Dalmasso	N	W	1937	1977
Star 50	(–)	Binova × Binova	C. Intrieri		R	1990	2014
Star 74	(–)	Binova × Binova	C. Intrieri		R	1990	2014
Terzi 1	12385	Barbera × Merlot	R. Terzi	N	W		1970
Valentino nero	12872	Chatus × Dolcetto	G. Dalmasso	N	W	1936	1977
Vega	12926	Furmint × Malvasia Istriana	G. Dalmasso	B	W	1936	1977
Virgilio	23044	Riesling Italico × Pinot nero	M. Fregoni, A. Vercesi	B	W	1989	2010

(–) Not yet included in VIVC. B, blanc; N, noir; Rs, rose; W, wine; R, rootstock.
[a]VIVC – Vitis International Variety Catalogue. www.vivc.de (accessed 09.12.14).

at the Experimental Station for Viticulture at Conegliano (TV) selected from Teleki 8B (*V. berlandieri* × *V. riparia*) two new rootstocks: Cosmo 2 and Cosmo 10.

In a breeding program started in 1990 at the University of Bologna, **Cesare Intrieri** obtained two new interesting genotypes from self-pollinated Binova – Star 50 and Star 74 – with good resistance to phylloxera and lime-induced chlorosis and with low vigour (Intrieri et al., 2013). These two rootstocks were registered in 2014 in the national catalogue.

7.1.2 Major Italian wine grape breeders

In the 1900s, the main breeding programs for wine grapes were conducted in northern Italy (Piedmont, Veneto and Trentino-Alto Adige) aiming to obtain new types of grapes with adaptability to the local environments. In 1924, **Luigi Manzoni** (1888–1968) began in Conegliano (Royal Experimental Station of Viticulture) a first series of crosses between *Vitis vinifera* varieties. In his breeding work, Manzoni used as parents the most popular red and white grape varieties grown in Northeast Italy. The most remarkable new varieties released by Manzoni were the crossing nos. 2.15 (Manzoni 2.15: Prosecco × Cabernet Sauvignon), 1.50 (Manzoni rosa: Traminer × Trebbiano Toscano), 6.0.13 (Manzoni bianco: Riesling × Pinot blanc) and 13.0.25 (Manzoni Moscato: Raboso Piave × Moscato d'Amburgo) (Cancellier and Roncador, 1997). A recent study (Lacombe et al., 2013) suggests that 2.15 is actually a crossing between Mathiasz Janosne and Kövidinka.

In 1931, **Giovanni Dalmasso** (1886–1976) started at Conegliano a breeding program to improve some wine varieties of Northeast Italy, crossing them with famous varieties from Hungary. From this work were released the crosses nos. XII/37 (Bussanello: Riesling Italico × Furmint), II/26 (Vega: Furmint × Malvasia Istriana), X/12 (Sirio: Verdiso × Maddalena Reale) and XIII/11(Covè: Hárslevelü × Malvasia Trevisana). It has recently been suggested that Covè is the result of self-pollination of Hárslevelü (Cipriani et al., 2010). Another breeding program was later continued at the University of Turin (1936–1938). Dalmasso used as parents the best wine varieties from Piedmont (Barbera, Nebbiolo, Dolcetto) with the objective to create intermediate types combining the qualitative aspects with fertility and rusticity. In recent times, it was discovered that the supposed Nebbiolo used as a parent was in reality Chatus, locally called Nebbiolo di Dronero. The most interesting wine varieties obtained were the crosses nos. XV/31 (Albarossa: Chatus × Barbera), XVII/25 (Passau: Dolcetto × Chatus) and IV/28 (Cornarea: Barbera × Chatus) (Fregoni and Bavaresco, 1986; Gribaudo and Gay Eynard, 2000; Schneider et al., 2001; Mannini et al., 2010).

In the 1930s, **Riccardo Terzi** (1877–1963), a private grape breeder, was active in Bergamo (North Italy). The main result of his work was a crossing of Barbera and Cabernet franc, named Incrocio Terzi no. 1, interesting for the high productivity and the intense colour of the wine. It has recently been discovered that the true pedigree is Barbera × Merlot (Cipriani et al., 2010).

At the Experimental Station of Agriculture and Forestry of S. Michele all'Adige (TN), **Rebo Rigotti** (1891–1971) carried on his breeding work starting in 1920. Among the hundreds of crosses produced, the most interesting was the Rigotti 107-3

(Merlot × Marzemino) or Rebo, obtained in 1948. Other interesting Rigotti crosses are 84-11 (Goldtraminer: Trebbiano Toscano × Traminer), 107-2 (Sennen: Merlot × Marzemino) and 123-4 (Gosen: Cabernet franc × Marzemino). Lately, it has been discovered that the Marzemino used by Rigotti was in reality Teroldego and Cabernet franc was Carmenère (Malossini et al., 2000; Roncador et al., 2002).

Bruno Bruni was working in the Marche region at the Provincial Consortium for Viticulture (Jesi-Ancona). Most of his crossings were created between 1933 and 1948, although he worked until the 1970s. The most interesting release was Incrocio Bruni no. 54 (Sauvignon × Verdicchio), obtained in 1936. In a recent study, the grape's parentage was suggested to be Aleatico × Lacrima (Cipriani et al., 2010).

After World War II (1950), at the Experimental Institute for Viticulture at Conegliano (TV), **Italo Cosmo** (1905–1980) continued the work of Dalmasso. The most interesting wine varieties released by Cosmo were the crosses nos. 76 (Flavis: Verdiso × Riesling Italico), 96 (Nigra: Merlot × Barbera), 103 (Italica: Verdiso × Riesling Italico), 108 (Fertilia: Merlot × Raboso Veronese) and 109 (Prodest: Merlot × Barbera).

More recently, in 1970, a group led by **Mario Fregoni** at Università Cattolica Sacro Cuore of Piacenza started a breeding program to cross Barbera and Croatina with the aim to obtain a variety for the production of Gutturnio, the most important red wine of Piacenza (Emilia-Romagna region) made with Barbera and Croatina. The progeny selection concluded in 1995 with the characterization of a new genotype (I.F. 108) that was named Ervi. This variety combines the quality of both parents, overcoming the problem of the low bud fertility of Croatina (Gribaudo and Gay Eynard, 2000; Zamboni and Fregoni, 2000). Another breeding program led by Fregoni aimed to obtain new grapes suitable for méthode Champenoise sparkling wines. Using Pinot noir, Chardonnay, Riesling Italico and Trebbiano Toscano as parents, in 1989 Celtica (Riesling Italico × Chardonnay), Virgilio (Riesling Italico × Pinot nero) and Pliniana (Riesling Italico × Pinot nero) were obtained. The productivity of these crosses is higher than that of their parents and the qualitative characteristics are very promising (Vercesi et al., 2014).

At the University of Bologna in 1983, **Cesare Intrieri** bred Merlese by crossing Merlot and Sangiovese (Intrieri et al., 2007a, 2007b). Merlese is a black variety of medium vigour with good basal bud fertility and good productivity (slightly less than Merlot). It has some improved characteristics compared with the parents, including looser clusters that are less susceptible to fungal diseases, early ripening than Sangiovese and higher anthocyanin content.

At Fondazione Edmund Mach – San Michele all'Adige (TN), a breeding program started in 1993 obtained the black varieties Iasma Eco 1 and Eco 2 (Teroldego × Lagrein) and the white varieties Iasma Eco 3 and Eco 4 (Moscato Ottonel × Malvasia Bianca Aromatica). These four varieties were registered in 2014 in the national catalogue. Iasma Eco 1 and 2 are characterized by a good resistance against Botrytis bunch rot, high content of anthocyanins and total polyphenols and a good sugar–acid ratio. Iasma Eco 3 and 4 are interesting for the production of fresh, light aromatic white wines, and in the case of Eco 4 also for late-harvest wines (Tomasi et al., 2014). Breeding programs also included a

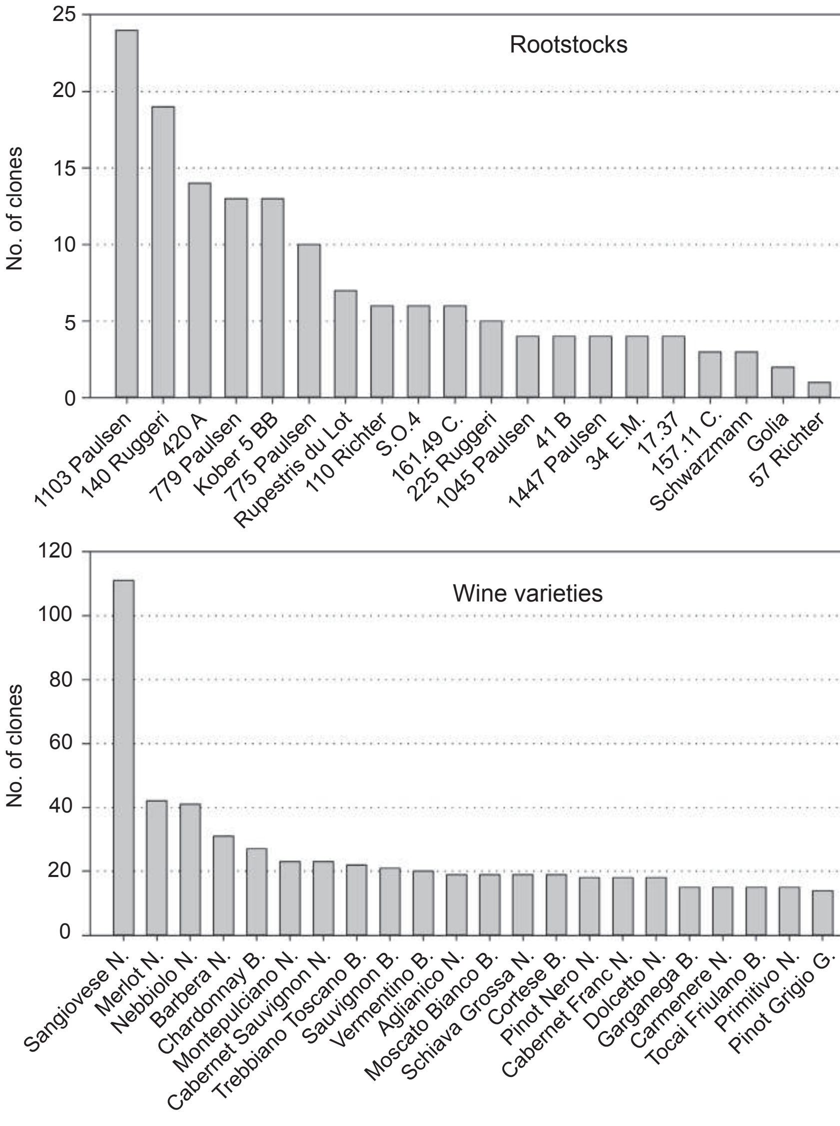


Figure 7.1 Wine grapes and rootstock clones registered in the Italian Catalogue of Vine Varieties (2014).

clonal selection, which began in Italy in the 1970s and produced many clones (Figure 7.1) involving many public and private institutions. Selection criteria changed with time, without prejudice to the sanitary aspect, emphasizing at the beginning the productive parameters and moving toward qualitative aspects in recent decades.

7.2 The major ongoing grapevine breeding programs in Italy

In Italy, three major breeding programs related to rootstocks and wine grape varieties are currently in progress:

- a program for breeding rootstocks mainly for tolerance to drought and active limestone, led by the University of Milan;
- a program to create new wine grape varieties resistant to downy (DM) and powdery mildew (PM; by introgression of resistance in *V. vinifera* background) and to improve quality traits (by intra-specific crossing of autochronous and international cultivar) led by the Research and Innovation Centre at Fondazione Edmund Mach (FEM) S. Michele all'Adige; and
- a program to obtain a wine variety resistant to DM and PM, crossing high-quality wine varieties with disease-resistant varieties, led by the University of Udine.

These programs are detailed in the following paragraphs.

7.2.1 Grapevine rootstock breeding for tolerance to water and nutritional stresses through the development of physiological and molecular markers

The progress of physiology and genomic studies in the role of roots in the regulation and functioning of the vegetative and reproductive processes of the canopy has opened new perspectives in recent years. Such perspectives concern the genetic improvement of rootstocks, which are considered not just for their resistance to phylloxera or lime-induced iron chlorosis but also for their ability to influence the interactive relationship between the vine and the different growing environments. In the nineteenth century, when the arrival of phylloxera forced the Europeans to graft vines on US rootstocks, 'traditionalists' saw such practice as an adulteration of the purity and quality of the wine produced from European vines. This is no longer the case, to the extent that even in those countries where phylloxera is not a threat, growers prefer to graft vines for their new vineyards and are developing programs aimed at genetic improvement to create rootstocks suitable for the different soil features of their vineyards. There is a steady growth of phytosanitary emergencies, which are caused by nematodes carrying viruses and parasites, by root rot and by the consequences of climate change on the availability of water and increase of salt in the soil. All of these emergencies show that the existing rootstocks are no longer adequate to the grower's needs and stress the importance to create new genotypes with new resistance to biotic and abiotic stresses.

The improvement of the adaptability is not the only goal – it is also important to develop rootstocks that are able to reduce energetic needs such as the use of fertilizers by using the great variability of the different *Vitis* species in the selective uptake of several mineral elements to reduce the risk of deficiencies and excesses that could, in the case of nitrogen, encourage fungal diseases, especially *Botrytis*.

Contemporary viticulture has been highly delocalized in other continents with pedo-climatic features that can hardly be compared to the European ones. Hence, they need rootstocks with particular features. Although the availability of rootstocks in viticulture is very high (≈90) at the moment, no more that five or six are extensively used by growers worldwide. They are selected mainly because they are robust (resistant to water stress and lime-induced chlorosis) and because they are easy to propagate: this feature is very important for the nursery business.

In this framework, a project is currently in progress: 'AGER-SERRES: Selection of new grape rootstocks resistant to abiotic stresses through the development and validation of physiological and molecular markers'. The project, led by the University of Milan, aims at the following experimental objectives:

- Evaluating the performance of four new genotypes (M series) obtained toward the end of the 1980s to face water stress in the quantitative and qualitative response of several grape varieties in different Italian wine-growing areas with critical pedo-climatic situations (Table 7.3).
- Establishment of molecular markers for the early diagnosis (marker-assisted selection (MAS)) of new genotypes that have recently been obtained and that are currently being phenotypically evaluated for tolerance to restricted water availability, high levels of salinity in the soil and iron chlorosis.

7.2.1.1 The research strategy of the AGER-SERRES project

To understand how the cellular functions are dynamically organized to react to stress, and which adaptations are activated both at the metabolic and phenotypic level, we should adopt a specific research strategy that is based on complex and multi-disciplinary experiments that are able to produce the so-called 'omics' data, which enable analysis of the functioning of the plant as a system, considering all of its molecular components (DNA, RNA, proteins, metabolites, ions, etc.). This *system biology* approach relies on the development of *high throughput* technologies allowing the analysis and processing of large data sets.

The research strategy adopted by AGER-SERRES to individuate the characters (and so the genes) of tolerance to abiotic stress for the selection of new vine rootstocks is based on the comparison between the behaviour of two rootstocks – a tolerant and a susceptible one – to water, salt and iron chlorosis stress. The aim is to find the genes, or the group of genes, which are the regulation factors that explain the adaptation to stress in the two rootstocks, even as far as timing is concerned: the speed and the length of the response. Such molecules are the best candidates to be used as markers for the assisted selection of new rootstocks, which are tolerant to abiotic stress (Table 7.4).

7.2.1.2 The evaluation of tolerance to water deficit for the study of the association between phenotype and genotype

The process of selection of new rootstocks, resistant to environmental stresses, can highly benefit from the availability of molecular markers for early selection

Table 7.3 **The four rootstocks of the M series**

Rootstock	Mother parent	Father parent	Main features
M1	106/8 [*Vitis riparia* × (*Vitis cordifolia* × *Vitis rupestris*)]	Resseguier No. 1 (*Vitis berlandieri*)	Low vigour, high resistance to iron chlorosis and medium resistance to salt
M2	Teleki 8B (*V. berlandieri* × *V. riparia*)	333 E.M. (*Vitis vinifera* × *V. berlandieri*)	Medium vigour, good resistance to iron chlorosis and medium resistance to salt
M3	R 27 (*V. berlandieri* × *V. riparia*)	Teleki 5C (*V. berlandieri* × *V. riparia*)	Low vigour, high efficiency in potassium uptake, low resistance to salt
M4	41B (*V. vinifera* × *V. berlandieri*)	Resseguier No. 1 (*V. berlandieri*)	Medium or high vigour, optimal resistance to drought and high resistance to salt
			

of the offspring obtained by hybridization. To discover such markers, it is necessary to develop ‘phenotyping techniques’ of the response to the stress that is being considered. Moreover, the useful correlations between DNA markers and phenotype descriptors of the considered trait must be identified. In this specific case, a phenotyping technique has been developed that takes into account the genotypes’ response to the progressive water deficit and successive recovery in terms of growth and regulation of the stomatal activity. The latter is estimated through the modification of the temperature of the leaf blade. The method was tested during the 2012 season. Approximately 100 selected genotypes were tested, with the criterion to represent as wide a genetic variability as available (core collection).

Table 7.4 The phases of the AGER-SERRES Project

Phenotyping of rootstocks • Analysis of the growth of the leaves and of the roots • Recording of physiological parameters under normal condition and under stress
Transcriptional regulation • Genomic sequencing of three rootstocks with different stress tolerance • Transcriptomic analysis of the stress response • Epigenetic modifications • Micro-RNA
Study of the post-transcriptional regulation • Proteomics • Interactions DNA–proteins • Interactions protein–protein • Metabolic profile
Monitoring of the global dynamics of the whole biologic circuit
Identification of markers

7.2.1.3 Evidence of transcriptomics on the response of the vine to abiotic stress

Generally speaking, tolerance to stress takes place through physiological adjustments, which are activated after modification of the transcriptome. Such modifications occur in a differential way in the different organs of the plant. At present, there are very few papers that compare – under condition of stress – the root's transcriptome with the canopy's one to understand, from a molecular point of view, how the two organs cope with stress. The AGER-SERRES program uses the RNAseq approach to study the changes of the transcriptome in the roots and canopy of rootstocks tolerant (M1 and M4) and not tolerant (101-14) to water, salt and iron chlorosis stresses. It is possible by this way to identify genes that can be associated with tolerance mechanisms in the two organs. The genes can be used as markers in the assisted selection of new rootstocks. Moreover, always through RNAseq, we are in the process of estimating the effect of M4 on the overall quality of the berry.

7.2.1.4 Proteomics and metabolomics for the comprehension of biochemical and physiological mechanisms of adaptation ability to abiotic stress

The research schedules the comparison between the susceptible genotype 101-14 with the tolerant genotype M4 subject to progressive water stress cycles. By means of gas chromatography combined with mass spectrometry, we are characterizing metabolic profiles of the vegetal material obtained from the two genotypes. Data have permitted identification of over 100 candidate putative metabolites involved in the previously observed tolerance of the genotypes. A particularly important side of the research performed for this project was combining 'omics' analysis with physiologic and biochemical analysis to define in a detailed way the physiologic state of the different genotypes (i.e. to evaluate their capability to respond to water, salt and iron deficiency stress conditions). The resulting information, along with the available knowledge, is eventually used for the choice of possible candidate genes, for which a deep functional characterization is needed, performed by the means of vegetal model systems.

7.2.1.5 The contribution of root micro-RNA in the responses of the canopy to abiotic stress

There has been the identification of several micro-RNAs able to influence the resistance of the vine to drought and salt stress in two different genotypes – Cabernet Sauvignon and the rootstock M4 – through a sequencing of a new-generation (sequencing by oligonucleotide ligation and detection) and polymerase chain reaction quantitative analysis. Moreover, we are studying the genes that they regulate to understand the ones that act in response to stress and the way they are influenced by the presence of the relative micro-RNA.

A group of micro-RNAs has been identified, the expression of which is exclusive of one of the two studied genotypes. The small RNAs involved in the response to stress are codified by genes that could be important molecular markers for the selection of new rootstocks. Through breeding techniques, it will be possible to allow the expression of these small RNA in rootstocks with higher resistance to environmental stress. Moreover, micro-RNA could be transferred to the grafted varieties, introducing traits of resistance, without having to seek crossing procedures that could drive the loss of traits that are important for quality and that are contained in the grafted variety.

7.2.1.6 The genetic control of rootstocks of the M series in the uptake of mineral nutrients

The mineral nutrients (macro and micro) in leaves of vines grafted on different rootstocks in the vineyards, or potted under controlled nutrition conditions, have been evaluated. M1 and M3 have induced a minor vigour and a different efficiency in the uptake and transport of several mineral elements. In particular, M2 jointly increases the concentrations of magnesium and potassium. M3 shows higher levels of manganese and a significant reduction of nitrogen, which is visible in several vines with the presence of looser bunches. M1 highlights contents of boron, which are 50% higher compared with other genotypes, and it seems to be less sensitive to increments of potassium in the substrate. The in vivo and in vitro growth on substrates with limitative iron uptake conditions (high pH, presence of soluble lime, absence of iron) allows the highlighting in M1 of a major capacity to mobilize and uptake iron compared with 101-14. Moreover, several physiological markers have been identified for early diagnosis of tolerance to high levels of soluble lime.

7.2.2.7 Characteristic of roots and aptitude to grafting and rooting

Despite the pedological features of the soils in which the experiments have been performed, the development and distribution of the roots were substantially conditioned. M1 and M4 rootstocks showed less extended roots compared with M2, M3 and 1103P. A 30% increase in roots was estimated for M3 compared with 1103P. As far as the nursery side is concerned, M4 has produced more grafting wood compared with other rootstocks and particularly compared with M1, which proved to be the weakest. The yield of the grafted vines in the nursery proved to be good, with M1 showing a greater root development compared with other genotypes, especially compared with M4, which has numerous but very fine roots.

7.2.1.8 Behaviour of new rootstocks of the M series in several Italian growing environments

Since the beginning of 2000, several experimental vineyards have been established for the comparative analysis of vegetative and productive performance of rootstocks belonging to the M series (M1, M2, M3 and M4) compared with six commercial rootstocks among the most popular in Italian viticulture: 1103P, 110R, 140Ru, 41B, 420A and SO4. At the moment, there are over 10 experimental vineyards in many Italian regions, following an experimental plan that includes the cultivation of Cabernet Sauvignon as a common grape variety along with a regional grape variety that is different according to the location of each experimental site. Results highlight several differential behavioural characteristics of the M series compared with the traditional ones:

- the four new rootstocks, particularly M1 and M3, induce a medium or low vigour;
- M2, M3 and M4 enhance major sugar accumulation and M3 tends to retain a lower pH compared with other rootstocks; and
- M1 and M3 induce a higher capacity to accumulate polyphenols (anthocyanin and tannins).

Broadly speaking, the yielding performances of the new rootstocks are equal or superior to those of the traditional ones. In particular, the analysis of the stability of vegetative, productive and qualitative performance has highlighted (e.g. in relation to the accumulation of anthocyanin) the ability of the new genotypes to maintain results that are superior on average, even under the most constraining conditions (Figures 7.2 and 7.3). New selections have also maintained the ability to react positively in favourable conditions. In general terms, this behaviour highlights a good tolerance to environmental stress, which shows itself through processes of accumulation in the regular berries and that allows enhancement of less favourable environmental conditions, such as anomalous climatic patterns. In 2014, the rootstocks M1, M2, M3 and M4 were registered in the national catalogue.

7.2.1.9 Conclusions and perspectives

The goal of genomic analysis is to evaluate the physiologic and molecular mechanisms that are the bases of tolerance of the new rootstocks to abiotic stress and to diagnose (at seedling growth phase) early the genetic features of the individuals that can be used in future crossing cycles. This early diagnosis is efficient not only to select new genotypes but also to choose parents to be used in future breeding programs. The pyramidalization technique is very promising because a different parent is used every time and therefore the final crossing carries all the forms of biotic and abiotic resistance

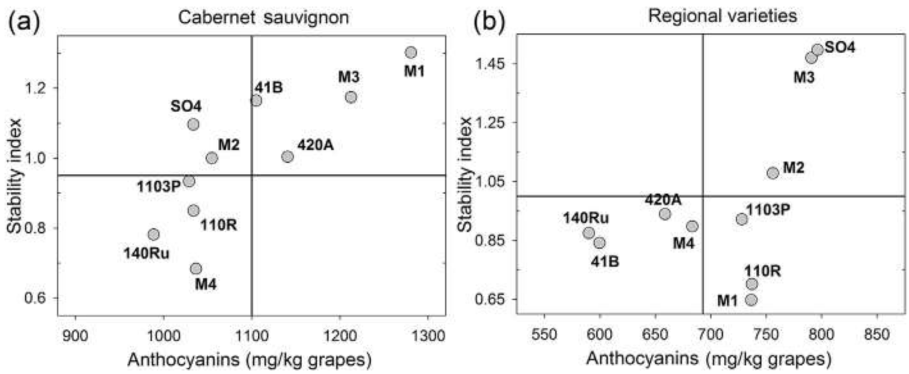


Figure 7.2 Mean and stability index of anthocyanins. The accumulation of anthocyanin in grapes is a qualitative index, which is highly important in the evaluation of agronomic performances induced by the rootstock. In the graphs, we can see the mean values recorded in a 4-year period in six experimental vineyards for (a) Cabernet Sauvignon and (b) regional varieties and the relative index of stability, which varies with the environmental conditions (vintage and location). All of the index values <1 highlight high stability, and all values >1 highlight reactivity to variations of environmental conditions. Rootstocks with the most interesting performance are those with values that are higher than average but that at the same time have stability indexes <1. These rootstocks, within the tested environments and vintages, have been able to allow good performances both in unfavourable and more favourable conditions. Other interesting rootstocks are those with values above average and indexes >1 because they have proved to be able to maintain good performances also in less favourable conditions and optimal performances in favourable conditions.

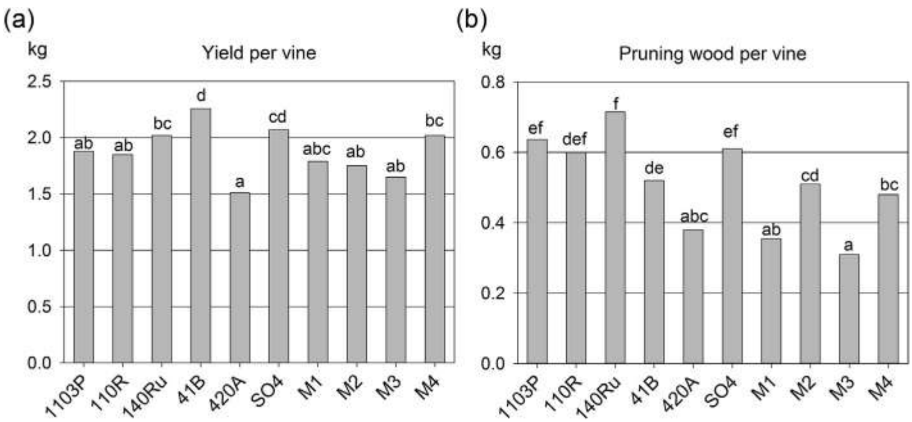


Figure 7.3 Production of grapes and evaluation of vigour (pruning wood). Vigour and productivity of the plant are with out doubt the two crucial aspects for the evaluation of the agronomic features of a rootstock. A relatively reduced vigour combined with a good productivity of the plant is a fundamental objective to achieve efficient vineyards with a high quality potential. The four rootstocks in the course of homologation are characterized by reduced to medium vigour and medium or higher than average productivity.

in the genus *Vitis*: this way one could have either one or few universal rootstocks. To choose the candidate parents every time, one needs the availability of fast and effective screening techniques. It is possible by this way to significantly reduce the generational interval and halve the required period to create a rootstock, passing from the current 20–25 years to 10–12 years.

7.2.2 The grapevine breeding program at the Edmund Mach Foundation

Grapevine breeding activity through crossing has been re-established at Fondazione Edmund Mach (FEM) in the mid-1980s thanks to the realization of a germplasm collection, encompassing at present 2273 accessions, lately genetically characterized with 22 common simple sequence repeat (SSR) and 384 single nucleotide polymorphism markers. This analysis identified 1085 unique genetic profiles, corresponding to 733 *V. vinifera* ssp. *sativa* varieties, 139 *V. vinifera* ssp. *sylvestris* accessions and 213 inter-specific hybrids of *Vitis*, including genotypes used for fruit production (86) and as rootstocks (127) (Table 7.5; Emanuelli et al., 2013).

This valuable genetic resource, the object of continuous investigation through ampelographic and molecular descriptors, allowed to straightforwardly choose the parental genotypes of a cross and to foresee if the seedling holds the potential to express peculiar phenotypic characteristics that are the objectives of the breeding. During the development of this long-time study, it is important to underline that

Table 7.5 Characterization of the four grape subpopulations identified within the entire FEM (Fondazione Edmund Mach) germplasm collection

Population	Accession analysed	Different simple sequence repeat (SSR) genotypes	SSR genotypes represented by one accession	SSR genotypes represented by two or more accessions	Average number of accessions with identical SSR genotype
Vitis vinifera sativa	1659	733	450	283	4.3
Vitis vinifera sylvestris	177	139	120	19	3.0
Hybrids	127	86	65	21	3.0
Rootstocks	310	127	78	49	4.7
Total	2273	1085	713	372	4.2

From Emanuelli et al. (2013).

because of the molecular marker analysis, the employed parental genotypes were verified and the accidentally occurring self-crossed individuals were identified.

Within the breeding program undertaken at FEM, the selection process has been based on the major need of innovation that arose from the grapevine growers. During past years, this request has been addressed to increase the complexity and the originality of wines, whereas in the last decade the need of new varieties resistant/tolerant to the abiotic and biotic stresses is emerging. To reach this goal, the germplasm collection is dynamic, continuously increasing its number of acquisitions. The FEM breeding activity currently follows two main motives: (1) the introgression of resistance/tolerance to the grape pathogens of primary importance (DM and PM) into *V. vinifera* background and (2) the increase of grape quality (including the aspect of the fruit development) as the most relevant final aspect to launch novel (resistant) varieties.

Disease resistance loci are present in U.S. *Vitis* species ($2n=38$) and in *Muscadinia rotundifolia* ($2n=40$) (Topfer et al., 2011). Various reports recently provided information on the resistant gene pool belonging to Asian species (Blasi et al., 2011; Schwander et al., 2011; Venuti et al., 2013). The FEM breeding program for disease resistances is based on two different approaches: pyramiding and pseudo-backcross (Table 7.6).

Pyramiding initially involves a cross performed between two resistant genotypes. In particular, *M. rotundifolia* (e.g. VRH3082-1-42), *V. rupestris* (e.g. Bianca) and *V. amurensis* (e.g. Solaris) are used as donors of resistant loci to DM (*Rpv*) whereas *M. rotundifolia* (e.g. VRH3082-1-42), *Vitis* spp. (e.g. Regent) and *V. vinifera* (e.g. Kishmish Vatkana) are used as donors of resistant loci to PM (*Run* or *Ren*). This resistant gene pyramiding approach currently relies on a hybrid strategy based on molecular marker screening coupled with phenotypic evaluation to validate the MAS system. In fact, through MAS it is possible to detect the progeny individuals carrying

Table 7.6 The 2010–2013 FEM breeding plan for DM and PM resistances

	Year	No. of cross combinations	No. of seeds	No. of seedlings
Pyramiding	2010	12	6742	2024
	2011	14	7181	2029
	2012	20	4816	1776
	2013	16		
Pseudo-backcross	2010	17	7555	1675
	2011	31	10,646	3505
	2012	29	7384	2584
	2013	43		
Resistances in table grape varieties	2010	2	576	154
	2011	2	376	110
	2012	3	187	78
	2013			

both resistant loci derived from each parental genotype, which can provide a durable resistance. Markers associated with the DM and PM resistance trait are currently derived from the literature; meanwhile, pedigree- and genomics-based research studies are ongoing to dissect the genetic basis of resistance in new genetic resources.

To evaluate DM resistance, either plant (in vivo) or leaf disc (in vitro) assay are performed according to the specific purpose. To perform both assays, a mixture of *Plasmopara viticola* (DM) spores is collected from natural infections in the FEM experimental field. Propagation of pathogen is conducted by spraying enough *V. vinifera* seedlings or cuttings with an inoculum suspension 1 week before the planned assay. For the in vivo DM phenotyping, fully expanded leaves of 8- to 10-week old plants are inoculated by spraying a conidial suspension of $10^4/10^5$ spores/mL onto the abaxial leaf surface and kept in an dedicated micro-greenhouse at 21°C with 100% relative humidity. At 7 days post-infection (dpi), the extent of sporulation on plants is assessed by visually estimating the percentage area of sporulation on the lower leaf surface of all infected leaves according to the European and Mediterranean Plant Protection Organization (EPPO) guidelines (EPPO, 1997). The magnitude of plant reaction and the level of sporulation per individual is simultaneously rated by a visual descriptor (code OIV452) recommended by the Office International de la Vigne et du Vin. For the in vitro DM phenotyping, two leaves from each genotype are detached from 10-leafed seedlings. For each leaf, two discs of 2-cm diameter are excised and placed with the abaxial surface up in Petri dishes covered at the bottom with dampened filter paper. Leaf discs are then infected under a hood by spraying a fresh spore suspension of 10^5 spores/mL and incubated in growing chamber at 21 °C and a photoperiod of 16/8 h (light/dark, respectively) for 6 days (Peressotti et al., 2011). Assessment of disease progress on leaf discs is done following two different methods: (1) visual evaluation of spore quantity, mycelium extension and necrosis presence according established disease classifications (code OIV452) at 4 and 6 dpi and (2) evaluation of the percentage of the leaf disc surface covered by pathogen sporulation through visual assessment and image analysis at 4 and 6 dpi. Regarding the evaluation of PM resistance, tested plants are kept for 10–15 days in the presence of grapevines with abundant symptoms of *Oidium tuckeri* (PM) infection. Evolution of disease is made by visual evaluation on the upper surface of all leaves using a four-class classification (class 1, no visible symptoms; class 2, lower presence of symptoms; class 3, medium presence of symptoms; class 4, high presence of symptoms). Assessments are repeated every 3 days. At present, several tens of F1 genotypes carrying DM and PM resistances are present at FEM. These superior genotypes represent pre-breeding products that will be used as a donor of durable resistances in subsequent breeding programs also taking into account quality traits. In particular, they can be used in cross plants with table and/or juice grape varieties to obtain plants that also ensure a sustainable viticulture in these sectors.

In a pseudo-backcross, a cross between a susceptible variety and a resistant hybrid is initially performed. In particular, the *V. vinifera* varieties most adapted to the Trentino-Alto Adige *terroir* and several DM and/or PM resistant hybrids of different geographical origin are used. At present, several hundreds of F1 genotypes carrying DM and/or PM resistances are present at FEM and can be addressed either to the phenotypic evaluation (as described above) for a straightforward employment in the traditional breeding process as a putative novel variety or to the successive back-crossing with various high-quality *V. vinifera* varieties. In this latter case, the goal is to create introgression lines in which the dilution of the *Vitis* spp. on behalf of the *V. vinifera* genome occurs with a selective and focused method based on the molecular detection of specific chromosome arms. In particular, the information derived from the Pinot noir ENTAV115 genome sequencing (Velasco et al., 2007) related to the presence of resistance gene analogue clusters along chromosomes 5, 7, 9, 12, 13, 15 and 18 will be exploited. This is a long-term objective that can be shortened by means of early-flowering genotypes and ad hoc agronomical practices.

During a grapevine breeding program, the quality cannot be evaluated earlier than 4–5 years from the cross and is strongly affected by environmental factors. It is also important to have available a suitable amount of grapes to perform optimized micro- and meso-winemaking. The FEM breeding program for quality traits (e.g. secondary metabolites) is based on specific strategies aimed at obtaining new cultivars with different aptitudes – for sparkling, white and red wine, and for table grapes. The FEM breeding program has been until now developed crossing two *V. vinifera* varieties chosen based on the agronomical performance and the grape quality. Overall, no selection method has been applied at the seedling stage. On the single plant in the field, the following selective criteria have been applied varieties adapted to medium-high altitude: late ripening for sparkling wine varieties, tolerance to grey mould (*Botrytis cinerea*), balance of acid–sugar content and good aroma and polyphenol composition for all wine varieties. Indeed, for table grape varieties the following characteristics have been searched: high berry size (weight), berry and rachis turgidity and seedlessness. Several hundred F1 genotypes are presently at a different level of selection and evaluation under greenhouse, tunnel or field conditions. Within the selection process of 15,000 seedlings coming from 50 intra-specific crosses, 200 genotypes have been chosen and put under evaluation of winemaking for four vintages. Of these 200, 20 genotypes have been selected as suitable for the registration to the Italian National Catalogue of wine grape varieties. Of these 20, four new selections have been requested to be registered to the Italian National Catalogue and to be patented as well. To register a new wine grape variety, it is necessary to write a document with its ampelographic and ampelometric description, the oenological description of its derived wine (minimum two vintages) and the list of the reference SSR allelic sizes (GENRES 081) for the varietal identification (fingerprinting). The identity card of these four FEM new selections has been provided to the appointed offices. This represents an important breakthrough toward the traceability and the protection of a new variety and allows it to be matched to its specific *terroir*, in which the same parental genotypes found the best adaptation and expressed their qualitative potential. Therefore, the breeding approach can increase biodiversity, producing innovation and putting the basis for an improved understanding of the genotype–environment interaction. At FEM, breeding for quality traits is presently still traditional, but a marker-assisted breeding approach is desirable for the future. In addition to the information available in the literature, this strategy can rely on the markers identified at FEM during the last decade associated with berry size and seedlessness (Costantini et al., 2008), monoterpene content (Battilana et al., 2009), muscat aroma

(Emanuelli et al., 2010), anthocyanin variation (Vezzulli et al., 2012) and flower sex (Battilana et al., 2013).

A global challenge for the grape industry is represented by the direct (temperature, precipitations, carbon dioxide concentrations) and indirect (management of resources, sustainability of productions, energetic efficiency) consequences of climate change. About this, grapevine varieties differ for the type and the speed of their physiological reaction to stress conditions and for the activation of adaptive mechanisms. An important goal of modern viticulture is to limit the yield fluctuation and the fruit organoleptic variation due to the change of climatic conditions. A possible solution is to choose different varieties and clones that are well adapted to a specific climatic range; regarding this aspect, the adoption of new rootstocks can play an important role.

7.2.3 University of Udine/IGA breeding program

A breeding program was launched in 1998 by the University of Udine with the aim of transferring mildew resistance from the introgression lines with the highest resistance in continental Europe (Germany, Hungary, Switzerland, Czech Republic, Serbia, Russia) into the background of cultivated varieties that could perform well in the Mediterranean climates of southern Europe. The University of Udine was committed to use only conventional methods of hybridization. Since 2006, the Institute of Applied Genomics joined this effort by providing advanced genotyping and sequencing platforms for the development and application of molecular markers that speeded up the selection for major resistance loci. Varieties of international and national interest (Chardonnay, Sauvignon blanc, Merlot, Cabernet Sauvignon, Sangiovese) and minor local varieties (i.e. Tocai Friulano) were crossed with the latest generation of resistant varieties released by breeding centres in continental Europe and advanced breeding lines made available by the Institute of Viticulture and Enology of Pecs (Hungary) and the University of Novi Sad (Serbia). Selection for disease resistance primarily focused on DM and secondarily on PM. Two major loci for DM resistance from North American and Asian donors were pyramided in the resistant varieties. Minor loci for PM resistance were donated by *Vitis* North American ancestors. To assist the selection, a major effort was dedicated to the identification of determinants of DM and PM resistance in the donors of the trait used in the breeding program. Molecular markers tightly linked to three major genes (REN1, Rpv3, Rpv12) were released and now allow grape breeders to distinguish the resistant haplotype from *V. vinifera* haplotypes, track it along generations, and guide the elimination of linkage drag around the introgressed gene in novel progeny (Coleman et al., 2009; Di Gaspero et al., 2012; Venuti et al., 2013). As of 2013, varieties with high oenological potential in northeastern Italy were selected from the resistant progeny of Tocai Friulano and Sauvignon blanc for the production of dry white wines and from the resistant progeny of Cabernet Sauvignon and Merlot for the production of red wines. The resistant varieties selected from Tocai Friulano produce wines with predominant norisoprenoids and terpenols that impart floral flavours. The wines of the resistant varieties selected from Sauvignon blanc highly resemble the typical aromatic of that parent and are dominated by thiols and methoxypyrazines. Resistant red varieties were selected with the oenological objective of producing fruity wines with the ability to age. The adaptability to different viticultural conditions of the new varieties is under investigation in multi-site agronomic trials using commercial-type vineyards across the country. A partnership was established with the nursery Vivai Cooperativi Rauscedo for the propagation and the distribution of certified plant material of the selected varieties. More recent breeding activity is focused on the pyramidization of multiple major genes using intercrosses of advanced introgression lines. In parallel, the medium-term objective of preparation of pre-breeding material with novel resistance specificities is pursued by backcrosses of wild accessions with a particular focus on the Asian germplasm of *V. amurensis*.

7.2.4 Other breeding programs

A breeding program for disease resistance began by CRA-VIT at Conegliano (TV) in 2012 by crossing two *V. vinifera* varieties of interest in the Veneto region of Northeast Italy (Glera, formerly known as Prosecco, and Raboso Piave) with new-generation disease-resistant hybrids (Bianca, Kunbarat, Solaris, Bronner, Regent). The seedlings are presently grown in a greenhouse and are under evaluation.

Acknowledgements

Part of this work has been supported by the AGER Project, grant no. 2010-2105. Scientific institutions involved in the AGER-SERRES Project include Università Degli Studi di Milano, Università Degli Studi di Padova, Università Degli Studi di Torino, Università Cattolica del Sacro Cuore – Piacenza, Consiglio per la Ricerca e la Sperimentazione in Agricoltura – Centro di Ricerca per la Viticoltura (CRA-VIT) Conegliano (TV), Fondazione Edmund Mach – San Michele All'Adige (TN) and Fondazione ENI Enrico Mattei – Milano.

References

Battilana, J., Costantini, L., Emanuelli, F., Sevini, F., Segala, C., Moser, S., Velasco, R., Versini, G., Grando, M.S., 2009. The 1-deoxy-d-xylulose 5-phosphate synthase gene co-localizes with a major QTL affecting monoterpene content in grapevine. Theor. Appl. Genet. 118, 653–669. http://dx.doi.org/10.1007/s00122-008-0927-8.

Battilana, J., Lorenzi, S., Moreira, F.M., Moreno-Sanz, P., Failla, O., Emanuelli, F., Grando, M.S., 2013. Linkage mapping and molecular diversity at the flower sex locus in wild and cultivated grapevine reveal a prominent SSR haplotype in hermaphrodite plants. Mol. Biotechnol. 54, 1031–1037. http://dx.doi.org/10.1007/s12033-013-9657-5.

Blasi, P., Blanc, S., Wiedemann-Merdinoglu, S., Prado, E., Ruhl, E.H., Mestre, P., Merdinoglu, D., 2011. Construction of a reference linkage map of *Vitis amurensis* and genetic mapping of Rpv8, a locus conferring resistance to grapevine downy mildew. Theor. Appl. Genet. 123, 43–53. http://dx.doi.org/10.1007/s00122-011-1565-0.

Cancellier, S., Roncador, I. 1997. Gli Incroci Manzoni. La Tipografica 2000, Treviso.

Cipriani, G., Spadotto, A., Jurman, I., Di Gaspero, G., Crespan, M., Meneghetti, S., Frare, E., Vignani, R., Cresti, M., Morgante, M., Pezzotti, M., Pe, E., Policriti, A., Testolin, R., 2010. The SSR-based molecular profile of 1005 grapevine (*Vitis vinifera* L.) accessions uncovers new synonymy and parentages, and reveals a large admixture amongst varieties of different geographic origin. Theor. Appl. Genet. 121 (8), 1569–1585. http://dx.doi.org/10.1007/s00122-010-1411-9.

Coleman, C., Copetti, D., Cipriani, G., Hoffmann, S., Kozma, P., Kovács, L., Morgante, M., Testolin, R., Di Gaspero, G., 2009. The powdery mildew resistance gene REN1 co-segregates with an NBS-LRR gene cluster in two Central Asian grapevines. BMC Genet. 10, 89. http://dx.doi.org/10.1186/1471-2156-10-89.

Costantini, L., Battilana, J., Lamaj, F., Fanizza, G., Grando, M.S., 2008. Berry and phenology-related traits in grapevine (*Vitis vinifera* L.): from quantitative trait loci to underlying genes. BMC Plant Biol. 8, 38. http://dx.doi.org/10.1186/1471-2229-8-38.

Emanuelli, F., Battilana, J., Costantini, L., Le Cunff, L., Boursiquot, J.M., This, P., Grando, M.S., 2010. A candidate gene association study on muscat flavour in grapevine (*Vitis vinifera* L.). BMC Plant Biol. 10, 241. http://dx.doi.org/10.1186/1471-2229-10-241.

Emanuelli, F., Lorenzi, S., Grzeskowiak, L., Catalano, V., Stefanini, M., Troggio, M., Myles, S., Martinez-Zapater, J.M., Zyprian, E., Moreira, F.M., Grando, M.S., 2013. Genetic diversity and population structure assessed by SSR and SNP markers in a large germplasm collection of grape. BMC Plant Biol. 13, 39. http://dx.doi.org/10.1186/1471-2229-13-39.

EPPO, 1997. Guidelines for the efficacy evaluation of plant protection products. EPPO Bulletin, 27, 385–387; OEPP/EPPO 1997.

Fregoni, M., Bavaresco, L., 1986. Il contributo italiano nel miglioramento genetico della vite. Proceedings fourth international symposium on grape-vine breeding, vol. XIII, Vignevini, pp. 1–6. 12.

Di Gaspero, G., Copetti, D., Coleman, C., Castellarin, S.D., Eibach, R., Kozma, P., Lacombe, T., Gambetta, G., Zvyagin, A., Cindrić, P., Kovács, L., Morgante, M., Testolin, R., 2012. Selective sweep at the Rpv3 locus during grapevine breeding for downy mildew resistance. Theor. Appl. Genet. 124, 277–286. http://dx.doi.org/10.1007/s00122-011-1703-8.

Di Lorenzo, R., Sottile, I., 2000. I portinnesti. Contributo della scuola italiana al progresso delle scienze vitivinicole, vol. 1, Accademia della vite e del vino, pp. 109–130.

Gribaudo, I., Gay Eynard, G., 2000. Il miglioramento genetico delle uve da vino e da tavola. Contributo della scuola italiana al progresso delle scienze vitivinicole, vol. 1, Accademia della vite e del vino, pp. 63–82.

Intrieri, C., Filippetti, I., Allegro, G., 2007a. Merlese un nuovo vitigno. Inf. Agrar. 11, 59–63.

Intrieri, C., Filippetti, I., Allegro, G.L., Ramazzotti, S., Colucci, E., Silvestroni, O., 2007b. Merlese: una nuova varietà da incrocio a bacca nera. Italus Hortus 14 (3), 72–76.

Intrieri, C., Filippetti, I., Allegro, G.L., 2013. Star 50 e Star 74, i nuovi portinnesti a ridotta vigoria. VQ – Vite, Vino & Qualità 6, 32–35.

Lacombe, T., Boursiquot, J.M., Laucou, V., Di Vecchi-Staraz, M., Peros, J.P., This, P., 2013. Large scale parentage analysis in an extended set of grapevine cultivars (*Vitis vinifera* L.). Theor. Appl. Genet. 126 (2), 401–414. http://dx.doi.org/10.1007/s00122-012-1988-2.

Malossini, U., Grando, M.S., Roncador, I., Mattivi, F., 2000. Parentage analysis and characterization of some Italian *Vitis vinifera* crosses. Acta Hortic. (ISHS) 528, 139–145.

Mannini, F., Cravero, M.C., Bonello, F., Marchese, E., Paravidino, E., Tragni, R., 2010. Caratterizzazione agronomica ed enologica della cultivar da incrocio intraspecifico 'Passau' per una utilizzazione commerciale. Quad. Vitic. Enol. Univ. Torino 31, 259–267 2009–2010.

Peressotti, E., Duchêne, E., Merdinoglu, D., Mestre, P., 2011. A semi-automatic non-destructive method to quantify grapevine downy mildew sporulation. J. Microbiol. Methods 84, 265–271. http://dx.doi.org/10.1016/j.mimet.2010.12.009.

Roncador, I., Malossini, U., Grando, M.S., Mattivi, F., Nicolini, G., Versini, G., 2002. Caratteristiche viti-enologiche dei nuovi vini Goldtraminer, Sennen e Gosen. Terra Trentina 10, 28–36.

Schneider, A., Carra, A., Akkak, A., This, P., Laucou, V., Botta, R., 2001. Verifying synonymies between grape cultivars from France and Northwestern Italy using molecular markers. Vitis 40 (4), 197–203.

Schwander, F., Eibach, R., Fechter, I., Hausmann, L., Zyprian, E., Topfer, R., 2011. Rpv10: a new locus from the Asian Vitis gene pool for pyramiding downy mildew resistance loci in grapevine. Theor. Appl. Genet. 124, 163–176. http://dx.doi.org/10.1007/s00122-011-1695-4.

Tomasi, T., Campestrin, A., Calovi, M., Visentin, M., Dalla Serra, M., Zatelli, A., Dorigatti, C., Clementi, S., Stefanini, M., Zulini, L., 2014. Nuove varietà di vite sostenibili: caratteristiche e utilizzo. Inf. Agrar. 45, 45–47.

Topfer, R., Hausmann, L., Eibach, R., 2011. Molecular breeding. In: Genetics, Genomics and Breeding of Grapes. Science Publisher.

Velasco, R., Zharkikh, A., Troggio, M., Cartwright, D.A., Cestaro, A., Pruss, D., Pindo, M., Fitzgerald, L.M., Vezzulli, S., Reid, J., et al., 2007. A high quality draft consensus sequence of the genome of a heterozygous grapevine variety. PLoS ONE 2, e1326. http://dx.doi.org/10.1371/journal.pone.0001326.

Venuti, S., Copetti, D., Foria, S., Falginella, L., Hoffmann, S., Bellin, D., Cindric, P., Kozma, P., Scalabrin, S., Morgante, M., Testolin, R., Di Gaspero, G., 2013. Historical introgression of the downy mildew resistance gene Rpv12 from the Asian species *Vitis amurensis* into grapevine varieties. PLoS ONE 8, e61228. http://dx.doi.org/10.1371/journal.pone.0061228.

Vercesi, A., Bavaresco, L., Fregoni, M., Zamboni, M., Gatti, M., 2014. Low-pressure selection for new grape crossings (Riesling italico × Pinot noir; Riesling italico × Chardonnay) . Acta Hortic. (ISHS) 1046, 211–218.

Vezzulli, S., Leonardelli, L., Malossini, U., Stefanini, M., Velasco, R., Moser, C., 2012. Pinot blanc and Pinot gris arose as independent somatic mutations of Pinot noir. J. Exp. Bot. 63, 6359–6369. http://dx.doi.org/10.1093/jxb/ers290.

Zamboni, M., Fregoni, M., 2000. Ervi, a new grapevine crossing between Barbera and Croatina. Acta Hortic. (ISHS) 528, 689–692.

Grapevine breeding programmes in Portugal

8

A. Martins, E. Gonçalves
Instituto Superior de Agronomia - ISA/University of Lisbon, Lisboa, Portugal

8.1 Introduction

Plant breeding involves selecting new cultivars with sets of traits that are genetically transmitted and well-adapted to the objectives of growers and consumers. These sets of traits often do not naturally exist. In these cases, breeding begins with an initial phase of creating genetic diversity through hybridisation and numerous other methods of gene recombination, followed by a second phase of genetic selection.

This plant breeding process is used for grapevines when breeding objectives include producing new cultivars of table grapes or cultivars that are resistant to biotic agents. However, in grapevine breeding for wine production, it is almost always possible to find sufficient natural variability among and within the numerous grape varieties cultivated along the Mediterranean coast (region of origin of the species *Vitis vinifera*) to meet all of the objectives of growers and winemakers. In this case, artificial creation of genetic variability is generally unnecessary, and grapevine breeding methods consist of mass and clonal selection of ancient varieties. In fact, wine production worldwide is today almost exclusively based on the cultivation of ancient grape varieties that have undergone mass and clonal selection. Therefore, in this chapter, we use the term ‘grapevine breeding’ in the narrower sense (i.e. to refer to mass and clonal selection of ancient varieties).

The effectiveness of mass and clonal selection of grapevine varieties essentially depends on two factors: (1) the existing diversity within an ancient variety (the raw material for selection) and (2) the methods used to evaluate that diversity and to objectively select superior genotypes. Our selection approach differs from the classic approach widely used in the world of wine production by recognising the importance of these two factors.

Recognising the importance of intra-varietal diversity of varieties means giving high priority to the quantification and clarification of their geographical distribution as a basic condition for effectiveness of selection. This contrasts with the classical approach, which involves selection without regard for maximising the indispensable genetic raw material. Our approach also prioritises the conservation of genetic diversity, which faces today a dramatic erosion pressure worldwide. Genetic conservation is critical for allowing for the continued selection of different traits to address new breeding objectives in the future.

Ensuring the adequacy of methods for genetic analysis and for efficient mass and clonal selection of varieties requires recognising that practically all of the traits to be

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00008-9

selected are quantitative traits for which the selection must necessarily follow the foundations of quantitative genetics. In contrast, the classical approach favours sanitary methods of selection, attributes less importance to genetic selection and disregards the possibility of obtaining high selection gains and new knowledge on ancient varieties.

In this chapter, we call attention to the need for a new integrated strategy of recognition, conservation and utilisation of the intra-varietal diversity of ancient varieties. We examine the feasibility of such an approach as an alternative to the current predominant strategy, which is focused on the short term and is based on selections with a narrow genetic base, which leads to an irreversible loss of genetic diversity and the demise of genetic selection itself. For this, we will follow the progress and results of the methodology developed in Portugal over the past 35 years. We begin with a short historical review of selection initiatives implemented since the 1940s (Section 8.2), which produced useful but short-lived results that did not significantly influence subsequent studies. Therefore, the work of mass and clonal selection started in Portugal in 1978 was initiated free of the weight of limiting traditions, which facilitated the recognition of the weaknesses of many empirical traditional methods, especially those arising from insufficient control of environmental deviations affecting quantitative traits to be selected, as described in Section 8.3.

Section 8.4 presents the new methodology, which is based upon more precise knowledge about the raw material for selection (intra-varietal diversity) and on the imperative use of the theory of quantitative genetics for better understanding and selecting quantitative traits. The results show that it is possible to reach a much higher level of selection efficiency than that observed in the past. In addition, this method produces new knowledge about the quantification of intra-varietal diversity and on the history of ancient grapevine cultivars and has the potential to contribute to genetic conservation efforts. With this new methodology, genetic selection is not performed for a single purpose alone, but instead forms part of a more comprehensive approach that comprises the use of diversity in a broader sense than traditional (rather than solely through selection) and their conservation for future use.

The integration of these multiple methods and objectives in a strategy for global conservation and valorisation of the diversity of autochthonous Portuguese varieties is discussed in Section 8.5. However, the conservation of genetic diversity is not a static process because genetic conservation is immediately followed by the evaluation of the conserved genotypes for several uses, including genetic selection. In Portugal, we have reached a point in which selection is no longer contributing to the loss of genetic diversity but is now a consequence of conservation efforts and is consistent with conservation goals. Lastly, in Section 8.6, we present the longer-term goals of this approach and the organisational, physical and informational support that guarantee its sustainability.

8.2 Early grapevine breeding efforts in Portugal

As is the case for many other wine-producing countries, Portugal has faced numerous crises and challenges in grape cultivation, including pests and diseases such as grape phylloxera, downy mildew and powdery mildew and the ‘degeneration’ of grape varieties, among others. In general, Portugal has overcome these crises through various experimental approaches that have also laid the foundation for where we are today with regard to selection and other developments in the field of genetic diversity of native vines.

We highlight three developments that are most directly associated with the problems addressed in this chapter. These include the creation of cultivars resistant to downy mildew by the School of Agronomy (Instituto Superior de Agronomia, ISA)/ University of Lisbon since the 1940s, the creation of new table and wine grape cultivars by the National Institute of Agrarian and Veterinarian Research (Instituto Nacional de Investigação Agrária e Veterinária, INIAV)/Ministry of Agriculture since the 1950s and the phenotypic mass selection of traditional varieties by the Ministry of Agriculture in the 'Vinhos Verdes' region since the 1960s.

8.2.1 The creation of cultivars resistant to downy mildew

After the problem of downy mildew arose in Europe near the end of the nineteenth century, various studies on cross-breeding of European varieties (*V. vinifera*) and U.S. resistant cultivars were performed in different countries (particularly in France). Although the resulting cultivars were also introduced in Portugal, they were not commonly used because of major shortcomings in their quality, except in certain specific contexts (e.g. Madeira Island).

In the 1930s, some researchers believed that it was possible to create another generation of *vinifera* × *vinifera* hybrids with disease resistance while maintaining the high-quality characteristics of European grapevines (Scherz, 1943; Husfeld, 1943). It was based on those ideas that emerged in the ISA at the beginning of the 1940s, a programme specifically for those purposes (Coutinho, 1950), which would continue until the early 1970s. During this period, much of the groundwork on the biology of downy mildew, fungus × host relationships and hybridisation support techniques was developed. Nearly 400 ancient grape varieties were characterised and classified into six resistance classes. On the basis of this characterisation and on the cultural and oenological importance of each cultivar, dozens of potential *V. vinifera* progenitors were selected, along with only one cultivar with a partially U.S. genetic base (a Couderc cultivar). The progenitors were used to perform more than 300 types of crosses that produced thousands of descendants. Additional descendants that resulted from self-fertilisation or open pollination were also obtained and were subjected to resistance evaluation and selection (Coutinho, 1950, 1964).

Various descendants that were considered resistant were subjected to a small-scale agronomic and quality assessment and some advanced to the phase of experimental cultivation, particularly on Madeira Island (e.g. C19 and C27). However, changes in the wine production market beginning in the 1970s, especially a greater appreciation of wine quality by the consumer and increased efficiency of chemical methods to counter downy mildew, decreased the demand for continuing this line of research.

In summary, the idea that exploring the natural diversity created over millennia within wine grape varieties could be more beneficial than trying to resolve viticulture problems by creating new diversity began to gain momentum. This was the guiding principle that led to the decline of sexual breeding for resistance in the ISA and gave rise to a new approach of mass and clonal selection. However, the behaviour of certain moderately resistant genotypes then obtained remained of interest as a future research topic.

8.2.2 The creation of new wine and table grape cultivars

The traits required for table grapes are found in low frequency in traditional ancient varieties. Therefore, a great effort has been made in many countries to create new cultivars by hybridisation. Portugal attempted to do this in the 1950s in INIAV with the objective of attaining higher precocity, high yields and high adaptation to the diverse cultivation conditions of the Portuguese territory in Europe and of the African colonies (Almeida, 1972). The creation of new wine grape cultivars also began at that time but is harder to explain because Portugal features an exceptionally high number of traditional cultivars (~250) in relation to planted area (~250,000 ha) and the country's total area (~89,000 km^2). Moreover, there are thousands of European ancient varieties with very diverse traits that could meet the requirements of most vinegrowers. However, during that period, high yields and gains in acidity, sugar and anthocyanins were prioritised above all other objectives. Over a period of only a few years, dozens of cultivars with these traits were created and gained interest from growers in some regions of the country, particularly northern Lisboa and Bairrada. These cultivars played an important economic role, and 29 are now included in the official list of wine grape cultivars. Despite their importance at the time, these cultivars fell into disuse when faced with the recent evolution of the wine sector in terms of quality, and today they are seldom cultivated. The breeding programme for table grape cultivars was also well known for its success, mostly associated with Dona Maria, which for many years was the most cultivated and consumed table grape cultivar in the country.

8.2.3 Phenotypic mass selection in the Vinhos Verdes region

A phenotypic mass selection programme was also launched in the Vinhos Verdes region in the 1960s by the regional office of the Ministry of Agriculture. This programme was coherent with similar studies in progress in various European countries and with a large research front underway in the region to promote traditional varieties and high quality of Vinho Verde.

The programme involved the main varieties of the region, which included approximately nine white and eight red grape varieties. The selection method consisted of labelling individual plants with a morphological pattern that corresponded to the variety under study, with medium vigour, good yield and no symptoms of the leafroll or fanleaf viruses. These plants were then monitored in summer and winter during several years. From the plants with the best scores were systematically collected cuttings then to be distributed to vinegrowers for grafting new vineyards.

For over two decades, millions of cuttings were distributed to vinegrowers, which resulted in significant improvements to regional wine yield and quality. This breeding programme was the most direct precedent of the current selection and conservation approach that is the focus of this chapter. The training acquired by numerous regional technicians and the increased familiarity of winegrowers with the use of selected materials greatly facilitated the transition to the new methods that would be introduced from 1978.

8.3 Widespread selection of ancient wine grape varieties in Portugal

Vinegrowers of the distant past most likely noticed that the ancient grapevine varieties, although originating from vegetative propagation from one original plant, they are not genetically homogeneous populations. This observation would have justified selecting the best plants to establish new vineyards. However, the idea of using the natural genetic variability within ancient varieties as a foundation for selection would only come about later when Bioletti (1926) in the United States and Sartorius (1926, 1928) in Germany reported contradictory findings on the subject. Levadoux (1951) and Rives (1961, 1971) would later explain that the apparent contradiction between the results of Bioletti and Sartorius was because the latter worked in the region of origin of the varieties, where all of the variability was concentrated, whereas the former worked in a region that had imported only a portion of this variability.

Through these developments, and as a consequence of other great advances in knowledge about grapevine viruses during the mid-nineteenth century, genetic and sanitary selection gained a new dynamic in Europe's wine-producing countries. The first European Community Directive on the certification of grapevine propagation materials was published in 1968 (Council Directive 68/193/EEC) and directly influenced the methods and potentiated the selection in several countries in Europe. Portugal did not immediately follow these trends, but by the end of the 1970s, before joining the European Union, external and internal influences favoured initial experiments on mass and clonal selection.

The first selection studies began in Portugal in 1978 with Touriga Nacional in the Porto/Douro region. These initial studies were followed by the selection of other diverse ancient varieties in the remaining wine-producing regions of the country. A network of universities and various departments of the Ministry of Agriculture was quickly established for the purpose of coordinating selection efforts. Without a prior history of selection in the country, the classic methodology from outside was used with three sequential cycles:

1. Individual phenotypic selection in old vineyards, during 3–4 years. This cycle included visual observations of yield, 'coulure,' vigour and symptoms of virus on approximately 1000 plants in more than 20 vineyards and ended with the selection of approximately 100 plants.
2. Planting an experimental collection with clones coming from the plants selected in the previous cycle under a completely randomised block design (4–5 replicates × four plants per genotype). For 3–4 years, data on yield, sugar, acidity and anthocyanins in the must

were collected, with the aim of selecting 20–30 superior clones. These clones were intended to be multiplied and distributed to growers as mixed material (mass selection material) and enter a third and final cycle of clonal selection.

3. Regional adaptation trials and clone selection. This third cycle also included standard virus diagnosis according to the European legislation of certification and evaluation of the wine from clones using micro-vinifications.

This methodology was initially applied to five autochthonous grape varieties. However, data obtained after 1984 in experimental clone collections (second cycle) showed notorious weaknesses in the method that resulted in profound methodological changes. The main problem was major inefficiencies in the initial phase of classic individual phenotypic selection in vineyards. These inefficiencies were identified using three types of results, presented below.

1. Large variation in yield results for individual plants of the same genotype.

Variation in yield among individual plants of the same genotype in the experimental clone collection (second cycle) of Tinta Miúda can be observed in Table 8.1. This type of variation can only be due to environmental variation at the site of the trials. The variation in yield due to environmental factors was so large that it completely masked the influence of genotype. Similar deviations have obviously influenced the selection of mother plants in old vineyards, making that selection not a result of their genetic value. In other words, the original method of visually selecting superior individual plants in a vineyard was nearly equivalent to randomly taking plants.

2. No correlation between the results of direct evaluation of mother plants in vineyards (individual phenotypic selection) and the results of evaluating the corresponding clones in the experimental collection.

There was no correlation between the yield values for 52 individual plants of Antão Vaz from four vineyards and the values of the corresponding clones in a trial with a completely randomised block design (five replicates × five plants) (Figure 8.1). Given that this experimental design ensures a notorious reduction of environmental deviations and makes the observed values close to the true genetic values, the lack of relationship between the values of the clones and those of their mother individual plants proves that in practice these do not have a genetic basis.

3. Very low yield heritability in large computer-simulated collections in which each genotype is represented by a single plant.

Yield heritability at the individual plant level (in a trial in which each genotype is represented by a single plant) can be determined by simulation using data such as those in Table 8.1 and applying the classical expression of genetic gain, R (Falconer and Mackay, 1996):

$$R = S \times h^2, \text{ or } h^2 = R/S, \tag{8.1}$$

where S is the selection differential (i.e. the difference between the mean of the selected genotypes and the overall mean) and h^2 is broad-sense heritability (i.e. the quotient

Table 8.1 **Yield (kg/plant) for individual plants of variety Tinta Miúda in a field collection with 100 clones (only 10 clones are presented)**

Clone	Yield (kg/plant)															
	Block 1				Block 2				Block 3				Block 4			
TM0201	0.78	3.38	4.78	0.48	2.93	1.38	0.93	1.03	0.78	2.18	0.78	1.88	2.38	4.28	2.78	0.78
TM0202	3.08	3.93	2.28	3.48	2.28	2.58	2.68	0.88	1.03	1.88	1.33	1.33	4.88	4.08	4.28	6.78
TM0207	5.08	1.58	0.28	4.28	5.08	4.48	4.13	1.58	3.58	3.58	0.48	3.68	1.58	3.18	1.68	0.98
TM0217	2.18	4.08	1.98	3.68	2.18	3.28	3.93	6.68	0.33	3.18	0.78	0.53	4.18	3.28	2.28	3.58
TM0218	2.88	2.48	0.88	0.28	4.98	0.98	1.38	2.08	2.13	1.73	5.63	1.58	1.18	4.68	3.78	2.68
TM0401	2.58	5.28	2.78	1.98	3.48	2.18	1.78	1.38	0.93	1.98	2.98	1.68	5.08	5.88	4.38	5.68
TM0404	0.73	0.68	0.78	0.68	0.48	0.00	0.83	0.48	0.53	0.58	0.28	0.08	2.38	1.38	1.78	0.98
TM0414	0.48	2.78	0.08	1.78	5.08	0.88	2.98	3.98	0.48	2.78	5.28	3.78	2.28	1.18	1.18	1.48
TM1102	2.58	0.58	1.03	1.28	2.38	1.33	1.33	0.00	2.43	1.13	1.03	1.33	1.78	2.03	1.28	1.63
TM1105	1.88	3.38	2.68	8.28	5.68	0.88	3.63	2.68	3.88	1.18	2.38	1.18	1.88	3.98	3.58	1.88

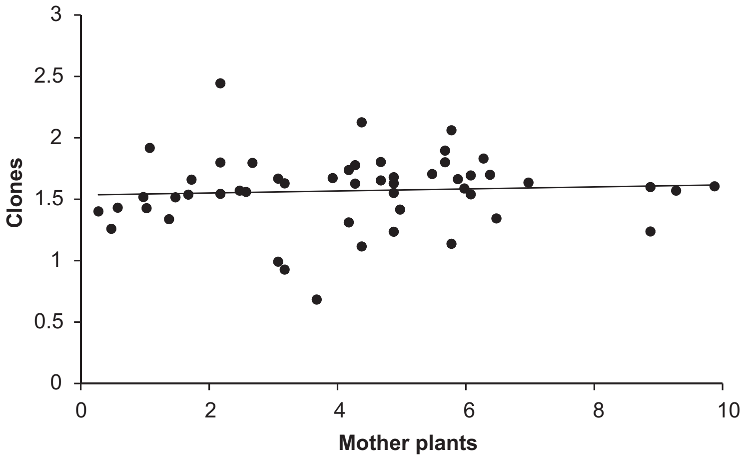


Figure 8.1 Regression analysis of the yield (kg/plant) of clones of variety Antão Vaz on their individual mother plants. Coefficient of determination (R^2) = 0.0041.

between genetic variance and phenotypic variance in the population, or a fraction of the phenotypic variance attributable to genetic causes).

To perform the simulation, we took two blocks, each one with four plants per genotype, from the field trial with 100 genotypes of Tinta Miúda represented in Table 8.1. From one of the blocks, we randomly extracted one plant of each genotype, thus simulating a new population in which each genotype is represented by only one plant. From this new population, we selected a specific number of high-yielding individual plants and calculated the selection differential (S). For the other block, which included four plants per genotype, now considered to be descendants of those of the first block, we calculated the difference in yield between the clones corresponding to the plants selected in the first block and the progeny of all plants (i.e. the genetic gain, R). Heritability is obtained by dividing the genetic gain by the selection differential (Eqn (8.1)). By running 10,000 simulations, we obtained estimates of broad-sense heritability between 0 and 0.25.

All of the different types of results above presented lead to the conclusion that the influence of environmental deviations on the yield of individual plants is very high and almost completely masks the genotypic value that generally we seek. We have also observed similar results in other trials with other varieties. However, more important is the fact that these results are highly predictable based on the theory of quantitative genetics. Indeed, yield and virtually all of the economically important grapevine traits are quantitative traits for which phenotypic value (P) is in part determined by the genotypic value (G) and in part by an environmental deviation (E),

$$P = G + E. \quad (8.2)$$

In a population supposedly composed of individual plants (one plant per genotype), if we represent the variance of environmental deviations by σ_e^2, then, according to the properties of the variance, in the population composed of *n* plants per genotype the variance *of* the mean environmental deviation would be given by

$$\sigma^2_{e(n)} = \sigma^2_e / n. \tag{8.3}$$

That is, the variance of environmental deviation is drastically reduced and, as a result, the genotypic values are more detectable when evaluating clones instead of individual plants.

The consequences that can be drawn from these practical observations and from genetic theory represent a radical split from the selection traditions of the past. However, the use of new methods is indispensable if we want to increase the efficiency of genetic selection and the genetic analysis of the diversity of ancient grape varieties based on the theory of quantitative genetics and statistics.

A major divergence from the classic methodological scheme that we have been discussing would mean replacing the first phase of individual phenotypic selection in old vineyards with a phase of sampling the intra-varietal diversity of the varieties in all of the regions where each is cultivated, followed by the immediate planting of a large experimental population of clones. It would then be possible to accurately assess all of the genotypic diversity within the variety (unmasked by high environmental deviations) with highly useful results, as will be shown in the next section.

8.4 Methodological innovation phase

The new methodology used in Portugal is briefly described in Figure 8.2. Sampling at the beginning of the selection process arose as a simple alternative to the inefficient method of individual phenotypic selection in vineyards, but this alternative proved to have enormous and unexpected potential for understanding and using genetic diversity. Indeed, intra-varietal genetic diversity is the raw material for selection, as is shown in Eqn (8.1), because the genetic gain directly depends on the selection differential (*S*) and this depends from the diversity within the target population to be selected. Thus, only by utilising all of the intra-varietal diversity, or a representative sample of it, can one obtain higher selection gains.

Another benefit of diversity sampling is that the results of analyses performed on a large experimental population of clones can be generalised to the entire variety previously sampled and to subpopulations of that variety grown in different regions. The sampling procedure functions as if actual populations of the variety, dispersed among many vineyards in various regions, were included in one single field trial. This makes it possible to objectively analyse and interpret the entire variety. Among the various possible analyses, the quantification of diversity is exceptionally useful because it yields the following new information:

- The amount of raw material available for new selections and for conservation and the locations (growing regions) where it is concentrated and must be prospected, and

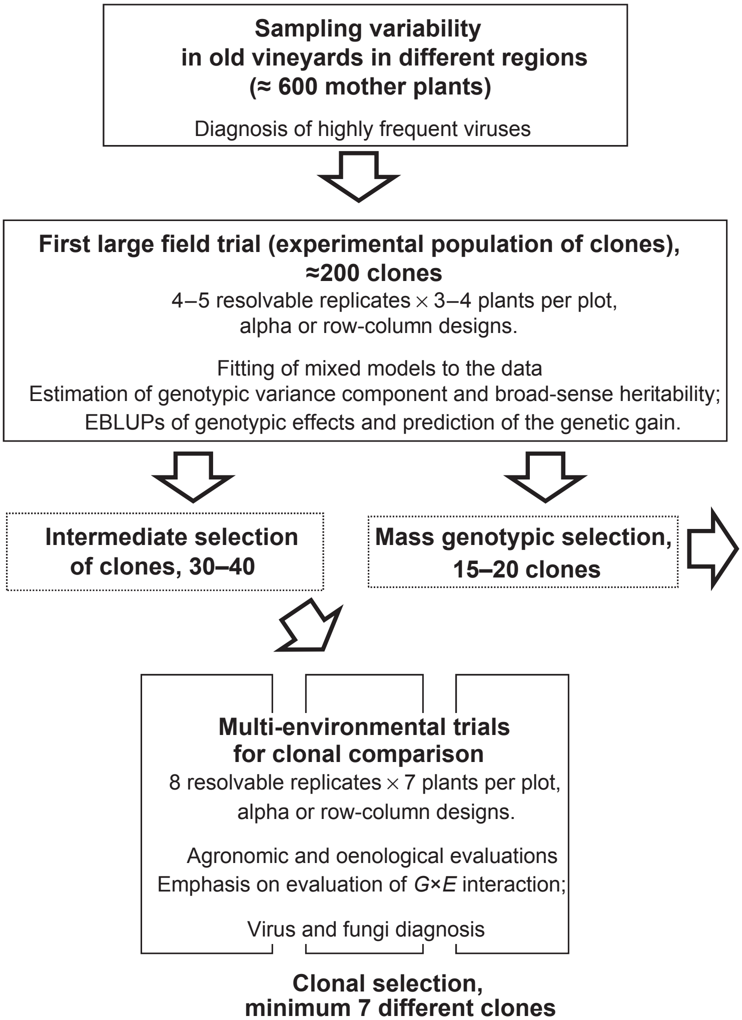


Figure 8.2 Methodology of grapevine selection in Portugal. EBLUPs: empirical best linear unbiased predictors.

- The approximate relative ages of the different varieties and regional populations of a specific variety, which leads to the formulation of new hypotheses about the origin and geographic expansion of varieties.

For a sample to be representative of a specific region where the variety is grown, it is first necessary to define the minimum number of mother plants (genotypes) required for the sample, which can be determined through simulation experiments (Martins et al., 1990; Gonçalves and Martins, 2012). Martins et al. (1990) collected an actual oversized sample of 198 mother plants of Touriga Nacional, which were then planted in the field as clones in a completely randomised block design with five replicates and three plants per plot. Yield and other traits were measured. Several subsamples were randomly extracted from the larger sample, and the coefficient of genotypic variation (CV_G) and the broad-sense heritability were calculated for all of the samples of different sizes. The results showed that CV_G increases with sample size and stabilises at a sample size of ≈50 clones. According to that study, an analysis of intra-varietal diversity (for selection and other uses) should be based on an experimental population of 50 clones when the variety is cultivated in one region or with 50*n* clones when it is cultivated in *n* regions. To reinforce these conclusions, new simulation studies with different sample sizes of four other Portuguese wine grape cultivars were performed by Gonçalves and Martins (2012). This study focused on the quality of the estimates obtained for genetic variance of yield and broad-sense heritability. The results showed that the minimum number of genotypes necessary to obtain accurate and precise estimates of the genetic variability of a variety in a growing region ranged from 50 to 70, depending on the quality of the trial. Thus, a minimum sample of 70 genotypes is recommended in less-controlled experimental situations.

The sample must also meet additional conditions that minimise the probability of relatedness between mother plants, including the labelling of plants only in vineyards planted before homogeneous propagation materials being available on the market (>25 years) and the labelling of a few plants (from two to five) in many vineyards (≥20 per region), vineyards from different owners, and vineyards that are geographically distant from one another. During the sampling of mother plants, the enzyme-linked immunoabsorbent assay diagnosis is used for viruses with a high frequency of natural occurrence in the variety and/or region, which is typically the case of leafroll type 3 virus (GLRaV3).

Planting of the experimental population is performed in homogeneous soil with an experimental design that adequately controls for environmental deviations and allows for the precise knowledge of the genotypic values of the clones. To find a good compromise between feasibility and efficiency in the experimental design, there are two practical considerations. First, it is not possible to produce more than approximately 15 plants from the shoots of one plant, and the number of plants per plot should be half of the number of plants between trellis posts (plots may only have three or four plants). Taking these conditions into account and based on the vast body of experiments performed over 30 years, we usually adopt experimental designs that control for the spatial variation that is likely to exist in trials with many dozens or even hundreds of genotypes, such as alpha designs and row-column designs (Gonçalves et al., 2010; Gonçalves and Martins, 2012). When the number of genotypes being evaluated is more than 400 and the main objective is to study the genetic variability of a variety, one possible alternative is the use of unreplicated designs (Gonçalves et al., 2013a).

Data collection usually begins 2 years after the grafting of the field trial and extends for at least 4 years. Data are collected on yield, sugar, acidity and anthocyanins in the must. Random or mixed models are fitted to the data (Gonçalves et al., 2007, 2010, 2013b; Gonçalves and Martins, 2012), always assuming random genotypic effects. The variance components are estimated by the residual maximum likelihood method (Patterson and Thompson, 1971). The empirical best linear unbiased predictors (EBLUPs) of the genotypic effects of the traits are obtained through the mixed-model equations (Henderson, 1975; Searle et al., 1992).

Estimates for the coefficient of genotypic variation and broad-sense heritability are then obtained. All analyses are guided by the objectives described in the following subsections.

8.4.1 Mass selection of clones (or polyclonal)

This method of selection is based on the principles of quantitative genetics and allows prediction of genetic gains. The predicted genetic gain obtained with the selection of a superior group of clones is the mean of the EBLUPs of the genotypic effects of the selected clones. When classical models are fitted, the genetic gain described by Eqn (8.1) can be also applied.

Examples of gains in yield obtained without losing quality traits are presented in Table 8.2. Often, gains in quality in terms of sugar, acidity and anthocyanins are also obtained, although this occurs to a lesser extent because of the lower intra-varietal diversity of those traits.

In total, approximately 60 varieties have been selected by mass selection in Portugal, and these selections are commonly propagated and used for new plantations. Among these cultivars, the predicted genetic gains differed (ranging from 1.6% to 91.4%) depending on the quality of the trial, the genetic diversity of the variety and the proportion of selected clones.

Table 8.2 Predicted genetic gains (PGG) of the yield (in percentage of the overall mean) obtained through mass genotypic selection of 38 Portuguese grapevine varieties

Variety	PGG	Variety	PGG
Alfrocheiro	16.7%	Loureiro	38.7%
Alvarelhão	12.7%	Malvasia Fina	32.2%
Alvarinho	21.5%	Moscatel Graúdo	17.3%
Antão Vaz	31.9%	Moscatel Galego	32.1%
Aragonez	20.3%	Negra Mole	46.0%
Arinto	15.6%	Rabigato	30.3%
Avesso	9.4%	Rabo de Ovelha	25.0%
Azal Branco	20.2%	Rufete	42.1%
Baga	17.6%	Tinta Barroca	11.6%
Bical	19.3%	Tinta Francisca	31.9%
Ratinho	14.0%	Tinta Miúda	30.9%
Borraçal	16.9%	Tinto Cão	11.6%
Camarate	17.6%	Touriga Franca	1.6%
Castelão	14.0%	Touriga Nacional	34.4%
Síria	29.0%	Trajadura	43.1%
Sercial	91.4%	Trincadeira	13.8%
Fernão Pires	17.6%	Vinhão	17.8%
Jaen	5.9%	Viosinho	30.9%
Jampal	26.7%	Vital	33.7%

Adapted from Martins (2009).

8.4.2 *Quantifying the intra-varietal diversity of varieties, globally and by growing region*

As previously mentioned, quantifying intra-varietal diversity is important because genetic diversity represents the raw material for selection and for conservation, and quantification of this diversity increases our knowledge of the origin and expansion of cultivars. Quantification of diversity can be performed for any quantitative trait. Yield is a suitable trait for this purpose because it is easy to evaluate and exhibits high relative diversity. There are various metrics to quantify diversity, and the coefficient of genotypic variation is a particularly objective one. As an example, the intra-varietal diversity of 42 varieties is shown in Table 8.3 expressed by the coefficient of genotypic variation of yield.

These results show that there are varieties with high diversity (e.g. Sercial, Negra Mole and Viosinho), which supports the hypothesis that these varieties have a very

Table 8.3 Intra-varietal genetic variability (CV_G) of the yield expressed by the coefficient of genotypic variation evaluated in experimental populations of clones for 42 Portuguese grapevine varieties

Variety	Number of clones in the trial	CV_G	Variety	Number of clones in the trial	CV_G
Seara Nova	40	6.9	Jampal	180	19.4
Jaen	200	7.2	Espadeiro	133	20.5
Avesso	164	9.6	Antão Vaz	210	20.8
Bical	240	12.4	Alvarinho	176	22.2
Trincadeira Preta	271	12.8	Moscatel Galego	200	22.2
Encruzado	179	13.2	Touriga Nacional	197	22.9
Castelão	189	13.7	Moscatel Graúdo	187	23.7
Touriga Franca	90	13.8	Síria	239	24.5
Alfrocheiro	237	14	Amaral	137	25
Ratinho	194	14.9	Viosinho	199	25.5
Cercial	50	15	Rufete	337	26.4
Tinto Cão	168	15.3	Arinto	247	27.8
Azal Branco	219	15.5	Loureiro	250	29.5
Tinta Barroca	190	15.5	Tinta Míuda	100	29.9
Camarate	242	15.6	Rabigato	127	30.7
Trajadura	237	15.8	Vital	232	30.8
Vinhão	211	16.4	Malvasia Fina	180	31.8
Fernão Pires	235	16.4	Rabo de Ovelha	250	32.3
Baga	200	16.5	Tinta Francisca	61	33.2
Borraçal	200	16.7	Negra Mole	193	38.9
Aragonez	245	17.9	Sercial	148	42.9

Adapted from Martins (2007).

old origin and indicates that the results of selection will be good. In contrast, other varieties are genetically homogeneous (e.g. Seara Nova, Avesso, Jaen and Touriga Franca), which denotes a very recent origin and indicates that selection results are likely to be poor. Seara Nova was developed through artificial crosses in the mid-1900s, which explains its high homogeneity. The results on Touriga Franca and Jaen were initially more intriguing but constituted a reliable indicator of short age, which guided us in the search for explanations for their origins, other than the domestication of wild vines in a distant past. Today, we know from our results that Jaen is a recent import of Mencía from Spain, and based on the interpretation of microsatellite data we know that Touriga Franca is a descendent of the natural crossing between Touriga Nacional and Marufo (Castro et al., 2011), which fully explains the genetic homogeneity of both varieties.

Comparing samples of the same variety grown in different regions can yield additional useful results. We examined data from an experimental population of clones from Garnacha (or Grenache or Cannonau) planted in Tomelloso (Spain) with representative samples of genotypes from four regions in three different countries (Toledo, Zaragoza, Vaucluse and Sardinia). The field trial was planted under a randomised complete block design with five replications and three plants per plot. Yield was evaluated in the years 1999, 2001 and 2002. Two mixed spatial models were fitted to yield data using SAS Proc Mixed (SAS Institute, 2008), and the methodology used to quantify intra-varietal diversity followed Gonçalves and Martins (2012). Table 8.4 lists the results of the two models. The first model considered all of the genotypes as a sample of the whole variety (total). The second model took into account the region of origin of the genotypes. For this model, we assumed unequal genotypic variances among the regions and fixed effects for growing regions. According to the fitted models, the total genetic variability in yield was significant ($p < 0.05$), and there was unequal variability among regions ($p < 0.05$). According to the results of the genotypic coefficients of variation, the greatest genetic variability was found in Sardinia (Italy). This finding indicates that the variety originated in Sardinia, which contradicts the widespread opinion that the variety has its origins in Spain. From Sardinia, the cultivar

Table 8.4 Estimates of the overall mean ($\hat{\mu}$), genotypic variance ($\hat{\sigma}_g^2$) and coefficient of genotypic variation (CV_G) of the yield (kg/plant) for variety Grenache, obtained with the fitting of two mixed models

Origin	Number of genotypes	$\hat{\mu}$	$\hat{\sigma}_g^2$	CV_G (%)
Total	205	1.13	0.078	24.6
Vaucluse (France)	53	1.23	0.005	5.5
Toledo (Spain)	47	1.22	0.057	19.5
Zaragoza (Spain)	54	1.16	0.097	26.8
Sardinia (Italy)	51	0.95	0.111	35.2

The first model assumed all of the genotypes as a sample of the whole variety (total) and the second assumed unequal genotypic variances (taking into account the region of origin of the clones).

was subsequently exported to the other regions of Spain and France, likely through selected material. This is a logical conclusion given that the region with the highest genetic variability shows the lowest mean yield. In multiple pairwise comparisons of the means (Tukey–Kramer), the mean yield for Sardinia was lower than the means for the other regions ($p < 0.05$). Mean yield was not different among the Vaucluse, Toledo and Zaragoza regions ($p < 0.05$). These results about intra-varietal diversity are of great interest because they highlight the cultural context of grapevine varieties and provide new rational guidance for selection and conservation.

8.4.3 Intra-varietal diversity conservation

Performing selection on large experimental clone populations attempts to address current viticulture objectives, but those objectives are constantly changing and demanding new and different solutions. Thus, a large experimental population can be conserved as a reservoir of variability for future use. The data from such a field trial are collected and stored in a large database in paper and digital formats. Later, these data will enable new 'real-time' selections (without the need for a new field experiment) to address new objectives. This type of conservation is already being used for certain varieties for which different traits will be selected than the traits that were prioritised during breeding programmes in the 1980s.

As of 2013, close to 91 experimental populations to be used for this type of conservation had been established in Portugal, amounting to a total of approximately 15,000 clones from 60 varieties. However, current theoretical foundations and recent field experimental work have supported an even more ambitious approach for conservation, as will be shown in Section 8.5.

8.4.4 Clonal selection

The selection of clones from a large experimental population begins with the collection of data according to the objectives mentioned above and the selection of approximately 30 superior clones. However, some testing cannot be performed on a large experimental population. In particular, wine cannot be evaluated in such a field trial because 15 plants/clone does not produce enough grapes to make experimental wines and the environmental stability of the clones cannot be analysed (data from several different environments are needed for this type of assessment). Therefore, the 30 pre-selected clones must be subjected to a final selection cycle performed in at least two or three additional trials established in the main cultivation regions of the variety using preferentially experimental designs of the family of incomplete blocks.

Wine testing is based on 30 L micro-vinifications followed by chemical analyses and tasting, according to the classic methods currently used by numerous breeders. The evaluation of environmental stability of the clones is a critical issue in the context of our selection work. Clones suffer the contrariety of having different and unpredictable behaviour in different environments regardless of the objective quality of these environments. Therefore, the clones should be rigorously studied as to their degree of environmental stability (genotype × environment interaction, $G \times E$).

The study of $G \times E$ interaction requires planting various trials in representative environments. Because trials using perennial plants are difficult and expensive, in most cases only two or three regional trials are established to study environmental effects. This low number of trials is balanced by collecting data on them for at least 3–5 years and by using analyses that include data from the same 30 clones from the large experimental population of the previous cycle.

The main techniques used to study $G \times E$ interaction generally include the classical analysis of variance with interaction, the coefficient of variation of different traits in distinct experimental environments, regression analyses using environmental indices (Finlay and Wilkinson, 1963), non-parametric methods based on genotype ranking in different environments (Hühn, 1990a,b), methods based on mixed-model theories (Smith et al., 2005) and principal components analyses (Kempton, 1984; Gauch, 2006).

Using all of these methods, it is usually possible to select clones that exhibit reasonably stable behaviour across different environments. Of the techniques above mentioned, one of the simplest and probably one of the most intuitive is based on rankings of the clones in different environments. An example of this type of analysis was performed using a yield data set from 35 clones of Arinto obtained in four trials installed in four sites (Bucelas – Buc, Mealhada – Mea, Felgueiras – Fel, Lousada – Lou). All trials were planted according to a randomised complete block design (varying from four to nine repetitions, according to the site). At each site, the yield was evaluated in several years and each combination site/year was considered as a distinct environment.

Two non-parametric phenotypic stability measures (Hühn, 1990a,b) were used: (1) the mean of the absolute rank differences of a genotype over the n environments and (2) the variance among the ranks over the n environments. These stability measures were computed using the ranks based on the corrected values proposed by Nassar and Hühn (1987). In Figure 8.3, the ranking of the clones across the different environments is illustrated. Both non-parametric measures detected six clones as stable (AR7502, AR0310, AR8007, AR3404, AR8204 and AR8808) and three clones as unstable (AR1501, AR3503, AR7507) ($p < 0.05$). For example, the behaviours of two unstable clones (AR1501 and AR3503) and two stable clones (AR0310 and AR7502) are highlighted (Figure 8.3). As can be seen, clone AR3503 is in the top in some environments but in other environments (including different years of the same site) is in the last positions. Clone AR1501 is also in the top in some environments and is in the last positions in the environments where the AR3503 was in the top. The latter two clones clearly reveal genotype by environment interaction. On the other hand, the two clones considered as stable showed few changes in the ranks among the different environments.

This and other methodologies described above allow us to conclude that not all clones are equally sensitive to the interaction. Therefore, choosing less-sensitive clones should be a priority criterion of any clonal selection. Even so, there is always a high risk that the behaviour of the supposedly stable clone could prove to be unstable in environments other than those studied. Therefore, this risk should be mitigated by the complementary strategy to always select several clones of each variety, allowing vinegrowers to plant mixtures of clones and benefit from the buffering effect of the mixtures on the interaction.

	Environments												
Rank	Buc91	Mea91	Mea93	Mea94	Mea95	Fel92	Fel93	Fel94	Fel95	Fel96	Fel98	Fel99	Lou96
1	AR7904	AR7507	AR3503	AR3503	AR7507	AR7904	AR8201	AR6007	AR3601	AR2423	AR1501	AR1501	AR2404
2	AR7301	AR0344	AR7904	AR7507	AR3502	AR3503	AR3201	AR2425	AR3702	AR1501	AR3503	AR8801	AR2410
3	AR7507	AR3503	AR0344	AR7904	AR9005	AR6007	AR3605	AR7301	AR1501	AR3601	AR3401	AR7503	AR3203
4	AR7207	AR7904	AR3401	AR0344	AR3401	AR3502	AR1501	AR3404	AR3012	AR3702	AR7904	AR3601	AR8801
5	AR3503	AR3401	AR7507	AR3502	AR8204	AR7301	AR2423	AR2410	AR0230	AR2425	AR3702	AR8308	AR3012
6	AR3601	AR7207	AR6007	AR0230	AR0344	AR0230	AR7301	AR3201	AR8201	AR3203	AR8201	AR0664	AR2041
7	AR8808	AR9005	AR9005	AR6007	AR0498	AR8308	AR3702	AR9005	AR9005	AR7207	AR6007	AR8007	AR0498
8	AR0664	AR0310	AR2041	AR9005	AR0664	AR0344	AR2404	AR7503	AR2410	AR3404	AR8007	AR7207	AR8201
9	AR8308	AR3502	AR8308	AR3401	AR2423	AR3012	AR0230	AR3702	AR6007	AR8007	AR0230	AR3203	AR2423
10	AR0344	AR0664	AR3502	AR8204	AR7904	AR3201	AR3203	AR0310	AR0664	AR2410	AR0344	AR3605	AR2425
11	AR0310	AR3601	AR7301	AR2041	AR2041	AR7507	AR8007	AR3601	AR8308	AR7503	AR7503	AR8808	AR8808
12	AR6007	AR8308	AR3601	AR7207	AR7207	AR3702	AR3502	AR2404	AR8204	AR7301	AR8308	AR3702	AR3605
13	AR3502	AR7301	AR7502	AR0310	AR3012	AR1501	AR8308	AR3605	AR8801	AR8201	AR3201	AR7502	AR7503
14	AR3404	AR8808	AR8808	AR7502	AR3404	AR0664	AR7503	AR8808	AR3502	AR7502	AR0310	AR2410	AR3201
15	AR9005	AR8007	AR0310	AR8007	AR7503	AR9005	AR8808	AR0498	AR3201	AR8204	AR7502	AR2404	AR3502
16	AR3401	AR8204	AR3012	AR8308	AR7301	AR0310	AR8204	AR8007	AR8808	AR3401	AR0664	AR2423	AR8204
17	AR0230	AR0230	AR0664	AR7301	AR3601	AR8007	AR2410	AR7502	AR3203	AR3605	AR3404	AR9005	AR7502
18	AR7503	AR6007	AR8007	AR0664	AR3605	AR2423	AR0310	AR0230	AR7503	AR8801	AR7207	AR8201	AR3702
19	AR3605	AR2041	AR0230	AR7503	AR0310	AR2425	AR7502	AR1501	AR7502	AR0230	AR9005	AR0230	AR3404
20	AR8007	AR7502	AR3404	AR8808	AR7502	AR3404	AR9005	AR7904	AR0310	AR0498	AR8801	AR3404	AR7207
21	AR3201	AR0498	AR7207	AR3201	AR8308	AR0498	AR2425	AR8204	AR2425	AR0310	AR7301	AR3012	AR6007
22	AR8801	AR3012	AR0498	AR3012	AR8801	AR8808	AR0664	AR3203	AR7904	AR3201	AR3012	AR6007	AR0310
23	AR3012	AR3404	AR3201	AR2425	AR3203	AR8201	AR6007	AR0664	AR8007	AR2041	AR3601	AR7904	AR3401
24	AR8204	AR2423	AR8204	AR0498	AR8201	AR3601	AR3601	AR3503	AR3404	AR0664	AR0498	AR8204	AR7507
25	AR2041	AR2425	AR2425	AR3404	AR8808	AR2410	AR7207	AR2423	AR3401	AR8308	AR7507	AR7301	AR8007
26	AR0498	AR7503	AR3702	AR2423	AR0230	AR7502	AR3503	AR8201	AR2423	AR9005	AR2410	AR2041	AR7301
27	AR1501	AR3605	AR3605	AR3601	AR8007	AR3605	AR7904	AR8801	AR2404	AR2404	AR8204	AR3201	AR0664
28	AR7502	AR8801	AR7503	AR3203	AR2410	AR8204	AR8801	AR8308	AR7507	AR0344	AR8808	AR2425	AR0344
29	AR8201	AR8201	AR1501	AR3702	AR3201	AR2041	AR7507	AR2041	AR3503	AR7507	AR2041	AR3503	AR8308
30	AR2425	AR3702	AR2423	AR8801	AR2425	AR3401	AR3404	AR3012	AR0344	AR3503	AR3502	AR0310	AR3601
31	AR2423	AR3201	AR8201	AR3605	AR6007	AR7207	AR0498	AR0344	AR7301	AR8808	AR2423	AR3401	AR0230
32	AR3702	AR3203	AR2404	AR8201	AR3503	AR3203	AR3401	AR7507	AR0498	AR3012	AR3605	AR0498	AR9005
33	AR3203	AR2404	AR8801	AR1501	AR3702	AR8801	AR0344	AR7207	AR3605	AR7904	AR3203	AR0344	AR1501
34	AR2404	AR2410	AR3203	AR2404	AR2404	AR7503	AR2041	AR3401	AR7207	AR6007	AR2425	AR7507	AR3503
35	AR2410	AR1501	AR2410	AR2410	AR1501	AR2404	AR3012	AR3502	AR2041	AR3502	AR2404	AR3502	AR7904

Figure 8.3 Ranking (based on the corrected values proposed by Nassar and Hühn, 1987) of the 35 clones of variety. Arinto across 13 environments (combinations site/year). For an easier visualisation four clones are shaded: two considered as unstable (AR1501 and AR3503) and two considered as stable (AR0310 and AR7502).

A more detailed analysis of the stabilising effect of the blends as well as the variation of this effect with the number of mixed clones is shown in Figure 8.4 for Arinto. The results of the regression analysis of yield of individual clones and of groups of clones on the average of 40 in 33 environments (environmental indices, Finlay and Wilkinson, 1963) showed that some individual clones have low coefficients of determination, which indicates high $G \times E$ interaction, although this varies from clone to clone. Rather, the coefficients of determination of the groups (1st, 1st–2nd to 1st–20th, represented by the upper curve) are always higher, which indicates greater stability of the groups in relation to individual clones. The coefficient of determination increases with the number of clones of groups and the growth is faster to 5–10 clones

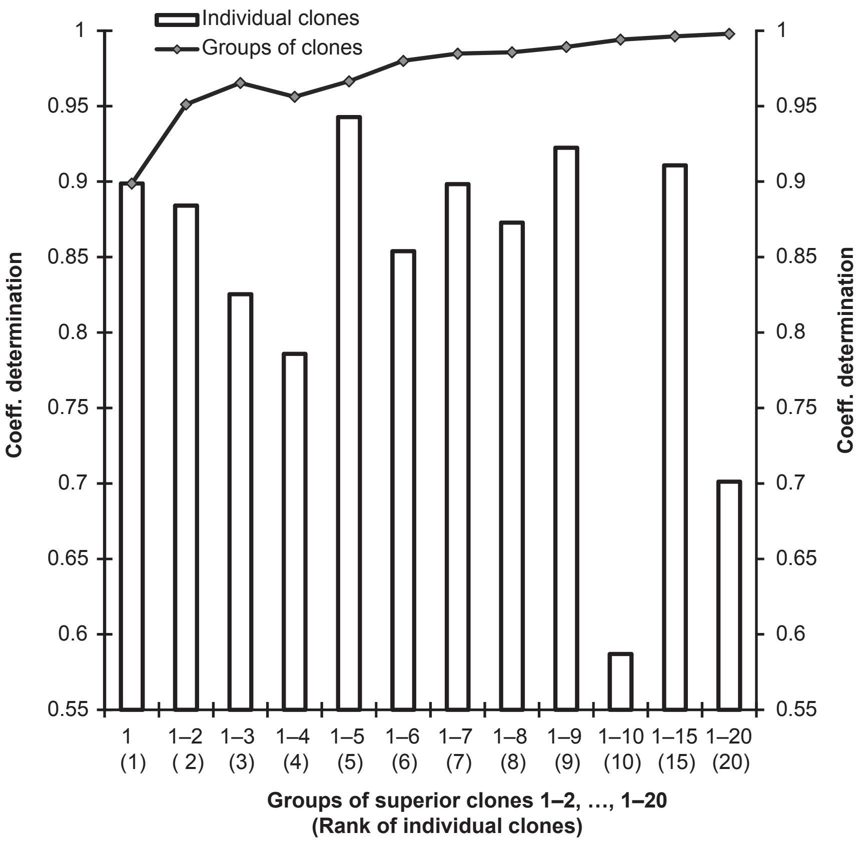


Figure 8.4 Regression analysis of yield of individual clones and of groups of clones of variety Arinto on environmental indices: coefficients of determination of clones 1st, 2nd,…,10th, 15th, 20th (bars) and of groups 1st, 1st–2nd, 1st–3rd,…,1st–10th, 1st–15th, 1st–20th (curve). Adapted from Martins et al. (1998).

becoming moderate to higher numbers. According to these results, it is reasonable to assume that the selection and the utilisation of mixtures of 7–10 clones could ensure stability close to that of the 40 clones and corresponding to a coefficient equal to 1.

In short, based on these results, we can conclude that the efficiency of clonal selection is highly conditioned by the $G \times E$ interaction and that there are essentially three approaches to mitigate their negative effects:

- Select clones less sensitive to interaction.
- Select a plural number of clones to authorise the cultivation of clonal mixtures by the grower.
- Performing polyclonal selection (Section 8.4.1) as an alternative to the selection of clones.

To make the selection more efficient and safer, all of these approaches should be used, each one with more or less intensity, depending on many different contexts that can be found in the wine industry worldwide.

8.5 Emergence of genetic erosion and strategies to counteract it

The erosion of intra-varietal genetic diversity is a grave problem and is mainly the result of changes in viticultural technology occurring from the mid-twentieth century. In particular, changes in nursery and selection technologies have had devastating effects on diversity. Historically, the plants for new vineyards were grafted with heterogeneous propagation materials from other old vineyards and contained high diversity that was continually created and accumulated over centuries. As the use of highly homogeneous materials provided by nurseries became increasingly common, this process of natural creation and accumulation of variability was interrupted. The homogenisation of nursery materials resulted from the need to simplify nursery operations and was precipitated by the practice of selection with a narrow genetic base as imposed by plant certification regulations.

If this process of erosion is not reversed, then the ancient varieties will become extremely genetically homogeneous (at the extreme, genetic variability would be reduced to a single clone), and this loss of diversity will be irreversible. This means that it will not be possible to select from these varieties to address new breeding objectives stemming from the need to adapt to new viticultural contexts, consumer demands or environmental change. Therefore, it is imperative and urgent that we develop strategies for conserving the intra-varietal diversity created naturally over the centuries or millennia that these cultivars have existed. The need for conservation strategies is strong in countries along the Mediterranean coast, where the first varieties were domesticated and where the largest amount of intra-varietal diversity has accumulated. Conservation is particularly critical in Portugal because we have an extremely high number of autochthonous varieties (particularly when considering the relatively small size of the country). These varieties are generally very old and heterogeneous, creating a great responsibility for genetic conservation. Furthermore, over the last 30 years, we have developed new methods of analysis and knowledge about diversity that has given us the capacity to counteract genetic erosion.

Fortunately, the main solution for preventing erosion is already present in the selection methodology described in the previous section. Indeed, any actions to conserve intra-varietal diversity must involve obtaining a representative sample of this diversity in regions where the varieties are cultivated and the grafting of an experimental population of clones for conservation. Current sampling and field trial methods for selection are already designed to be representative of the total diversity within a variety. Thus, achieving full compatibility between selection and conservation requires no more than a few changes that we will now describe.

First, conservation has become a priority in breeding programmes in Portugal, including all of the approximately 250 autochthonous varieties in the country. Therefore, large clonal populations that are representative of natural diversity are already planted according to adequate experimental designs that allow for the evaluation of genotypic values as well as selection (and other analyses). As a complement to the populations planted in the field, additional copies of clones are propagated in pots containing inert substrate and fertigation to minimise risks and guarantee better plant health. Both of these methods constitute *ex-situ* conservation, which is the only type of genetic conservation that can result in the conservation of a large amount of diversity in an effective and sustainable manner. This conservation strategy has been applied in Portugal for 30 years and has been reinforced since 2010. The goal of these conservation efforts is to conserve 50,000 clones of 250 varieties, both in pots and in the field. Approximately half of this goal has already been met.

The data collected from field populations are analysed for various purposes, particularly for selection focused on wine industry objectives. However, the data can also be used in the future to perform different selections in 'real time' (without the need for a new experiment) according to the future constantly changing objectives of the industry.

Given that the main causes of genetic erosion are associated with selection and multiplication, a complementary mitigation strategy would involve regulatory changes in the area of selection and certification that help maintain a certain amount of diversity in vine (*in situ* conservation). These regulations are not currently in place because people from wine and vineyard institutions believe that clones are the highest quality propagation materials, although this belief is not supported by scientific evidence and in fact helps intensify genetic erosion. In the European Union, only clones can be classified as 'certified material' (an expression that suggests superiority), whereas other propagation materials are considered to be of lower quality and are designated as 'standard material' (an expression that suggests inferiority). In contrast, studies show that clonal selection is a fragile method that leads to a product with unknown genetic gains that exhibits unpredictable behaviour in new environments (see Section 8.4). In contrast, mass selection can be performed using new, powerful methods; is theoretically founded in quantitative genetics and statistics; and produces the highest, most stable, and most predictable genetic gains (see Section 8.4.1).

Two forms of regulatory changes are needed to correct the favouring of clones and successfully mitigate genetic erosion: (1) breeders should be required to maintain on the market several clones of a specific variety to ensure that vinegrowers can always plant groups of clones rather than a single clone and (2) a new class of materials should be obtained through genotype-based mass selection (as described in Section 8.4.1).

In summary, Portugal began selecting varieties in 1978 by following the empirical procedures used in other wine-producing countries, without giving particular attention to indispensable factors for success (i.e. the raw material of intra-varietal diversity and the use of adequate methods for the evaluation of diversity) or to the negative side effects of selection (e.g. the degradation of raw material for future selections and the instability of clones in different environments). However, we quickly noticed these weaknesses in the current methods and developed a new approach for using the intra-varietal diversity of ancient varieties as follows: (1) the current priority is diversity conservation, especially *ex situ* but complemented with *in situ* conservation, and recognition of the amount and geographical distribution of diversity; (2) genetic selection is now viewed as a way to utilise diversity and is performed with care to prevent the erosion of genetic diversity and protect vinegrowers from negative consequences from $G \times E$ interactions; and (3) it is now recognised that all of the traits subject to analysis are quantitative traits for which understanding requires extensive use of quantitative genetics theory and techniques.

Only with this type of comprehensive breeding strategy will Portugal be able to take advantage of the current wide range of intra-varietal variability inherited from our history and pass on this resource, more or less intact, to future generations.

Precisions about "variety" and "cultivar"

In the vine and wine area we observe today a marked confusion about the concepts of variety, clone, cultivar... This confusion comes mainly from insufficient knowledge about the reality of intra-varietal diversity and about differences in the amount of diversity among varieties: very high in old varieties and zero (or near) in new varieties. And also the lack of a clear terminology to distinguish between those different situations and communicate about them.

However, realizing the genetic nature of the old variety (landrace) and bearing in mind the definitions in the International Code of Nomenclature of Cultivated Plants, it becomes possible to clarify this confusion.

In the context of vine growing countries of Eurasia (Centre of Origin of *Vitis vinifera*), there are essentially two types of varieties: old varieties (aged centuries or millennia) and new varieties resulting from selection within the ancient variety, or from genetic improvement by hybridization, mutation or other methods.

The old varieties are usually genetically homogeneous for morphological traits, but highly heterogeneous with respect to agronomic and technological traits. For example, within several Portuguese old varieties we can find a very high number (undetermined) of different genotypes, some of these with genetic potential for yield tenfold greater than others; and genotypes with genetic potential for soluble solids twofold higher than others. And these genotypes may be spread across different regions or countries, no one knows exactly where.

So when a grower wants to plant a new vineyard with a variety like this, he never exactly will plant the entire variety (with all its diversity and with averages for all traits equal to the overall means): he can only plant a selected part of this variety (one clone, or a combination of clones, that will always be different from the whole population). We mean, the old variety (eg Touriga Nacional) can't really be planted by anyone, consequently it is not a cultivated variety (cultivar). But a clone (or group of clones) selected within the Touriga Nacional (eg "Touriga Nacional clone 23 ISA") may be, so this is the true cultivar.

This same view is supported by the definition of cultivar in the International Code of Nomenclature of Cultivated Plants (http://www.actahort.org/chronica/pdf/sh_10.pdf), Art. 2.3, 2.5.: "cultivar is an assemblage of plants that (a) has been selected for a particular character or combination of characters, (b) is distinct, uniform and stable in these characters, and (c) when propagated by appropriate means, retains those characters".

Continued

This definition of cultivar does not include the old variety: because it was not objectively selected by anyone in particular (is a legacy of history) is not uniform and can't be fully propagated (nobody knows how many different genotypes exist within the variety neither where to find them).

In conclusion, the different types of vine varieties should be explained by an accurate coding and referred by a non confusionist terminology. But in the absence of those coding and terminology applied to the grapevine, it is reasonable to designate "cultivar" the biological material which is effectively cultivated and is in accordance with the definition in the ICNCP. So in this chapter we use "old variety" (or ancient variety, or simply variety) to mean "heterogeneous old variety" (landrace) and "cultivar" to mean "new variety selected within the old variety", or obtained by hybridization, or another method.

8.6 Stakeholders and the organizational structure of diversity management in Portugal

Selection was initiated in Portugal in 1978 by researchers at universities and the research department of the Ministry of Agriculture. From the initial adoption of the selection approach, the large amount of field work involved required help from other collaborators from regional departments of the Ministry of Agriculture and wine production companies themselves. These collaborators partially work as part of an informal network generally known as the National Grapevine Selection Network (Rede Nacional de Selecção da Videira, RNSV).

From the beginning, the network's work was self-funded and supplemented with occasional funds through applied research projects financed by the National Scientific System. Wine production companies provided vineyards study sites for numerous field trials throughout the country (≈150 trials), which was a unique and economic solution for the rapid expansion of selection techniques with minimal logistic and financial costs. The ISA ensured continuous methodological research in the area of quantitative genetics, which resulted in large advances in selection efficiency and a completely new understanding of the nature of intra-varietal diversity and the major threats to that diversity.

These developments allowed for the rapid growth of selection techniques from 1985 to 1995. At the same time, the need to prioritise the management and conservation of diversity by creating an organisational structure that was more stable and long-lasting also became apparent. This organisation was created in 2009 in the form of a private non-profit organisation called the Portuguese Association for Grapevine Diversity[1] (Associação Portuguesa para a Diversidade da Videira, PORVID). PORVID brings together three types of participants: those that perform research in the field of genetic diversity and selection (e.g. universities and related institutions), those that use the

[1] https://www.facebook.com/porvid.portugal/.

results of this research (e.g. companies of the wine industry) and other entities directly interested in the development of vine and wine production (e.g. wine-producing municipalities). The objectives of the association are to investigate, conserve and evaluate the genetic variability of ancient varieties and wild grapevine populations; to perform genetic and sanitary selection of these varieties; to develop methods and conduct fundamental studies in grapevine breeding; to collaborate with other entities that aim to increase the value of grapevine cultivars; and to conduct outreach about the activities of the association and the grapevine varieties.

Conservation of the diversity of main autochthonous varieties was once performed on private vineyards (when selected materials did not yet exist), but this approach is now outdated because winegrowers do not have the interest to plant materials for the purpose of diversity conservation (rather than planting existing selected materials), much less varieties of lower current value. Therefore, the Portuguese government has granted a 150-ha area with viticultural potential (Experimental Conservation Centre) to PORVID for a 50-year renewable term. The area is dedicated to long-term conservation of the diversity of all autochthonous grapevine varieties.

References

Almeida, F., 1972. Melhoramento e improdutividade em viticultura, Relatório Final do Curso de Engenheiro Agrónomo. ISA/UTL, Lisboa.

Bioletti, F., 1926. Selection of planting stock for vineyards. Hilgardia 2, 1–23.

Castro, I., Martin, J., Ortiz, J., Pinto-Carnide, O., 2011. Varietal discrimination and genetic relationships of *Vitis vinifera* L. cultivars from two major controlled appelation (DOC) regions in Portugal. Sci. Hortic. 127, 507–514.

Coutinho, M., 1950. Melhoramento da videira, seu aspecto particular da resistência à Plasmopara vitícola. Anais da Junta Nacional do Vinho 2, 13–135.

Coutinho, M., 1964. Some vine clones resistant to Plasmopora. Vitis 4, 341–346.

Falconer, D., Mackay, T., 1996. An Introduction to Quantitative Genetics, fourth ed. Prentice Hall, London.

Finlay, K., Wilkinson, G., 1963. The analysis of adaptation in a plant breeding program. Aust. J. Agric. Res. 14, 742–754.

Gauch, H., 2006. Statistical analysis of yield trials by AMMI and GGE. Crop Sci. 46, 1488–1500.

Gonçalves, E., St Aubyn, A., Martins, A., 2013a. The utilization of unreplicated trials for conservation and quantification of intravarietal genetic variability of rarely grown ancient grapevine varieties. Tree Genet. Genomes 9, 65–73.

Gonçalves, E., Carrasquinho, I., St Aubyn, A., Martins, A., 2013b. Broad-sense heritability in the context of mixed models for grapevine initial selection trials. Euphytica 189, 379–391.

Gonçalves, E., Martins, A., 2012. Genetic variability evaluation and selection in ancient grapevine varieties. In: Abdurakhmonov, I.Y. (Ed.), Plant Breeding. Intech, pp. 333–352.

Gonçalves, E., St Aubyn, A., Martins, A., 2007. Mixed spatial models for data analysis of yield on large grapevine selection field trials. Theor. Appl. Genet. 15, 653–663.

Gonçalves, E., StAubyn, A., Martins, A., 2010. Experimental designs for evaluation of genetic variability and selection of ancient grapevine varieties: a simulation study. Heredity 104, 552–562.

Henderson, C., 1975. Best linear unbiased estimation and prediction under a selection model. Biometrics 31, 423–447.

Hühn, M., 1990a. Nonparametric measures of phenotypic stability. Part 1: Theory. Euphytica 47, 189–194.

Hühn, M., 1990b. Nonparametric measures of phenotypic stability. Part 2: Applications. Euphytica 47, 195–201.

Husfeld, B., 1943. A situação actual do melhoramento da videira e a sua importância em viticultura. Agros 26, 243–261.

Kempton, R., 1984. The use of biplots in interpreting cultivar by environment interactions. J. Agric. Sci. 103, 123–135.

Levadoux, L., 1951. La sélection et l'hybridation chez la vigne. Imprimerie Charles Déhan, Montpellier.

Martins, A., 2007. Variabilidade genética intravarietal das castas. In: Böhm, J. (Ed.), Portugal vitícola, o grande livro das castas. Chaves Ferreira Publicações, Lisboa, pp. 53–56.

Martins, A., 2009. Genetic diversity of Portuguese grapevines: methods and strategies for its conservation evaluation and conservation. Acenología 112. Available from: http://www.acenologia.com/cienciaytecnologia/variedades_portuguesas_cien1209.htm.

Martins, A., Carneiro, L., Mestre, S., Gonçalves, E., Neves-Martins, J., Almeida, C., Ramadas, I., Eiras-Dias, J.E., Madeira, D., Magalhães, N., 1998. Facteurs d'instabilité du rendement de clones de vigne. Proc. XXIII Congrès Mondial de la Vigne et du Vin 1, 169–174.

Martins, A., Carneiro, L., Castro, R., 1990. Progress in mass and clonal selection of grapevine varieties in Portugal. Vitis 485–489 (special issue).

Nassar, R., Hühn, M., 1987. Studies on estimation of phenotypic stability: tests of significance for nonparametric measures of phenotypic stability. Biometrics 43, 45–53.

Patterson, H., Thompson, R., 1971. Recovery of inter-block information when block sizes are unequal. Biometrika 58, 545–554.

Rives, M., 1961. Bases génétiques de la sélection clonale chez la vigne. Ann. Amélior. Plantes 11, 337–348.

Rives, M., 1971. Génétique et amélioration de la vigne. In: Ribereau-Gayon, J., Peynaud, E. (Eds.), Traité d'ampélologie, Sciences et Techniques de la vigne. Dunod, Paris, pp. 171–219.

Sartorius, O., 1926. Zur Rebenselektionunter besonderer Berücksichtigung der Methodik under der Ziele auf Grund von 6-14 jährigen Beobachtungen an einem Klon. Z. für Pflanzenz 11, 31–74.

Sartorius, O., 1928. Uber die wissenschaftlichen Grundlagen der Reben selektion in reinen Bestanden. Z. für Pflanzenz 13, 79–86.

SAS Institute, 2008. SAS Proprietary Software, Release 9.2. SAS Institute Inc., Cary, NC.

Scherz, W., 1943. Ein weg zum auffinden gegen Plasmopara viticola resistenter soma-tischer mutanten innerhalb der spezies Vitis vinifera. Zünchter 15.

Searle, S., Casella, G., McCulloch, C., 1992. Variance Components. John Wiley & Sons Inc, Hoboken, New Jersey.

Smith, A.B., Cullis, B.R., Thompson, R., 2005. The analysis of crop cultivar breeding and evaluation trials: an overview of current mixed model approaches. J. Agric. Sci. 143, 449–462.

Grapevine breeding and clonal selection programmes in Spain

9

J. Ibáñez[1], *J. Carreño*[2], *J. Yuste*[3], *J.M. Martínez-Zapater*[1]
[1]Instituto de Ciencias de la Vid y del Vino (CSIC, UR, Gobierno de La Rioja), Logroño, Spain; [2]Instituto Murciano de Investigación y Desarrollo Agrario y Alimentario, Murcia, Spain; [3]Instituto Tecnológico Agrario de Castilla y León, Valladolid, Spain

9.1 Introduction

Spain is the country with the largest surface area dedicated to grapevines in the world (OIV, 2013). The vineyard surface area represents 5.6% of the total cultivated surface area in the country, and the area occupied by wine varieties represents more than 98% of the total cultivated grapevines in Spain. In recent years, it has diminished from 1,316,281 ha in 1990 to 1,128,735 ha in 2005 and to 954,020 ha in 2012 (MAGRAMA, 2013). About 60% of this surface area is dedicated to the production of wines within any VQPRD (Quality Wines Produced in Specified Regions) (MAGRAMA, 2012). In 2009, Spain was the third largest grape producer in the world, after Italy and France, with 5.7 MTn (OIV, 2013). Almost 95% of the total Spanish grape production is destined to produce wine; with an average production of 39 MHl in the period from 2006 to 2012 (Anon., 2013), Spain keeps the third position in the world ranking. The estimations for 2013, although very preliminary, point to a considerable production: 45 MHl, which means an increase above 30% in 2012 (Anon., 2013).

The varietal landscape in Spain is very rich: in 2009, there were 127 varieties in culture. Half of them (65) are local varieties with a cultivated surface lower than 500 ha, while three varieties (Airén, Tempranillo and Bobal) account for 52% of the total surface. The eight most cultivated varieties in 1990 were still the most cultivated in 2011: Airén, Tempranillo, Bobal, Garnacha Tinta, Monastrell, Cayetana Blanca, Viura and Palomino Fino, but their relative position in the ranking and their surface figures have changed considerably in the past years (Figure 9.1). Airén continues to be the most extended variety, but its surface has decreased by more than 200,000 ha from 1990 to 2009. Garnacha Tinta has also experienced a drastic reduction of 100,000 ha. The opposite tendency occurred in Tempranillo, which has increased its surface area almost five times in 21 years. This variety and Verdejo are the only Spanish varieties that have significantly increased their surface area in this period. The rest are French and are currently worldwide distributed varieties: Cabernet Sauvignon, Merlot, Syrah and Alicante Henry Bouschet (Garnacha Tintorera in Spain) (Figure 9.1).

The geographic distribution is quite diverse for the different varieties. Thus, 97% of Airén is cultivated in one Comunidad Autónoma (CA, or autonomous community, a first-level political and administrative division of Spain): Castile-La Mancha, 99%

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00009-0

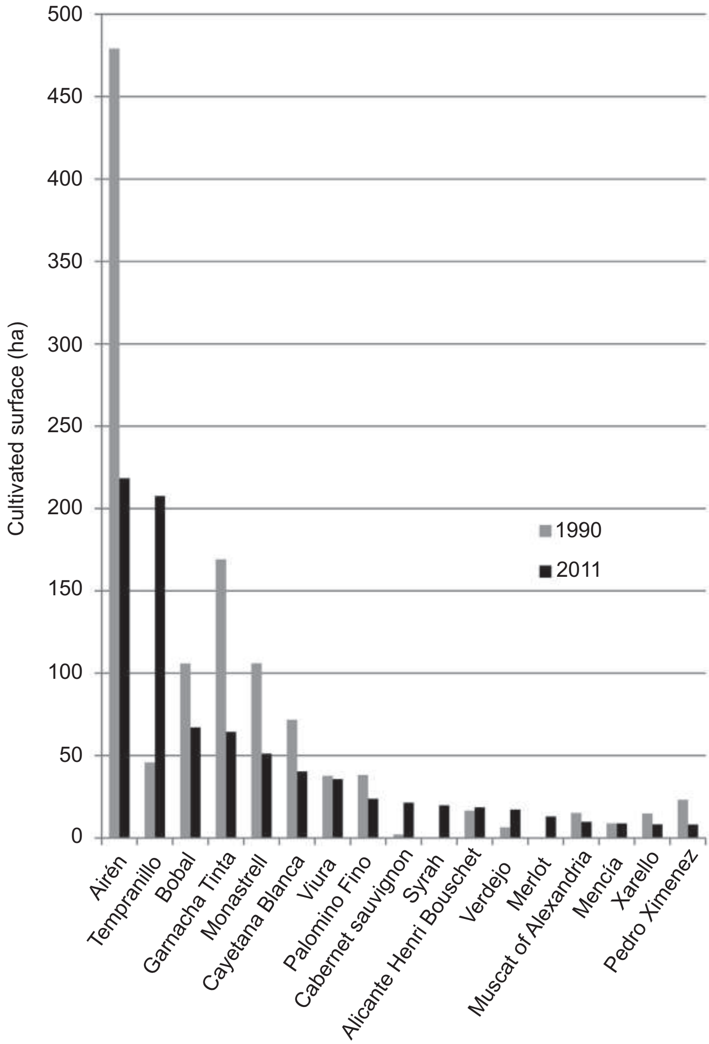


Figure 9.1 Cultivated surface (ha) of the widest-planted varieties in Spain in 1990 and 2012. Data from Cabello et al. (2011), Anon (2012).

of Bobal, is cultivated in two CAs, Castile-La Mancha and Valencia; and Tempranillo is cultivated in 16 of the 17 CAs, with a relevant surface in many of cases. Garnacha Tinta and Viura (synonym Macabeo) are also extended through the country, and the same occurs with the French varieties (Cabello et al., 2011).

Regarding table grape varieties, the total surface area dedicated to this crop in Spain has been reduced from the 23,000 ha cultivated in 2003 (OIV, 2004) to the 11,391 ha that were cultivated in 2012 (MAGRAMA, 2013). Cultivation of table grapes is concentrated on the Mediterranean region, with Valencia, Murcia and Andalusia as the main producing areas. The average yield obtained for table grapes in Spain is 17,000 kg per ha, although in the Murcia region, using overhead trellis systems, yield varies between 20,000 and 40,000 kg per ha with an average of 24,500 kg. Thirty years ago, all the table grape production corresponded to seeded varieties, such as the Spanish autochthonous Aledo, Dominga, Napoleón and Ohanez, or other international ones, such as Italia, Cardinal, Muscat of Alexandria, etc. However, in the last 20 years all of these traditional seeded varieties have been progressively replaced by seedless varieties that currently occupy 20% of the table grape surface, mainly with cultivars such as Sugraone, Crimson Seedless and Autumn Royal. More recently, in the last five years, new seedless cultivars from different foreign breeding programmes are being introduced, such as Prime, Mistery, Early Sweet, Ralli, Mid Night Beauty, Scarlota, Allison, Timpson, etc. or from the Spanish breeding programme being developed in the Murcia region with cultivars such as Itumfive, Itumfour, etc.

The improvement of grapevines in Spain has mainly followed two alternative routes, depending on the grape use: wine varieties have been improved through clonal selection, and only a few timid experiments have been initiated on the breeding of new varieties, which could change in future years. By contrast, there is an active programme for the breeding of new table varieties.

9.2 Clonal selection in Spain

9.2.1 Why clonal selection?

There are several causes favouring the developing of clonal selection programmes for wine varieties and not breeding programmes, but the main reason is related to the existing wine protection figures. The Protected Designations of Origin (DOP) and Protected Geographical Indications (IGP) constitute the system used in Spain for the recognition of a differentiated quality. Most of the quality wine produced in Spain is included in one of the 90 DOP (equivalent to French VQPRD) or of the 41 IGP. Both types of protection figures include in their regulation an exhaustive list of varieties authorized in any particular DOP or IGP. The selection of clones within any of those authorized varieties gives rise to a plant material, which is immediately accepted by the protection figure. However, that is not the case with new bred varieties that require a long administrative pathway of registration and acceptance by the DOP regulatory boards, as well as by the consumers.

Grapevine is a woody plant, and it takes some years from the initial steps of planting until there is a consistent and quality crop. For that reason, mistakes are very costly, and grape growers are conservative in many senses, including the varieties and rootstocks to be used. The problem was (and it still is, for many varieties) that there were no healthy plants to multiply and distribute to grape growers or, at least, there were no guarantees of health. The official clone certification system offers such guarantees for some common diseases, especially viruses.

9.2.2 Clonal selection process and goals

The word ‘clone’ derives from the Greek term ‘klon’ that means ‘twig’ or ‘branch’, and refers to the asexual or vegetative reproduction from a single origin. In viticulture, it refers to the vegetative descendant of a vine selected for its indisputable identity, its phenotypic characteristics and health status. Grapevine clonal selection started in Germany in the nineteenth century and continued in other European countries like France or Italy in the second half of the twentieth century. In Spain, it started in the 1970s in the regions of La Rioja and Catalonia. Initially, the basic aim of clonal selection was to get healthy plants and to increase yield. Today, quality has also been considered as a relevant goal, in some cases in detriment of the yield. In addition, the selection of colour variants or other type of variants that strongly affect quality opened the way to the generation of derived cultivars, such as the recently registered and accepted Tempranillo Blanco in the DOCa Rioja (Martínez et al., 2006).

The intravarietal variability has its origin in the somatic mutations occurring at a very low rate in any cell division, including point mutations, large deletions, illegitimate recombination or variable number of repeats in microsatellite sequences (Pelsy, 2010). Given that many wine varieties have been vegetatively multiplied over centuries, the probability of accumulating such rare mutations increases. Thus, many current varieties can be considered as populations of very similar plants but carrying mutations in different regions of their DNA sequence and in different chimerical states (Torregrosa et al., 2011). Clonal selection tries to exploit such variation by selecting those plants with useful characteristic features for grape growers.

The major benefit of using clones is the possibility to select the best adapted genotype within a variety to a certain environment (soil, climate) and to produce a certain type of wine. Besides, identical genotypes in a vineyard have identical behaviour and growth stages, facilitating management and harvesting (Forneck et al., 2009). On the other hand, the possible reduction of genetic variability may be counteracted by using several clones, thus reducing the uniformity of the vineyard.

The clonal selection process starts with the prospection of vines in the field (Figure 9.2). Normally, plots with vines older than 30 years are chosen for the prospection, because they have a larger probability of carrying mutations. The selected vines are studied in situ for at least three years in a process known as clonal preselection, or mass selection. At this stage, the agronomic performance, sanitary status and varietal identity are individually evaluated. Agronomic characterization includes harvest weight per vine, sugar content and weight of pruning (vigour), as well as many other possible measures, which will depend on the aim of the selection (acidity, sugar/acidity ratio, phenology, etc.). Sanitary status is usually evaluated at this stage by a visual inspection of the vines and for the presence of several viruses through the enzyme-linked immunosorbent assay (ELISA). This test is usually considered as definitive when a positive is found, but it does not exclude an infection when the result is negative. The European Union, in the Directiva 2005/43/EC on the marketing of grapevine propagation material, demands each member state to ensure the absence of Grapevine fanleaf virus (GFLV), Arabis mosaic virus (ArMV) and Grapevine leafroll associated virus (GLRaV-1 and GLRaV-3) in grapevine nursery plants. Varietal identity may be checked through ampelography (morphological) descriptions, but presently is commonly checked through the use of molecular markers, mainly microsatellites.

After the initial evaluation, apparently healthy mother plants are chosen according to the purpose of the clonal selection. These mother vines are multiplied and planted

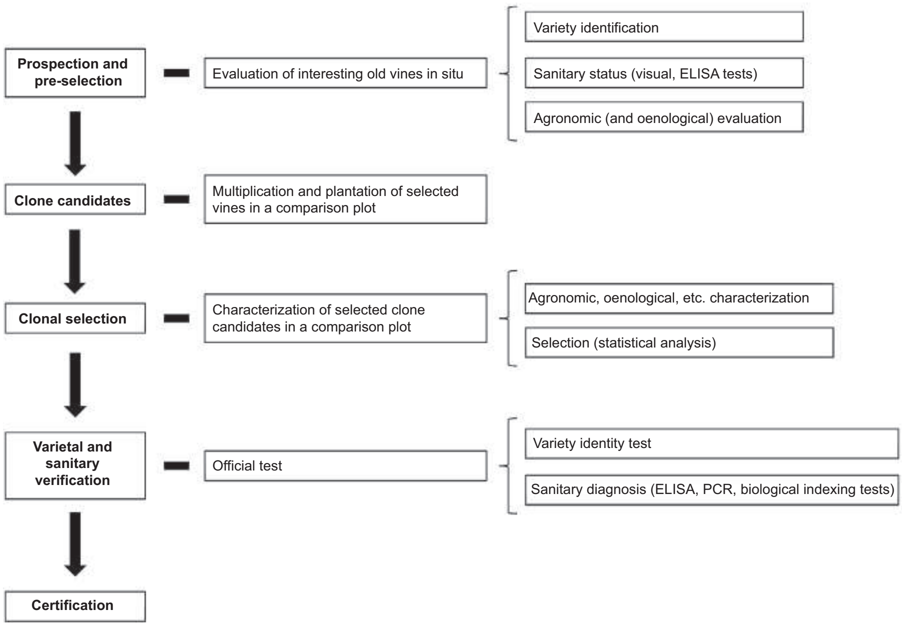


Figure 9.2 Scheme of the selection process for clonal certification in Spain.

both in a comparative plot and in individual containers to keep then isolated and protected from new infections. When the planted vines in the comparative plot are in full production (2 or 3 years later), they are fully characterized for at least 3 years, normally more. Also, material from these mother plants is sent to the national reference centre to be officially evaluated for sanitary status. In Spain, the reference centre is the Instituto Murciano de Investigación y Desarrollo Agrario y Alimentario (IMIDA), which carries out the virus diagnosis using immunoassay, DNA-based and biological indexing techniques. It takes 3 years to get the official results of the diagnosis. Full characterization may include many traits, depending on the aims, and in wine varieties, it requires oenological characterization and sensory analysis by a panel of experts. A huge amount of data is collected over many years, and these data need to be statistically examined to reach significant conclusions. Normally, several clones with different characteristics are chosen and submitted for certification.

Authorities responsible for the certification process do not examine the 'quality' of the clones but only the varietal identity and the sanitary status, mainly regarding the presence of the above-listed viruses. Although is not mandatory, the presence of other viruses is also checked at IMIDA: Grapevine leafroll associated virus (GLRaV-2, GLRaV-4 and GLRaV-6), Rugose Wood complex (RW) and Grapevine fleck virus (GFkV, mandatory for rootstocks). When the certification process is completed, certified plants may be sold by authorized nurseries. These plants arise from base material, which arise from the mother plants conserved in an appropriate way (isolated containers) and are warranted for the varietal identity and for the absence of the virus of the official list. The certified plants carry a blue label to distinguish them from the standard plants, which carry a yellow label. The standard material is the only one available for those varieties for which clones have not been selected or clonal selection has not been successful, for example because no virus-free plants could be found in the prospection. In this last case, an alternative is available, although it is time-consuming and not always successful: in vitro culture of meristems and thermotherapy. This method has been used mainly for local, almost extinct varieties: Malvasia de Banyalbufar in the Balearic Islands and Blasco and Melonera in Andalusia. The material obtained in this way should be checked to determine that no somaclonal variation altering the typicity of the cultivar has been produced as a consequence of in vitro culture.

9.2.3 Clonal selection programmes in Spain

In Spain, clonal selection has been mainly carried out by public institutions at a regional level, although there are a few important exceptions, like the private nurseries Viveros Provedo and Agromillora-Vivai Cooperativi Rauscedo (VCR), the winery Bodegas Roda or, more recently, the nursery Vitis Navarra. The first clonal selection programme was started in 1976 by the regional government of CA La Rioja, through its Centro de Investigación y Desarrollo Tecnológico Agroalimentario (CIDA), who began a programme of clonal selection of Tempranillo, the main red wine variety in La Rioja and in Spain (Renedo et al., 1995). This programme gave rise to the certification of eight clones in 1990, including some which are among the most planted in Spain. At the same time, another public institute, INCAVI (Catalonia), started their clonal selection programmes, which have given rise to more than 60 certified clones. In the 1980s, other CAs, such as Andalusia (IFAPA Centro Rancho de la Merced), Galicia (EVEGA, MBG-CSIC), Navarre (EVENA), Valencia (UPV) or Madrid (IMIDRA), began clonal selection programmes, and this continued in the 1990s in Castile and Leon (ITACYL), Basque Country (EFZ), Aragon (CTA), Extremadura (SIDT) and also by private companies like Viveros Provedo, Agromillora-VCR and Bodegas Roda. In the 2000s, the CAs of Asturias (SERIDA), Balearic Islands (UIB) and Castile-La Mancha (IVICAM) and the nursery Vitis Navarra started their clonal programmes. In addition, clonal and sanitary selection of the main traditional table grape cultivars was also performed between 1978 and 1987 at IMIDA (Murcia).

The type of cultivar subjected to selection differs depending on the nature of the selection programme developer. Public institutions belonging to CA governments have normally focused more on local and minor varieties (even in danger of extinction sometimes) or on varieties of regional relevance, although in some cases the variety may be also relevant in other regions. Private companies focus on widely planted varieties or on those varieties with a specific commercial interest.

The criteria for selection have evolved within the limited period of time of clonal selection programme development in Spain. At the beginning, the aim of the selections was to obtain healthy clones (main criterion) with a good, consistent yield. Both criteria are still very important, but others have also become important. In a survey done among the most active institutions and companies currently working in clonal selection, different descriptors were used to define their selective criteria. In the ongoing selections, probable alcohol (sugar content) and titratable acidity are among the most generalized criteria. To keep high levels of acidity is a special challenge in many regions of Spain because of its hot climate. Other criteria are more type-specific, like colour for the red varieties or aroma for the white ones. Again, the challenge is to keep primary aromas or a high phenolic content under the Spanish climate. In addition, low bunch compactness and small berry size are selective criteria to get a uniform ripening and a healthy, high-quality harvest. There are also variety-specific criteria, such as high fruit set in varieties with coulure problems (e.g. Garnacha Tinta, Merlot). Also, the resistance to *Botrytis* infection (also influenced by the bunch compactness) is a criterion used for some clonal selection programmes.

There are several active clonal selection programmes in Spain, while others have been finished, and other programmes have been cancelled because of funding difficulties. Currently, selection programmes are being developed by public institutions in Andalusia, Aragon, Asturias, Balearic Islands, Basque Country, Castile and Leon, Catalonia, Galicia, La Rioja, Madrid, Murcia and Navarre, while Extremadura and Valencia maintain previously obtained certified material. Currently, no clonal selection programmes are being developed in the Canary Islands, Cantabria or Castile-La Mancha. Also, some programmes are being developed by private companies: Agromillora-VCR, Bodegas Roda, Vitis Navarra and Viveros Provedo. Currently, there are at least 64 varieties under clonal selection, most of which (50) are included in just one selection programme. On the other side, Garnacha (white and red), Tempranillo and Airén are included in three or more selection programmes, while Albariño, Bobal, Cabernet Sauvignon, Godello, Graciano, Merenzao, Merlot, Moscatel de Grano Menudo, Viura and Xarello are being selected in two different programs.

It is important to mention that in many selection programmes, the aim is to get several clones that present a range of variability for several of the selection criteria. This offers the grape grower the possibility of choosing a single clone with the characteristics better adapted to its zone of production or several clones with complementary characteristics. In this sense, Bodegas Roda performed a selection in Tempranillo that was not focused on obtaining certified clones, but a family of clones (called Familia Roda 107) adapted to produce a type of wine. According to their data, more than 400,000 vines of this clone family have been distributed up to now.

9.2.3.1 The clonal selection programmes developed in Castile and Leon

The Instituto Tecnológico Agrario de Castilla y León (ITACYL) has developed two clonal selection programmes, which may exemplify public clonal selection programmes in Spain. The first programme was initiated in 1990 (Yuste et al., 2006) and focused on the main varieties cultivated in the region, although some of them are important in other regions, even at a national level: Albillo Mayor, Albillo Real and Verdejo (white berried) and Garnacha Tinta, Juan García, Mencía, Prieto Picudo and Tempranillo (black berried). The aim of this selection was to obtain clones with a good yield, alcoholic degree and acidity, and, in the case of the red varieties, high phenolic content (TPI, Total Polyphenol Index). In a first phase, many plots were prospected and between 41 vines (from 9 plots, Albillo Real) and 340 vines (from 38 plots, Tempranillo) were initially selected from each variety. Over 3–5 years, these vines were studied in situ, mainly following the sanitary status and doing a preliminary agronomical and oenological characterization.

In a second phase, the virus-free vines that showed better characteristics in their original plots (clone candidates) were multiplied and planted in 1993 in a comparison plot in the Valladolid province. For each potential clone, several vines were planted to allow making individual microvinifications. The number of clone candidates was different for each variety: 15 of Albillo Mayor, 15 of Albillo Real, 30 of Garnacha Tinta, 38 of Juan García, 30 of Mencía, 37 of Prieto Picudo, 90 of Tempranillo and 45 of Verdejo. Thus, a total of 300 clone candidates of eight varieties was further evaluated. After 4 years, once the plants acquired the adequate status, the potential clones were characterized both agronomically and oenologically during at least 5 years. The characteristics evaluated were vegetative development, productive behaviour and oenological and organoleptic qualities. Those characteristics were valued through different parameters, including number of shoots, weight of pruning, bunch number and weight, analytical composition of the must and wine tasting. Each potential clone was valued in comparison with the set of clones under evaluation for such variety, and the final evaluation included three aspects, weighted as follows: agronomic 30%, oenological 35% and organoleptic 35%.

Thus, a total of 41 clones of the eight varieties were considered suitable for certification because of their sanitary status and their evaluated characteristics (Rubio et al., 2009). These certified clones were named with numbers preceded by the acronym of Castile and Leon (CL):

- Albillo Mayor: CL7, CL17, CL30
- Albillo Real: CL35, CL207
- Garnacha Tinta: CL52, CL53, CL55, CL288, CL294
- Juan García: CL12, CL21, CL52
- Mencía: CL51, CL79, CL94
- Prieto Picudo: CL9, CL31, CL58, CL110, CL116
- Tempranillo: CL16, CL32, CL98, CL117, CL179, CL242, CL261, CL271, CL280, CL292, CL306, CL311, CL326
- Verdejo: CL4, CL6, CL21, CL34, CL47, CL77, CL101

The clone mother vines were planted in individual pots and are maintained at ITACYL facilities to warrant their health status, and as a backup material. ITACYL also has a field with plants from the mother vines to provide cuttings to the nurseries, who multiply and sell certified material to the grape growers. In 2000, these clones began to be distributed among nurseries to produce certified plants for grape growers.

This first clonal selection programme done at ITACYL has had considerable effects on the viticulture sector. For instance, the clone CL306 of Tempranillo is presently one of the most used in Northern Spain. In the case of Verdejo, a variety for which about 80% of the currently planted vines are certified material, there is a predominance of clones CL101, CL6, CL77 and CL21, although the final election of a given clone by a grape grower depends on the clone characteristics and on the local soil and climate conditions of the cultivation field.

The second clonal selection programme developed by ITACYL since 2002 focused on less cultivated varieties in the cited region of Castile and Leon: Godello, Malvasía Castellana (synonym Doña Blanca), Moscatel de Grano Menudo, Puesta en Cruz and

Verdejo Serrano (white berried); Garnacha Roja and Verdejo Colorado (red berried); Bastardillo Chico (synonym Merenzao), Bruñal, Estaladiña (synonym Pan y Carne), Gajo Arroba, Mandón, Negro Saurí (synonym Merenzao), Prieto Picudo Oval, Rufete and Tinto Jeromo (black berried).

Some of the chosen varieties are in risk of extinction, and thus, the project is at the same time a clonal selection programme and a recovery programme. This is the case of Puesta en Cruz, Verdejo Serrano, Verdejo Colorado, Estaladiña, Gajo Arroba, Prieto Picudo Oval and Tinto Jeromo. The methodology used is similar to the first programme, but the number of plots and plants located for each variety has been much scarcer. For this reason, the search for plants has been a greater effort, but the selection of clone candidates has been easier. The number of clone candidates selected was the following: three of Godello, three of Malvasía Castellana, three of Moscatel de Grano Menudo, six of Puesta en Cruz, 54 of Verdejo Serrano; 18 of Garnacha Roja, three of Verdejo Colorado, nine of Bastardillo Chico, 12 of Bruñal, three of Estaladiña, nine of Gajo Arroba, nine of Mandón, 15 of Negro Saurí, 16 of Prieto Picudo Oval, 51 of Rufete and nine of Tinto Jeromo. These clone candidates were multiplied and planted in comparison plots in different locations, according to their original cultivation regions. The planting of the different varieties was not done in the same year, and so the progress in the selection programme is not the same for each one. Thus, Rufete, Prieto Picudo Oval and Negro Saurí are the most advanced varieties in the selection program, and there are already characterization data of their clone candidates. The first certified clones of these varieties are expected for 2016. In the case of Estaladiña (for which clone candidates were planted in 2013), Garnacha Roja and Verdejo Serrano (planted in 2012), the first certified clones would be expected for 2020.

9.2.4 Certified clones in Spain

In Spain, the first *vinifera* clone was certified in 1987. It was Xarello I-20 and was selected by INCAVI (Catalonia). Since then, a total of 638 clones of 108 *Vitis vinifera* varieties have been certified (data provided by the Spanish Office of Plant Varieties: OEVV-MAGRAMA, 2013), although, of course, the list is open. More than 95% of all *vinifera* certified clones in Spain are from wine varieties, and Table 9.1 shows the number of certified clones for each wine variety. Garnacha Tinta is, by far, the variety with the highest number of certified clones (72), followed by Tempranillo (49), Palomino Fino (26) and Cabernet Sauvignon (23). About 45% of the certified clones have been obtained from white-berried varieties and 55% from red/black berried varieties. Regarding the origin of the cultivars, and according to the *Vitis* International Variety Catalogue (VIVC), more than 60% of the certified clones are from Spanish varieties and 26% are from French varieties.

In most of the clonal selection programs, the initial success is measured through the number of certified clones obtained. In that sense, INCAVI (Catalonia), IFAPA-Rancho La Merced (Andalusia), EVEGA (Galicia) and ITACYL (Castile and Leon) are among the most successful institutions, with 61, 48, 48 and 42 certified clones of wine varieties, respectively. The full success is achieved when the certified clones are multiplied by nurseries and planted by grape growers in a significant way, which of

Table 9.1 Number of certified clones of wine varieties in Spain

Prime name[a]	Original name	Variety number[a]	Country of origin of the variety[a]	Colour of berry skin[a]	No. of certified clones
Airen	Airen	157	Spain	Blanc	4
Alarije	Alarije	213	Spain	Blanc	3
Albarin Blanco	Albarin Blanco	22838	Spain	Blanc	2
Albillo Mayor	Albillo Mayor	12581	Spain	Blanc	3
Albillo Real	Albillo Real	247	Spain	Blanc	2
Aledo	Aledo	262	Spain	Blanc	1
Alicante Henri Bouschet	Garnacha Tintorera	304	France	Noir	3
Alvarinho	Albariño	15689	Portugal	Blanc	16
Blaufraenkisch	Limberger	1459	Austria	Noir	1
Bobal	Bobal	1493	Spain	Noir	7
Borba	Borba	15501	Portugal	Noir	4
Bourboulenc	Bourboulenc	1612	France	Blanc	1
Cabernet Franc	Cabernet Franc	1927	France	Noir	4
Cabernet Sauvignon	Cabernet Sauvignon	1929	France	Noir	23
Caladoc	Caladoc	1989	France	Noir	1
Carignan Noir	Mazuela	2098	France	Noir	19
Cayetana Blanca	Cayetana Blanca	5648	Spain	Blanc	3
Cayetana Blanca	Pardina	5648	Spain	Blanc	1
Chardonnay Blanc	Chardonnay	2455	France	Blanc	16
Chasan	Chasan	2470	France	Blanc	1
Chasselas Blanc	Chasselas	2473		Blanc	1
Chenin Blanc	Chenin Blanc	2527	France	Blanc	4
Clairette Blanche	Clairette	2695	France	Blanc	2
Colombard	Colombard	2771	France	Blanc	2
Cot	Malbec	2889	France	Noir	5

Prime name[a]	Original name	Variety number[a]	Country of origin of the variety[a]	Colour of berry skin[a]	No. of certified clones
Dona Blanca	Doña Blanca	15673	Spain	Blanc	15
Doradilla	Doradilla	3654	Spain	Blanc	3
Ekigaina	Ekigaïna	16844	France	Noir	1
Gamay Noir	Gamay Noir	4377	France	Noir	1
Garnacha Blanca	Garnacha Blanca	4457	Spain	Blanc	4
Garnacha Peluda	Garnacha Peluda	4460	Spain	Noir	1
Garnacha Tinta	Garnacha Tinta	4461	Spain	Noir	72
Garrido Fino	Garrido Fino	4470	Spain	Blanc	2
Gouveio	Godello	12953	Portugal	Blanc	4
Graciano	Graciano	4935	Spain	Noir	12
Juan Garcia	Juan Garcia	5841	Spain	Noir	3
Loureiro Blanco	Loureira	6912	Spain	Blanc	2
Malvar	Malvar	7254	Spain	Blanc	1
Malvasia Di Sardegna	Malvasia Aromática	7266		Blanc	1
Manseng Gros Blanc	Gros Manseng	7338	France	Blanc	1
Manseng Petit Blanc	Petit Manseng	7339	France	Blanc	1
Manto Negro	Manto Negro	7348	Spain	Noir	1
Mantuo	Montua	2520	Spain	Blanc	1
Marsanne	Marsanne	7434	France	Blanc	1
Marselan	Marselan	16383	France	Noir	1
Mencia	Mencia	7623	Spain	Noir	5
Merlot Noir	Merlot	7657	France	Noir	18
Merseguera	Merseguera	7660	Spain	Blanc	2
Monastrell	Monastrell	7915	Spain	Noir	17
Moristel	Moristel	12353	Spain	Noir	5
Muscat A Petits Grains Blancs	Moscatel De Grano Menudo	8193	Greece	Blanc	18

Continued

Table 9.1 **Continued**

Prime name[a]	Original name	Variety number[a]	Country of origin of the variety[a]	Colour of berry skin[a]	No. of certified clones
Muscat A Petits Grains Rouges	Moscatel De Grano Menudo Rojo	8248	Greece	Rouge	1
Muscat Of Alexandria	Moscatel De Alejandria	8241	Italy	Blanc	8
Ondarrabi Beltza	Hondarrabi Beltza	8768	Spain	Noir	1
Ondarrabi Zuri	Hondarrabi Zuri	8769	Spain	Blanc	8
Palomino De Jerez	Palomino	8887	Spain	Blanc	2
Palomino Fino	Palomino Fino	8888	Spain	Blanc	26
Parellada	Parellada	8938	Spain	Blanc	11
Parraleta	Parraleta	8951	Spain	Noir	8
Pedro Ximenes	Pedro Ximenez	9080	Spain	Blanc	5
Perruno	Perruno	9185	Spain	Blanc	8
Picapoll Blanco	Picapoll Blanca	9232	Spain	Blanc	2
Pinot Gris	Pinot Gris	9275	France	Gris	2
Pinot Meunier	Meunier	9278	France	Noir	2
Pinot Noir	Pinot Noir	9279	France	Noir	10
Prieto Picudo Tinto	Prieto Picudo	9694	Spain	Noir	5
Redora	Redora	9982	Spain	Blanc	1
Riesling Weiss	Riesling	10077	Germany	Blanc	7
Roussanne	Roussanne	10258	France	Blanc	2
Sangiovese	Niellucio	10680	Italy	Noir	1
Sangiovese	Sangiovese	10680	Italy	Noir	1
Sauvignon Blanc	Sauvignon Blanc	10790	France	Blanc	13
Sauvignon Gris	Sauvignon Gris	22513	France	Gris	1
Sciaccarello	Sciacarello	10837	Italy	Noir	1

Prime name[a]	Original name	Variety number[a]	Country of origin of the variety[a]	Colour of berry skin[a]	No. of certified clones
Semillon	Semillon	11480	France	Blanc	2
Servant	Servant	11527	France	Blanc	1
Syrah	Syrah	11748	France	Noir	17
Tannat	Tannat	12257	France	Noir	3
Tempranillo	Tempranillo	12350	Spain	Noir	49
-	Torrontes	-	Spain	Blanc	1
Touriga Nacional	Touriga Nacional	12594	Portugal	Noir	3
Trajadura	Treixadura	12629	Spain	Blanc	7
Traminer Rot	Gewürztraminer	12609	Italy	Rouge	5
Trebbiano Toscano	Ugni Blanc	12628	Italy	Blanc	1
Trepat	Trepat	12633	Spain	Noir	12
Verdejo Blanco	Verdejo	12949	Spain	Blanc	7
Verdejo Negro	Verdejo Negro	12950	Spain	Noir	6
Verdot Petit	Petit Verdot	12974	France	Noir	1
Vermentino	Vermentino	12989	Italy	Blanc	3
Vijiriega Comun	Vijariego Blanco	13075	Spain	Blanc	2
Viognier	Viognier	13106	France	Blanc	1
Viura	Macabeo	13127	Spain	Blanc	17
Xarello	Xarello	13270	Spain	Blanc	12
Zalema	Zalema	13375	Spain	Blanc	6

[a]According to the Vitis International Variety Catalogue (VIVC, www.vivc.de, accessed November 2013).
Data provided by OEVV, MAGRAMA.

course does not mean the same for a minor variety than for Tempranillo, for instance. Precisely, clones from Tempranillo are among the most distributed in Spain. Although is difficult to have exact figures, RJ43 (CIDA, La Rioja) has probably been the widest distributed Spanish certified clone during the previous decade, followed by RJ51, but Tempranillo CL306 is currently the clone most widely used. Garnacha Tinta has been selected in many regions, and 75 certified clones are available. Regarding their distribution, the clones that stand out arise from EVENA (EVENA11, EVENA13, EVENA 14, EVENA 15), Aragon (ARA2, ARA4, ARA24) and ITACYL (CL53), although the French clone ENTAV70, which is very productive, continues to be the most planted in La Mancha. Another successful selection programme was done with Graciano in La Rioja, with more than 500,000 plants distributed. In the case of Verdejo, the most increasing white variety in Spain, the clonal selection of ITACYL (Castile and Leon) was also very well received by grape growers, who have planted more than 1,000,000 certified vines of different CL clones, prevailing those mentioned above. More than 100,000 vines have been planted of clones from Parellada, Viura and Xarello (INCAVI, Catalonia). In the case of more local varieties, there are examples of successful clones of Malvar (IMIDRA, Madrid), Mencía and Prieto Picudo (ITACYL, Castile and Leon) or Albariño (MBG-CSIC, Galicia), which have overcome 40,000 plants each.

The figures of certified plants must be put into the context of the total amount of plants sold by nurseries, which has decreased during the past 10 years (Figure 9.3). From the 2005/2006 season to the 2007/2008 season, a decrease of more than 50% was produced (data from OEVV-MAGRAMA 2012). In all the seasons considered, nurseries sold more certified than standard plants, although the proportion has decreased, from about 67% (2005/2006 and 2007/2008) to 56% (2010/2011). One reason for this reduction may be the slightly higher price of the certified material in comparison with standard material. This small difference is important in a country with a deep economic crisis. Also, the use of material that was somehow selected but not submitted to the certification process may have contributed to the mentioned reduction.

In Spain, grapevine plants are mainly produced in two regions: Valencia (55%) and Navarre (30%). Other minor producers are located in Castile-La Mancha, Catalonia, Extremadura, Murcia and La Rioja. The market of Valencian nurseries is primarily the centre and south of Spain (Andalusia, Extremadura, Castile-La Mancha, Murcia and Valencia) with varieties like Airén, Bobal, Cayetana Blanca, Monastrell or Pedro Ximenez. The number of available certified clones for many of these varieties is small, or even null, and so a considerable amount of standard material is produced. On the contrary, the major market of Navarre nurseries is Northern Spain, with varieties like Tempranillo, Garnacha Tinta, Verdejo or Albariño. In this case, there are many certified clones for the most important varieties, and consequently, the production of certified material is larger than that of standard material.

In addition to *vinifera* clones, a number of rootstock clones are available for grape growers in Spain. In total, 144 clones from 29 different rootstocks are registered in the OEVV database (MAGRAMA). There exist clones for 20 of the 22 authorized rootstocks in Spain, with Richter 110 having the largest number of clones (26 clones), followed by Millardet et Grasset 41B (21), Selektion Oppenheim 4 (15) and Couderc 161-49 (11).

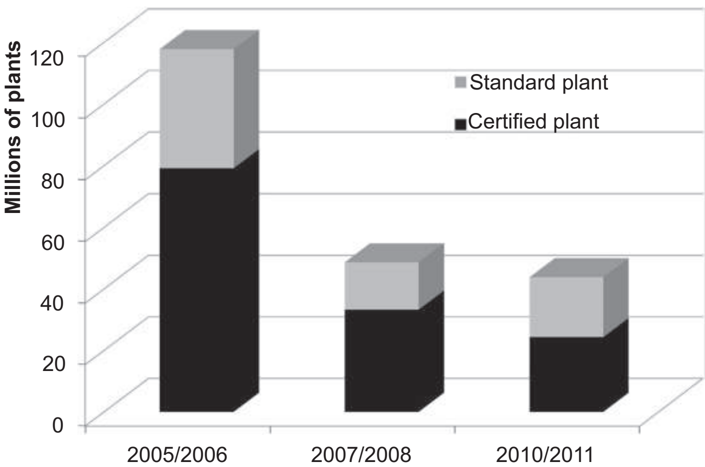


Figure 9.3 Certified and standard plant material sold by nurseries in three seasons (in millions of plants).

9.3 Breeding of new grapevine varieties in Spain

Breeding new varieties is the best way to improve adaptation of a given crop, not only to environmental changes but to the evolution of production requirements and markets. This is fully true for table grapes, for which breeding programmes are producing new cultivars with a higher rate since the last century, and a Spanish breeding programme has been successful in the production of new breeds, as will be described later. However, in the case of wine cultivars, the conservative wine market has promoted the maintenance of recognized cultivars for decades and even centuries, while technological developments have focused on the improvement of production systems better adapted to the high-quality production of those elite cultivars. As we will see, this situation is now slowly changing in Spain, even for wine varieties as the markets and producers are defining new goals.

9.3.1 Breeding of wine varieties

The improvement of wine varieties in Spain can be described as moving through different stages. In the first stage, all the genetic progresses have been based on the clonal selection already described in the previous section. As described above, the goals of this selection have changed but have always moved within a narrow range of cultivars and within what could be considered as the international taste definition. Perhaps the highest innovation within this stage has been the development of new, essentially derived varieties more appropriate to new types of wines that still conserved the main name (and fame) of the original variety. This is the case of Tempranillo Blanco, a somatic variant of Tempranillo, recently selected and registered as a new cultivar in the DOCa Rioja.

In a second stage (and probably as a response to a market demand for regional typicity and diversity), we are now witnessing in Spain and in other European countries with ancient viticulture an increased interest to rescue forgotten minority cultivars. These minor cultivars show a very narrow regional distribution, and multiple studies, focused on their genetic and oenological characterization, are generating new sorts of wines. These cultivars and wines can also identify local productions or small geographical regions, providing them with special identities. Some examples are the minor cultivar Rufete in D.O. Sierra de Salamanca, cultivar Prieto Picudo in D.O. Tierra de León, or Bruñal in D.O. Arribes. These rediscovered cultivars and wines exploit the added value of diversity, contrasting with the uniformity showed by many wines produced with widespread cultivars. This trend goes against the rapid loss of genetic diversity in vineyard plantations and can be considered as a very positive mean to maintain a higher genetic diversity in the vineyards, as well as product diversity in the markets.

Finally, a third stage in the improvement of Spanish wine cultivars through breeding programmes still needs to be fully developed. At present, it is currently starting, as a result of two major challenges identified by the growers. On the one hand, there is the need to develop new varieties that are more resilient to climate change and that are able to keep the main features of elite cultivars under the evolving climate conditions. This can be very important in Spain, because it is located in a geographical region where an increase of at least two degrees and a reduction in water precipitation is expected in the next 50 years. On the other hand, fungal pathogens are a problem in some regions of the country, especially Northern regions with higher precipitation, and production requires the use of pesticides, but, at the same time, consumers are increasingly demanding wines where production is more respectful to the environment, what could be achieved through the obtention of new, fungal resistance wine varieties.

The oldest breeding programme in Spain was started in Jerez by Gonzalo Fernández de Bobadilla at the Estación de Viticultura y Enología de Xerez (EVEX) in the 1940s, first focused on the development of new rootstocks and later of new wine varieties using locally cultivated varieties as progenitors: Cañocazo, Garrido, Palomino and Pedro Ximenez. As a consequence of this wine breeding programme, the variety Redora (Palomino Fino × Pedro Ximénez 17) was included in the national registry of commercial varieties. In 2003, Miguel Lara started another breeding programme in Jerez at IFAPA-Centro Rancho de La Merced (Andalusia), using Palomino Fino clone 6 as a female parent and Merlot, Syrah, Alicante Henri Bouschet, Tempranillo and Regent as male parents. The aim of this programme was to obtain new varieties with higher tolerance to mildew, *Oidium* and *Botrytis*, well adapted to the local environment and with good aptitude for wine quality. The progenies obtained are quite small and are still under evaluation; some hybrids (Palomino × Regent) stand out for their tolerance to fungus diseases. More recently, searching to improve quality traits of specific varieties, some progenies have also been generated by IMIDA (Murcia) using Monastrell and by Viveros Provedo (La Rioja) around Tempranillo. Crosses always involved different wine grapevine cultivars and generated small progenies, a few hundred individuals that are being characterized for quality and production. Somehow, in spite of some obtained varieties, these first trials can be considered more as proofs of concept than as the initials of solid breeding programmes.

9.3.2 Breeding of table grape varieties

Decades ago, table grape production in Spain was limited to seeded varieties, including some autochthonous ones like Ohanez, Aledo, Dominga and Don Mariano (also known as Napoleón) and others bred in other countries like Italia and Cardinal. The development of new seedless cultivars derived from Sultanina in the 1960s in the United States caused the rapid reduction of Spanish table grape exports and some well-known production areas in Andalusia disappeared (Alonso et al., 2006). Sultanina (Thompson Seedless) and Flame Seedless were the first seedless varieties introduced in Spain about 30 years ago. However, their production was not successful because these varieties bear compact clusters and small berries, and require specific production techniques to get quality crops, such as gibberellin treatments, cluster arrangements and girdling, that were not usual for Spanish grape growers and, as a result, were expensive. Later, seedless varieties, such as Sugraone, Crimson Seedless, Autumn Royal, etc., have promoted a rapid increase of the vineyard surface dedicated to seedless table grape cultivars, especially in the last 25 years.

Although different table grape breeding programmes around the world are currently offering new seedless varieties, there are two main problems regarding their introduction and use in Spain. The first problem, affecting the production, is that the Spanish production system is commonly different from the systems used in the areas of variety selection; therefore, these new varieties show adaptation problems, such as skin browning, split berries, etc. The second problem is that many of the new cultivars are protected by law (Plant Breeders' Rights), and the rights' owners only offer them to a limited number of producers in each country, generally the largest and most solvent companies.

The first known breeding programme for table grapes in Spain was also initiated in Jerez, at IFAPA, by Alberto García de Luján and collaborators in the 1970s. They obtained several hundred hybrids, using Ahmeur bou Ahmeur, Cardinal, Delizia di Vaprio, Italia, Muscat of Alexandria, Opale, Palomino Fino, Perlette, Puya de Gallo, Sultanina and Torralba as parents. The variety Corredera (Palomino Fino × Cardinal 4) stood out and was registered in the national registry of commercial varieties. In the 1980s, the programme continued with many other crosses using Aleático, Aledo, Baúl, Cardinal, Delizia di Vaprio, Don Mariano, Doroni Macerón, Garnacha Blanca, Moscatel de Alejandría, Palomino, Perola de Gestosa, Sultanina, Rosetti and Torralba. From this set of crosses, the seedless variety Cantarera (Palomino × Sultanina 1) was the most remarkable, with good production. In 2007, Miguel Lara obtained 700 hybrids from crosses involving Italia, Muscat of Alexandria and Flame Seedless, focused on the selection of new table grape seedless varieties with Muscat flavor, firm texture, and large berry size. These hybrids are currently under evaluation.

Later in the 1990s, IMIDA (Murcia) initiated a table grape breeding programme for the selection of new seedless varieties adapted to production conditions in this region

(Carreño et al., 1997, 2009; García et al., 2000). A few years later, the breeding company ITUM (Investigación y Tecnología de Uva de Mesa) was constituted to generate new table grape cultivars, and since 2003, there is a joint project between IMIDA and ITUM to breed new table grape varieties in Spain. Currently, this project has two major goals: generate new seedless cultivars of high production and commercial quality and generate new cultivars that are resistant to fungal pathogens such as downy and powdery mildew. The specific selection criteria in this breeding programme can be classified in three groups, depending on whether they are focused toward the producer, the commercialization chain or the consumer.

Improvement goals for the producer focus on the increase of yield and quality while maintaining or reducing the production costs. Quality objectives include avoiding some berry problems such as small or split berries, berry shattering or skin burning. Production cost reduction aims to minimize requirements for cluster management or growth regulators treatments, as well as pathogen resistance. In addition, the value of the product increases when the offer in the market is lower, and so early or late cultivars are generally selected.

Commercialization goals are summarized in a good postharvest behaviour, including transport tolerance and a good response to low temperature storage that contributes to a longer commercial life. Finally, regarding the consumers, requirements on taste and colour can vary depending on the market. However, as a general rule, consumers prefer good appearance clusters with large and uniform berries that are firm, tasty and crispy. In addition, the presence of phytosanitary residues is a growing concern for consumers and fruit stores.

9.3.3 IMIDA-ITUM breeding program for obtaining new table grape seedless varieties

A major goal within the IMIDA-ITUM breeding program is the generation of seedless cultivars. The classic breeding method for the selection of seedless varieties is based on the selection of seedless plants in F1 progenies generated by pollinating seeded varieties used as females with pollen from seedless ones. Depending on the progenitors, this method can give a variable percentage of seedless plants, since the penetrance of the trait can be as low as 10–15% (Weimberger and Harmon, 1964; Loomis and Weinberger, 1979). In addition, expressivity of the seedlessness trait is frequently low or imperfect, with different seedless genotypes showing different sizes of seminal rudiments or seed traces with different lignification levels that affect the commercial quality of the fruits. One alternative to this strategy is the use of two seedless cultivars as progenitors followed by the rescue of embryos through in vitro culture. This procedure can generate between 75% and 100% of seedless progeny plants, depending on the progenitor's genotype (Barlass et al., 1988). This in vitro rescue of grapevine embryos from seminal rudiments has been implemented in different laboratories since the early 1980s (Cain et al., 1983; Bouquet and Davis, 1989; García et al., 2000; Emershad and Ramming, 1984).

The IMIDA-ITUM breeding program has used both crossing strategies. At the beginning of the program, it included seeded autochthonous Spanish table grape varieties (Dominga, Napoleón, Ohanez, Aledo), as well as foreign seeded varieties (Italia, Red Globe). Seedless parents used included Autumn Seedless, Ruby seedless, Thompson Seedless, Rutilia, Moscatuel, Crimson Seedless or Autumn Royal.

The programme can be divided in four phases:

Phase 1. Generation of F1 progenies

The breeding process starts 1 week before full flowering, when the flowers of the chosen female progenitor are emasculated (Gray et al., 1990). Then, at the beginning of anthesis, flowers are pollinated (Olmo, 1942), with pollen harvested from the selected male progenitors, mainly from seedless cultivars. The viability of pollen is evaluated through germination tests and it is used to pollinate the emasculated flowers during several days, as long as the flower stigmas show signs of receptivity. After fruit set and ripening, if the cross involves a seeded female parent, clusters are harvested at maturity and seeds are extracted, cleaned, dried and conserved until sowing. For sowing, they are scarified and hormone-treated before being placed in nursery trays to stratify and germinate. When crosses involve two seedless varieties as progenitors, in vitro culture for embryo rescue is required. In this case, clusters are harvested before full ripening, approximately 2 months after pollination. Berries are sterilized and seminal rudiments are extracted and cultured in vitro (Spiegel-Roy, 1979) using a modified Murashige and Skoog medium (Bouquet and Davis, 1989). Two or three months later, embryos are extracted and these embryos germinate in four additional weeks. Germinating seedlings are first grown in test tubes and later transferred to small pots in a growth chamber for acclimation before they are moved to the greenhouse and field.

Phase 2. First selection on rapidly grown vines planted on their own roots

During the first year, all generated plants are transferred to the field on their own roots and at high density. Their growth and development is forced by using fertirrigation and adequate growing techniques. The goal is to obtain a rapid production of fruits in the first or second year to carry out an initial selection based on qualitative traits of fast characterization, such as cluster shape, colour, seedlessness, taste and texture. This acceleration of fruit production and rapid evaluation is an important component of the selection programme that allows rapidly discarding those individuals that do not show a minimal set of quality requirements, thus saving a considerable amount of cultivation land.

Phase 3. Second selection on primary selected materials grafted on rootstocks and grown after the traditional production system

Selected hybrids are grafted at commercial density and grown as a regular production field in the Murcia region. This means an overhead trellis system with plants spaced 3 × 2.5 m and with drip fertirrigation. In this phase, different aspects related to quality and yield are individually analysed and fine-tuned for the preselected genotypes. Then, a characterization is completed, which includes phenology information and quality aspects (visual aspect, colour, taste, texture), also noting possible problems (presence of 'shot berries', berry drop, berry crack, colour problems, etc.). In addition, postharvest behaviour is evaluated following the evolution of clusters and berries in a cold room. All the information collected in this phase is used to determine the final selection of the future varieties that fully comply with the goals of the breeding programme.

Phase 4. Evaluation of the behaviour of preselected varieties in different growing areas

Finally, the genotypes selected are cultivated in different growing areas and by different growers (ITUM associates) to increase the data regarding yield, production quality, culture problems and commercialization behaviour. Those selected hybrids that comply with the programme goals are finally registered as commercial varieties.

This breeding programme has produced so far a total of 12 new varieties that have been officially registered. These varieties have been named from Itumone to Itumtwelve and include white-, red- and black-berried varieties, with medium to late maturation times, mostly seedless, with large and firm berries of neutral tastes (Table 9.2, Figure 9.4).

9.3.4 IMIDA-ITUM breeding program for obtaining new table grape varieties resistant to downy and powdery mildew

The diseases with the highest economic impact for grapevines are the fungi that cause powdery mildew (*Uncinula necator* Schwein 1834, recently renamed as *Erysiphe necator*) and downy mildew caused by *Plasmopara viticola* [(Berk. and M.A. Curtis) Berl. and De Toni 1888]. As previously mentioned, a second goal of the IMIDA-ITUM program is the generation of new table grape varieties resistant to downy and powdery mildew. The cultivated grapevine is generally susceptible to these pathogens, and resistance sources originate in American and Asian wild species (Alleweldt and Possingham, 1988; Eibach et al., 2010). Those resistances are due to several loci located in various linkage groups. Since the genetic identification of the first resistance locus against downy mildew, *Rpv1* (for resistance to *Plasmopara viticola* 1) in *Muscadinia rotundifolia* (Merdinoglu et al., 2003), many resistant loci have been genetically identified in different American and Asian wild accessions, named as *Rpv2* to *Rpv13* (Bellin et al., 2009; Blasi et al., 2011; Fischer et al., 2004; Marguerit et al., 2009; Moreira et al., 2011; Schwander et al., 2012; Welter et al., 2007). Regarding powdery mildew, several resistance loci have also been identified and named as *Run* (for resistance to *Uncinula necator*) or *Ren* (for resistance to *Erysiphe necator*). To date, at least eight powdery mildew resistance loci are known (*Run1*, *Run 2.1*, *Run 2.2*, *Ren1*, *Ren2*, *Ren3*, *Ren4* and *Ren5*) (Barker et al., 2005; Blanc et al., 2012; Dalbo et al., 2001; Hoffmann et al., 2008; Mahanil et al., 2012; Riaz et al., 2011; Welter et al., 2007).

In order to incorporate some of the aforementioned resistance genes in new table grape varieties within the IMIDA-ITUM breeding program, four populations were generated by crossing two susceptible table grape cultivars, Crimson Seedless and Autumn Royal, with the two partially resistant wine cultivars, Gf.Ga-52-42 and Felicia. These two cultivars are sources of both powdery and downy mildew resistance (*Ren3* and *Rpv3*), and of downy mildew resistance (*Rpv3*), respectively. The final goal of this selection is to reduce or eliminate the fungicide treatments used against those pathogens that cause severe damage on clusters, leaves and stems. This would increase production,

Table 9.2 Features of the new table grape varieties obtained in Spain by IMIDA-ITUM

Variety	Seed	Colour	Harvest time[a]	Berry diameter	Berry texture (N)[b]	Berry taste	Bunch weight (g)	F.I.[c]
Itumone	No	White	20 July–10 September	21–24	21–25	Neutral-acid	600	1–1.6
Itumtwo	No	White	20 July–10 September	19–22	20–24	Light muscat	600	0.8–1.1
Itumthree	No	White	15 August–15 October	19–22	21–24	Neutral	600	0.8–1
Itumfour	No	White	September–December	19–21	17–20	Neutral	600	1.2–1.5
Itumfive	No	White	September–December	20–23	22–28	Neutral	800	0.4–0.8
Itumsix	No	White	September–December	19–21	19–23	Neutral	700	0.8–1.1
Itumseven	No	Red	20 July–20 September	20–23	20–24	Neutral	800	0.6–1
Itumeight	No	Red	August–20 October	20–22	24–30	Neutral	800	0.8–1.2
Itumnine	No	Red	August–October	20–22	24–28	Neutral-acid	750	0.8–1
Itumteen	No	Red	10 August–November	18–21	20–24	Neutral-acid	650	1–1.3
Itumeleven	Yes	Black	15 August–November	22–24	23–25	Neutral	850	1–1.2
Itumtwelve	No	Black	15 August–30 October	19–21	18–22	Neutral-acid	550	0.8–1

[a]Harvest time in Murcia region, Spain.
[b]Force in Newton (N) needed to deform 20% of the berry diameter (<15N: Soft, 15–20N: Firm, >20N: Very firm).
[c]F.I.: Fertility index (average number of bunches per shoot).

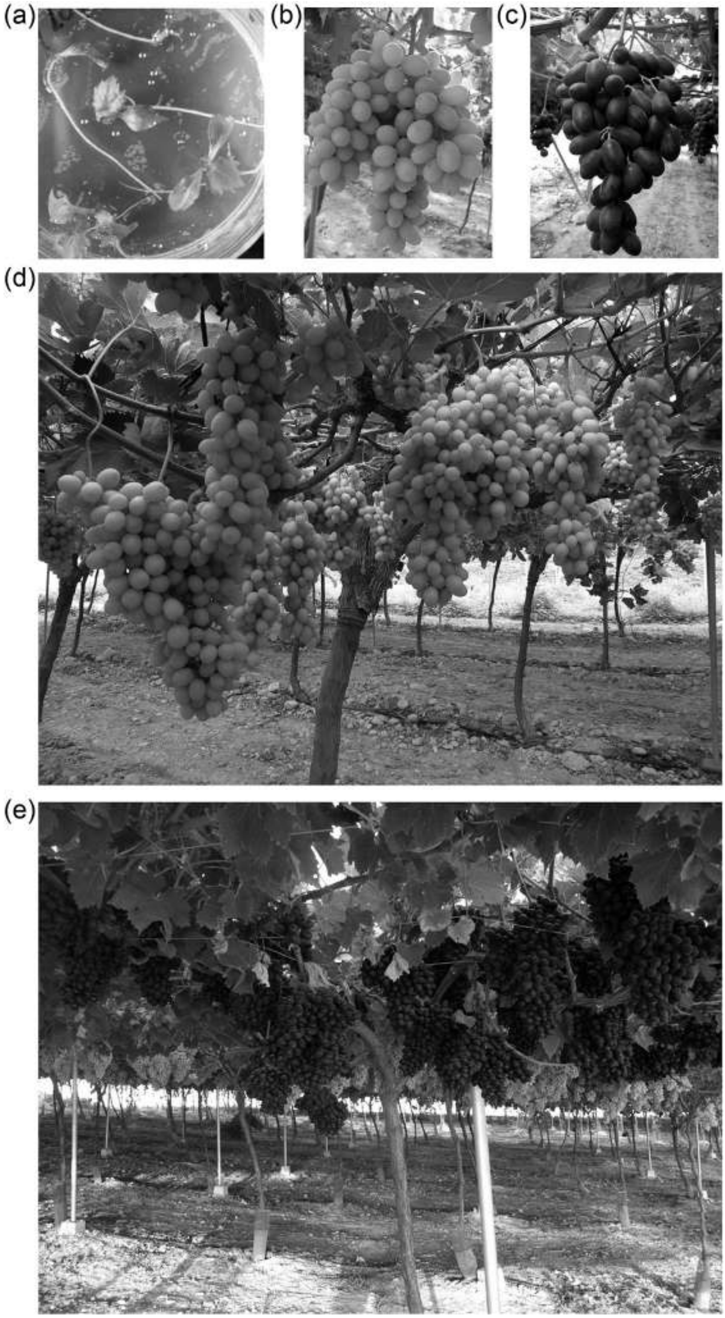


Figure 9.4 Photographs from the breeding programme developed at IMIDA-ITUM. (a) Rescued embryos germinating in vitro; (b) bunch of Itumsix; (c) bunch of Itumseven; (d) plot of Itumfive; (e) plot of Itumtwuelve.

reduce production costs and also reduce the level of fungicide residues in the fruits. The first crosses to initiate this programme were carried out at the Institute for Grapevine Breeding Geilweilerhof in Siebeldingen (Germany) in 2007. The evaluation of resistance to downy mildew is performed following disease symptoms in leaves and clusters using OIV codes 4555 and 456. Only plants with resistant scores higher than three are maintained. The evaluation for powdery mildew resistance is visually performed following leaves symptoms, using OIV code 452, as well as using the leaf disc test evaluation (Staudt and Kassemeyer, 1995) after OIV code 452-1. Again, only plants with score values higher than five are maintained for further screening. Resistant plants passing this highly selective screening are then analysed and selected on the basis of fruit quality and production traits mentioned above. In the first F1 generation, no resistant plant showed enough commercial quality, and so selected plants were used in a second round of crosses with high quality table grape varieties. This second generation is under evaluation.

Finally, it is important to mention that the IMIDA-ITUM selection program is starting to use molecular markers to help optimize the process of selection for seedlessness and resistance to downy and powdery mildew. Given the rapid production and evaluation of fruits, seedlessness and fungal pathogen resistance can be evaluated phenotypically in most cases. However, depending on the cost of the marker analyses, the use of marker-assisted selection for seedlessness screening could save up between 50% and 75% of the planting surface and labour if performed upon germination. Moreover, correct genotyping of resistance loci can be of great interest when the goal is to generate a complex resistance system based on the inheritance of a set of resistant genes.

9.4 Future prospects

The evolution observed in the Spanish table grape breeding programmes during the last decade, where the producers have moved from depending on foreign breeding stations to develop their own breeding programmes in collaboration with public institutions, demonstrates that the driving force exists within the table grape community to keep adding new milestones to this successful programme in the upcoming years. Fungal pathogen resistance certainly looks like the next goal, but others will come, both on quality requirements and in production.

In parallel, a renewed interest has been generated around the breeding of pathogen-resistant wine grape cultivars, the so-called PIWI cultivars (the acronym arises from the initials of the German name for ‘fungus resistant grape varieties’). The goal is to use fungal pathogen-resistant breeding lines (derived from crosses between *Vitis vinifera* and other resistant *Vitis* species or lines) as progenitors in crosses involving traditional varieties and to select hybrids that have incorporated resistance while maintaining the main quality and typicity features of the traditional cultivars. This initiative is being promoted by several wineries in Catalonia in collaboration with members of the PIWI-International association.

Apart from that initiative, it is difficult to predict how the evolution of wine grape breeding programmes will be in Spain, due to the conservativeness predominating in the wine world. However, the search for increased resilience to the climate change and a more restrictive European legislation regarding the use of phytosanitary products (in support of the increased demand of sustainable viticulture practices from the consumers) can drive the initiation of programmes in the upcoming years. Examples of newly bred fungal-resistant cultivars are appearing in other European countries, and this can exemplify the possibilities of breeding in wine grapes. Moreover, the stringent rules that limit the varieties grown in every D.O. have already been changed in several cases to admit additional varieties, demonstrating that the general interest can also promote those legally required changes. In this sense, it is tentative to speculate that future Spanish breeding programmes will focus first on white cultivars, because consumers feel white wines as more diverse and look for innovations and variations with more interest. By contrast, innovation in red wines could take more time, given the appreciation existing for classical red wines and for conservation of these wine styles.

The challenges on wine grape viticulture that are promoting the initiation of breeding programmes are also coming together with new technologies and knowledge derived from the advancement of our understanding of the genetic control of relevant agronomical and quality traits in grapevines. This knowledge is now rapidly growing thanks to the new set of molecular tools that derive from the study of the grapevine genome and all the related 'omics' technologies. These tools and the new genetic knowledge are certainly helping to pave the way to develop more scientifically based breeding programs supported by new technologies. Still, phenotypic selection will probably predominate over genetic selection for many polygenic quantitative traits. Improvement of phenotypic strategies is certainly a major goal that will support both the development of fundamental research, as well as future breeding programs in grapevines.

9.5 Sources of further information

General

MAGRAMA. Denominaciones de Origen e Indicaciones Geográficas Protegidas. http://www.magrama.gob.es/es/alimentacion/temas/calidad-agroalimentaria/calidad-diferenciada/dop/default.aspx

VIVC. Vitis International Variety Catalogue. www.vivc.de

Clonal selection

Legislation

Directiva 68/193/C.E.E.del Consejo, de 9 de abril de 1968 (Comercialización de los materiales de multiplicación vegetativa de vid); transposition: R.D. 208/2003 de 21 de febrero, Reglamento Técnico de Control y Certificación de Plantas de Vivero de Vid.

Directiva 2005/43/CE de la Comisión, de 23 de junio de 2005, por la que se modifican los anexos de la Directiva 68/193/CE; transposition: Orden APA/2474/2006, de 27 de julio, por la que se modifican determinados anexos del Reglamento Técnico de Control y Certificación de Plantas de Vivero de Vid (R.D. 208/2003 de 21 de febrero).

Grupo Español de Seleccionadores de Vid (GESEVID). Last meeting was held in Madrid in November 2012: (http://www.madrid.org/cs/Satellite?c=CM_InfPractica_FA&cid=1354184529991&idConsejeria=1109266187260&idListConsj=1109265444710&idOrganismo=1109266227162&language=es&pagename=ComunidadMadrid%2FEstructura&sm=1109266100977)

Breeding

IMIDA-Table Grape. http://www.imida.es/paginas/eq_uva_mesa.html
PIWI-International association. http://www.piwi-international.org

Acknowledgements

We want to thank many people who have contributed to this chapter, especially P. Villalba (Agromillora-VCR), L. Martínez (Bodegas Roda), E. García-Escudero and E. Baroja (CIDA-La Rioja); F. Aguirrezábal (EVENA), M. Lara (IFAPA Centro Rancho de la Merced), I. Carreño and M. Tornel (IMIDA-ITUM); G. Muñoz (IMIDRA), C. Domingo and A. Puig (INCAVI); P. Chomé and A. Martínez-Treceño (OEVV-MAGRAMA); R. García and J. Eraso (Vitis Navarra); I. Provedo (Viveros Provedo); and V. Villanueva (Viveros Villanueva).

References

Alonso, F., Cuevas, J., Hueso, J.J., Marzo, B., Pérez, J.J., Sánchez, A., 2006. La uva de Almería. Dos siglos de cultivo e historia de la variedad Ohanes. Cajamar, Almería.

Alleweldt, G., Possingham, J.V., 1988. Progress in grapevine breeding. Theor. Appl. Genet. 75, 669–673.

Anon, 2012. SeVi 3379, 1031.

Anon, 2013. SeVi 3409, 1678–1681.

Barker, C.L., Donald, T., Pauquet, J., Ratnaparkhe, M.B., Bouquet, A., Adam-Blondon, A.F., Thomas, M.R., Dry, I., 2005. Genetic and physical mapping of the grapevine powdery mildew resistance gene, Run1, using a bacterial artificial chromosome library. Theor. Appl. Genet. 111, 370–377. http://dx.doi.org/10.1007/s00122-005-2030-8.

Barlass, M., Ramming, D.W., Davis, H.P., 1988. In-ovulo embryo culture: a breeding technique to rescue seedless x seedless table grape crosses. Aust. Grapegrower Winemaker 259, 123–125.

Bellin, D., Peressotti, E., Merdinoglu, D., Wiedemann-Merdinoglu, S., Adam-Blondon, A.-F., Cipriani, G., Morgante, M., Testolin, R., Di Gaspero, G., 2009. Resistance to *Plasmopara viticola* in grapevine 'Bianca' is controlled by a major dominant gene causing localised necrosis at the infection site. Theor. Appl. Genet. 120, 163–176. http://dx.doi.org/10.1007/s00122-009-1167-2.

Blanc, S., Wiedemann-Merdinoglu, S., Dumas, V., Mestre, P., Merdinoglu, D., 2012. A reference genetic map of Muscadinia rotundifolia and identification of Ren5, a new major locus for resistance to grapevine powdery mildew. Theor. Appl. Genet. 125, 1663–1675. http://dx.doi.org/10.1007/s00122-012-1942-3.

Blasi, P., Blanc, S., Wiedemann-Merdinoglu, S., Prado, E., Ruehl, E.H., Mestre, P., Merdinoglu, D., 2011. Construction of a reference linkage map of *Vitis amurensis* and genetic mapping of Rpv8, a locus conferring resistance to grapevine downy mildew. Theor. Appl. Genet. 123, 43–53. http://dx.doi.org/10.1007/s00122-011-1565-0.

Bouquet, A., Davis, H.P., 1989. Culture in vitro d'ovules et d'embryons de vigne (*Vitis vinifera* L.) appliquée à la sélection de variétés de raisins de table sans pépins. Agronomie 9, 565–574. http://dx.doi.org/10.1051/agro:19890604.

Cabello, F., Ortiz, J., Muñoz-Organero, G., Rodríguez-Torres, I., Benito, A., Rubio, C., García-Muñoz, S., Sáiz, R., 2011. Variedades de Vid en España. Comunidad de Madrid and Editorial Agrícola.

Cain, D.W., Emershad, R.L., Tarailo, R.E., 1983. In ovulo embryo culture and seedling development of seeded and seedless grapes. Vitis 22, 9–14.

Carreño, J., Martínez-Cutillas, A., García, E., Ortiz, M., Pinilla, M.F., García, M.G., 1997. Cultivo de embriones de vid (*Vitis vinifera* L.) para la obtención de nuevas variedades de uva de mesa sin semillas. Viticultura Enología Profesional 52, 37–45.

Carreño, J., Oncina, R., Tornel, M., Carreño, I., 2009. New table grape hybrids developed by breeding and embryo rescue in Spain. In: Peterlunger, E., Gaspero, G.D., Cipriani, G. (Eds.), Ninth International Conference on Grape Genetics and Breeding, 2008. ISHS, Udine, pp. 439–444.

Dalbo, M.A., Ye, G.N., Weeden, N.F., Wilcox, W.F., Reisch, B.I., 2001. Marker-assisted selection for powdery mildew resistance in grapes. J. Am. Soc. Hort. Sci. 126, 83–89.

Eibach, R., Toepfer, R., Hausmann, L., 2010. Use of genetic diversity for grapevine resistance breeding. Mitteilungen Klosterneuburg 60, 332–337.

Emershad, R.L., Ramming, D.W., 1984. In ovulo embryo culture of *Vitis vinifera* L. cv Thompson Seedless. Am. J. Bot. 71, 873–877. http://dx.doi.org/10.2307/2443478.

Fischer, B.M., Salakhutdinov, I., Akkurt, M., Eibach, R., Edwards, K.J., Töpfer, R., Zyprian, E.M., 2004. Quantitative trait locus analysis of fungal disease resistance factors on a molecular map of grapevine. Theor. Appl. Genet. 108, 501–515. http://dx.doi.org/10.1007/s00122-003-1445-3.

Forneck, A., Benjak, A., Rühl, E., 2009. Grapevine (Vitis ssp.): example of clonal reproduction in agricultural important plants. In: Schön, I., Martens, K., Dijk, P. (Eds.), Lost Sex. Springer, Netherlands, pp. 581–598. http://dx.doi.org/10.1007/978-90-481-2770-2_27.

García, E., Martinez, A., García de la Calera, E., Perez, L.J., Cenis, J.L., Carreño, J., 2000. In vitro culture of ovules and embryos of grape for the obtention of new seedless table grape cultivars. In: Bouquet, A., Boursiquot, J.-M. (Eds.), VII International Symposium on Grapevine Genetics and Breeding, 1998. ISHS, Montpellier, France, pp. 663–666.

Gray, D.J., Mortensen, J.A., Benton, C.M., Durham, R.E., Moore, G.A., 1990. Ovule culture to obtain progeny from hybrid seedless bunch grapes. J. Am. Soc. Hort. Sci. 115, 1019–1024.

Hoffmann, S., Di Gaspero, G., Kovacs, L., Howard, S., Kiss, E., Galbacs, Z., Testolin, R., Kozma, P., 2008. Resistance to Erysiphe necator in the grapevine 'Kishmish vatkana' is controlled by a single locus through restriction of hyphal growth. Theor. Appl. Genet. 116, 427–438. http://dx.doi.org/10.1007/s00122-007-0680-4.

Loomis, N.H., Weinberger, J.H., 1979. Inheritance studies of seedlessness in grapes. J. Am. Soc. Hort. Sci. 104, 181–184.

MAGRAMA, 2012. Encuesta base de viñedo 2009. Ministerio de Agricultura, Alimentación y Medio Ambiente.

MAGRAMA, 2013. Encuesta sobre Superficies y Rendimientos de Cultivos. Análisis de las plantaciones de viñedo en España. Ministerio de Agricultura, Alimentación y Medio Ambiente.

Mahanil, S., Ramming, D., Cadle-Davidson, M., Owens, C., Garris, A., Myles, S., Cadle-Davidson, L., 2012. Development of marker sets useful in the early selection of

Ren4 powdery mildew resistance and seedlessness for table and raisin grape breeding. Theor. Appl. Genet. 124, 23–33. http://dx.doi.org/10.1007/s00122-011-1684-7.
Marguerit, E., Boury, C., Manicki, A., Donnart, M., Butterlin, G., Nemorin, A., Wiedemann-Merdinoglu, S., Merdinoglu, D., Ollat, N., Decroocq, S., 2009. Genetic dissection of sex determinism, inflorescence morphology and downy mildew resistance in grapevine. Theor. Appl. Genet. 118, 1261–1278. http://dx.doi.org/10.1007/s00122-009-0979-4.
Martínez, J., Vicente, T., Martínez, T., Chavarri, J.B., García-Escudero, E., 2006. Una nueva variedad blanca para la D.O.Ca. Rioja: el Tempranillo blanco. In: XIX Congreso Mundial de la Viña y el Vino. Logroño (La Rioja).
Merdinoglu, D., Wiedemann-Merdinoglu, S., Coste, P., Dumas, V., Haetty, S., Butterlin, G., Greif, C., 2003. Genetic analysis of downy mildew resistance derived from Muscadinia rotundifolia. In: Hajdu, E., Borbas, E. (Eds.), Proceedings of the Eighth International Conference on Grape Genetics and Breeding, 2002, pp. 451–456.
Moreira, F.M., Madini, A., Marino, R., Zulini, L., Stefanini, M., Velasco, R., Kozma, P., Grando, M.S., 2011. Genetic linkage maps of two interspecific grape crosses (Vitis spp.) used to localize quantitative trait loci for downy mildew resistance. Tree Genet. Genomes 7, 153–167. http://dx.doi.org/10.1007/s11295-010-0322-x.
OIV, 2004. World Statistics. Organisation Internationale de la Vigne et du Vin.
OIV, 2013. OIV Vine and Wine Outlook 2008–2009. Organisation Internationale de la Vigne et du Vin, Belgium.
Olmo, H.P., 1942. Storage of grape pollen. Proc. Am. Soc. Hort. Sci. 41, 219–224.
Pelsy, F., 2010. Molecular and cellular mechanisms of diversity within grapevine varieties. Heredity 104, 331–340. http://dx.doi.org/10.1038/hdy.2009.161.
Renedo, T.V., González-Vitón, J.M., Martínez-García, J., Martínez-Martínez, T., 1995. Selección clonal-sanitaria de las viníferas de Rioja. Instituto de Estudios Riojanos, Zubía. Logroño.
Riaz, S., Tenscher, A.C., Ramming, D.W., Walker, M.A., 2011. Using a limited mapping strategy to identify major QTLs for resistance to grapevine powdery mildew (Erysiphe necator) and their use in marker-assisted breeding. Theor. Appl. Genet. 122, 1059–1073. http://dx.doi.org/10.1007/s00122-010-1511-6.
Rubio, J.A., Yuste, J., Yuste, J.R., Alburquerque, M.d. V., Arranz, C., Barajas, E., 2009. Clones certificados de las principales variedades tradicionales de vid en Castilla y León. Instituto Tecnológico Agrario de Castilla y León (ITACYL).
Schwander, F., Eibach, R., Fechter, I., Hausann, L., Zyprian, E., Toepfer, R., 2012. Rpv10: a new locus from the Asian Vitis gene pool for pyramiding downy mildew resistance loci in grapevine. Theor. Appl. Genet. 124, 163–176. http://dx.doi.org/10.1007/s00122-011-1695-4.
Spiegel-Roy, P., 1979. Genetics and breeding of almond and grape. Genetica Agraria 4, 275–293.
Staudt, G., Kassemeyer, H.H., 1995. Evaluation of downy mildew resistance in various accessions of wild Vitis species. Vitis 34, 225–228.
Torregrosa, L., Fernandez, L., Bouquet, A., Boursiquot, J.M., Pelsy, F., Martínez-Zapater, J.M., 2011. Origins and Consequences of Somatic Variation in Grapevine, Genetics, Genomics, and Breeding of Grapes. Science Publishers, pp. 68–92. http://dx.doi.org/10.1201/b10948-4.
Weimberger, J.H., Harmon, F.N., 1964. Seedlessness in vinifera grapes. Proc. Am. Soc. Hort. Sci. 85, 270–274.
Welter, L., Göktürk-Baydar, N., Akkurt, M., Maul, E., Eibach, R., Töpfer, R., Zyprian, E., 2007. Genetic mapping and localization of quantitative trait loci affecting fungal disease resistance and leaf morphology in grapevine (*Vitis vinifera* L). Mol. Breed. 20, 359–374. http://dx.doi.org/10.1007/s11032-007-9097-7.
Yuste, J., Arranz, C., Alburquerque, M.V., Rubio, J.A., 2006. Variedades autóctonas de vid en Castilla y León: clones certificados a disposición de la viticultura. SeVi 3123, 1942–1947.

Grapevine breeding in Central and Eastern Europe

10

P. Pavloušek
Mendel University, Brno, Czech Republic

10.1 Introduction

In Central Europe, the history and traditions of viticulture are very long. Roman legions introduced the grapevine (*Vitis vinifera* L.) in the second century AD. In Central Europe, the wine-growing countries are the Czech Republic, Slovakia and Poland (which can be regarded as an emerging wine country). In the Czech Republic and Slovakia, the total areas of vineyards are 19,633 and 18,705 ha, respectively. In Poland, the total area of vineyards is relatively very small; at present, there are only ≈400 ha of vineyards in the country, but there is an increasing acreage of vineyards there (Kubal and Piziak, 2010). In former Czechoslovakia, the tradition of grapevine breeding and selection stretches back to the end of the nineteenth century. A phylloxera calamity occurred in 1890 in the village of Šatov near Znojmo. This was a trigger of the first steps in the field of grapevine breeding and selection. In the following years, the first nurseries with imported American *Vitis* species were established step by step in the country, as well as the first breeding stations. After World War II, that is in 1952, breeding efforts were coordinated from the Research Institute of Viticulture and Oenology in Bratislava (Slovakia). In this institution, new rootstock, wine and table cultivars were created (as well as several seedless table cultivars of grapevine).

10.2 Evaluation of grapevine gene sources as a basis of successful breeding and selection

In Czechoslovakia, the history and traditions of collection, maintenance and usage of plant genetic resources are very long. Since the very beginning of the twentieth century, these genetic resources have been purposefully collected, and their active evaluation began in the 1930s (Bareš, 1987). In the 1960s, the collection of grapevine genetic resources consisted of ≈1300 cultivars originating from various European, Asian and American countries (Pospíšilová, 1990). In a collection of *V. vinifera* cultivars originating from different ecological and geographical habitats, individual types were evaluated with the objective of choosing taxon (i.e. cultivars) that could be used for a further breeding work and selection.

At present, the Czech collection of grapevine genetic resources is concentrated in three important research institutions and workplaces. This collection of grapevine genetic resources is coordinated from the Crop Research Institute in Prague-Ruzyně and its Viticultural Research Station in Karlštějn. Other genetic resources

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00010-7

are concentrated in Lednice na Moravě at the Faculty of Horticulture (Mendel University in Brno) and at the Viticultural Breeding Station AMPELOS a.s. in Znojmo. Today, the Czech collection of genetic resources involves ≈797 different cultivars and cultivars of the genus *Vitis* spp. They are, above all, cultivars of *V. vinifera*, but there are also some interspecific hybrids. These cultivars can be used as table, juice and rootstock plants.

An important collection of grapevine cultivars is also at the Faculty of Horticulture in Lednice na Moravě. This collection involves, above all, interspecific cultivars of *V. vinifera* × *Vitis amurensis*, *V. vinifera* × French–American hybrid vines (Seibel, Seyve Villard, Baco, etc.) and *V. vinifera* × *V. amurensis* × French–American hybrids. This collection involves ≈300 cultivars and hybrids.

The evaluation of genetic sources from the viewpoint of their resistance to fungal diseases, for example to downy mildew (*Plasmopara viticola*), was also performed under field conditions. In this study, the resistance to downy mildew of 44 grapevine cultivars was evaluated in a long-term field experiment (1996–2003). The resistance was evaluated under conditions of a natural infection pressure using the OIV 452 scale on the one hand and on the base of the evaluation of disease incidence of sporulation and disease incidence of necrosis on the other (Table 10.1).

When using the OIV (Organisation Internationale de la Vigne et du Vin) 452 scale for the evaluation, the highest degree of resistance was recorded in resistance donors Seyve Villard 12375 and Seibel 13666 and in the cultivar Bianca. A high degree of resistance was observed also in cultivars Laurot, Merlan, Morela, Riton and Augustovskyi. It was concluded that the method based on the OIV 452 scale represented the basic method of evaluation of resistance of grapevine plants to downy mildew under field conditions. Similar results were also obtained when using the DIN (disease incidence of necrosis) and the DIS (disease incidence of sporulation) methods. DIS and DIN were evaluated on 100 randomly selected leaves collected from seven grapevine plants under study. The DIS value was calculated using the equation:

$$\frac{\text{Number of leaves with symptoms of sporulation}}{\text{Total number of evaluated leaves}} \times 100$$

The DIN value was calculated according to the equation:

$$\frac{\text{Number of leaves with symptoms of necrosis}}{\text{Total number of evaluated leaves}} \times 100$$

From the viewpoint of grapevine breeding and selection, it is very important to know that it is possible to also compare the resistance of genetic resources to downy mildew on the basis of the pedigree of plants. A wide spectrum of cultivars evaluated in this study enabled such a comparison (Table 10.2). The highest degree of resistance was observed in cultivars with Seyve Villard 12375 resistance donor in their pedigree; they showed lowest average values of DIS and the highest average values of DIN. On the other hand, the lowest degree of resistance to downy mildew was found in cultivars with *V. amurensis* in their pedigree.

Table 10.1 Evaluation of resistance to downy mildew using the OIV 452 scale, disease incidence of sporulation and disease incidence of necrosis. Data followed by different letters in the same column are significantly different by Tukey test ($p < 0.05$)

Grapevine cultivar	Resistance donor	OIV scale	Disease incidence of sporulation	Disease incidence of necrosis
Blaufränkisch	*Vitis vinifera*	2.57 ± 0.63a	76.25 ± 11.88v	0.00 ± 0.00a
Riesling	*V. vinifera*	2.50 ± 0.53a	71.25 ± 14.58v	0.00 ± 0.00a
Cvetoschnyi	*Vitis amurensis*	5.38 ± 0.74def	44.38 ± 4.17tu	25.00 ± 5.35e
Kunleany	*V. amurensis*	5.88 ± 0.64fghi	37.50 ± 7.07pqrs	13.75 ± 5.18b
Zolotistyi Ustoichivyi	*V. amurensis*	4.75 ± 0.46bc	39.38 ± 7.76qrst	15.63 ± 4.96bc
Golubok	*V. amurensis*	5.13 ± 0.83bcd	46.25 ± 10.26u	15.00 ± 5.35bc
Peking-1	*V. amurensis*	6.13 ± 0.35ghijk	33.75 ± 9.16opq	17.50 ± 4.63bcd
Rani Rizling	*V. amurensis*	6.13 ± 0.64ghijk	30.00 ± 7.56mno	16.25 ± 3.54bc
Lela	*V. amurensis*	5.88 ± 0.83fghi	36.25 ± 5.18pqr	16.88 ± 5.30bc
Liza	*V. amurensis*	5.75 ± 0.71efgh	36.25 ± 5.18pqr	17.50 ± 2.67bcd
Mila	*V. amurensis*	5.75 ± 0.71efgh	40.00 ± 5.35rst	18.75 ± 4.43bcd
Zlata	*V. amurensis*	5.63 ± 0.74defg	38.75 ± 6.41qrst	16.25 ± 4.43bc
Petra	*V. amurensis*	5.63 ± 0.74defg	37.50 ± 8.86pqrs	19.38 ± 3.20cd
Erilon	Seibel 13666	6.63 ± 0.52klmn	18.13 ± 2.59cdefghi	47.50 ± 8.86klmn
Flakera	Seibel 13666	5.88 ± 0.35fghi	43.13 ± 8.43stu	25.00 ± 5.35e
Mendeleum	Seibel 13666	5.25 ± 0.46cde	38.75 ± 5.82qrst	17.50 ± 3.78bcd
Merlan	Seibel 13666	6.75 ± 0.46lmn	13.13 ± 3.72bcd	53.75 ± 7.44op
Morela	Seibel 13666	6.75 ± 0.46lmn	13.75 ± 3.54bcde	60.00 ± 7.56q
Luminica	Seibel 13666	4.63 ± 0.52b	41.25 ± 13.56rstu	18.13 ± 2.59bcd
Laurot	Seibel 13666	6.86 ± 0.35mn	13.13 ± 3.72bcd	53.75 ± 7.44op
Marlen	Seibel 13666	6.14 ± 0.64ghijk	23.75 ± 3.54ijkl	43.75 ± 5.18jkl
Kofranka	Seibel 13666	6.43 ± 0.49ijklm	16.88 ± 2.59cdefg	53.75 ± 5.18op
Cerason	Seibel 13666	6.71 ± 0.45klmn	15.63 ± 4.17cdef	52.50 ± 7.07nop
Nativa	Seibel 13666	5.13 ± 0.35bcd	27.50 ± 3.78klmn	22.50 ± 7.07de
Mi-5-50	Seibel 13666	6.00 ± 0.76ghij	23.13 ± 2.59hijk	36.25 ± 4.43gh

Continued

Table 10.1 Continued

Grapevine cultivar	Resistance donor	OIV scale	Disease incidence of sporulation	Disease incidence of necrosis
Mi-5-55	Seibel 13666	5.13 ± 0.35bcd	28.13 ± 2.59klmno	33.75 ± 5.18gh
Mi-5-70	Seibel 13666	6.50 ± 0.93jklm	18.75 ± 4.43defghi	50.00 ± 5.35mno
Mi-5-86	Seibel 13666	6.00 ± 0.93ghij	20.63 ± 4.96fghij	26.25 ± 5.18ef
Mi-5-114	Seibel 13666	6.25 ± 0.89hijkl	17.50 ± 2.67cdefgh	48.75 ± 8.35lmno
Mi-5-122	Seibel 13666	5.63 ± 0.52defg	20.00 ± 3.78fghij	25.63 ± 4.96e
Seibel 13666	Seibel 13666	7.50 ± 0.93	8.75 ± 3.54ab	71.25 ± 8.35r
Bianca	SV 12375	7.13 ± 0.35no	13.75 ± 3.54bcde	60.00 ± 7.56q
Rakisch	SV 12375	6.13 ± 0.35ghijk	31.88 ± 2.59nop	31.25 ± 6.41fg
Riton	SV 12375	6.75 ± 0.46lmn	12.50 ± 5.98bc	56.25 ± 9.16pq
Phoenix	SV 12375	5.38 ± 0.74def	37.50 ± 8.86pqrs	18.13 ± 2.59bcd
XIV-1-76	SV 12375	6.25 ± 0.46hijkl	22.50 ± 2.67ghijk	46.25 ± 5.18klm
Seyve Villard 12375	SV 12375	8.75 ± 0.71p	4.38 ± 3.20a	85.00 ± 5.35s
Augustovskyi	SV 18315	6.75 ± 0.46lmn	19.38 ± 4.96efghi	43.75 ± 5.18jkl
Biona	SV 18315	6.13 ± 0.35ghijk	29.38 ± 4.17lmno	38.75 ± 6.41hij
Demetra	SV 23657	6.25 ± 0.46hijkl	25.63 ± 4.17jklm	38.75 ± 6.41hij
Festivalnyi	SV 23657	6.50 ± 0.53jklm	17.50 ± 2.67cdefgh	51.25 ± 6.41mnop
Rubin Tairovskyi	SV 23657	6.38 ± 0.52ijklm	18.75 ± 5.18defghi	42.50 ± 7.07ijk
Malverina	Seibel 13666 SV 12375	5.12 ± 0.63bcd	37.50 ± 7.07pqrs	25.00 ± 4.63e
Savilon	Seibel 13666 SV 12375	6.13 ± 0.64ghijk	18.75 ± 3.54defghi	37.50 ± 4.63hi

Results of a long-term evaluation of resistance to fungal pathogens obtained under field conditions are important above all when selecting genetic resources for further selection and/or when introducing new, prospective cultivars into the viticultural practice. Results of this study also fully corroborated the observation that when evaluating resistance of plants to *P. viticola* under field conditions, the obtained results were dependent on the cultivar (Boso et al., 2006, 2011; Boso and Kassemeyer, 2008).

North American and East Asian members of the genus *Vitis* are the main source of resistant plant material (Alleweldt, 1996). A survey of the genetic resources used

Table 10.2 **Evaluation of resistance to downy mildew according to the donor of resistance. Data followed by different letters in the same column are significantly different by Tukey test ($p < 0.05$)**

Resistance donor	OIV scale	Disease incidence of sporulation	Disease incidence of necrosis
Vitis vinifera	2.53 ± 0.57a	73.75 ± 13.10 d	0.00 ± 0.00a
Vitis amurensis	5.64 ± 0.76b	38.18 ± 8.07c	17.44 ± 5.14b
Seibel 13666	6.12 ± 0.93c	22.33 ± 10.85a	41.11 ± 16.58d
SV 12375	6.73 ± 1.18d	20.42 ± 12.54a	49.48 ± 22.44e
SV 18315	6.44 ± 0.51cd	24.38 ± 6.80ab	41.25 ± 6.19d
SV 23657	6.38 ± 0.49cd	20.63 ± 5.38a	44.17 ± 8.30de
Seibel 13666 and SV 12375	5.62 ± 0.80b	28.13 ± 11.09b	31.25 ± 7.85c

for early resistance breeding made evident that just a limited number of resistance donors provided the basis of today's elite lines for wine grapes (Eibach et al., 1989). A systematic approach to take advantage of genetic resources is the introgression of resistance traits from wild *Vitis* species, followed by consecutive backcrosses with *V. vinifera* subsp. *vinifera* (Töpfer et al., 2011).

10.3 Rootstock breeding and selection in the Central European region

In the former Austro-Hungarian Monarchy, former Czechoslovakia and the present Czech Republic, the breeding work was performed by the Hungarian breeder Zsigmond Teleki. His breeding and selection process resulted in the creation of a number of rootstocks that are still being used in all of the wine-growing countries of the world (Bakonyi et al., 1997). Teleki's rootstocks are used also in the Czech Republic, and they are still an important part of the breeding programme of resistant rootstocks.

When breeding and selecting rootstocks for certain site conditions and localities, not only the resistance to phylloxera but also some other properties are of great importance. These involve affinity and compatibility, growth intensity, adaptation to soil and climatic conditions of the site and, last but not least, influence on grape and wine quality.

In the territory of the Czech Republic, the origins of rootstock breeding date back to the end of the nineteenth century. F. Schwarzmann, the director of the chateau in Bzenec in Moravia was an important personality in the field of breeding and selection of rootstocks in the Czech Republic. In 1891, Schwarzmann selected in Bzenec a rootstock cultivar that was named Schwarzmann in his honour. Schwarzmann sowed several thousands of seeds of *Vitis riparia*, and from the resulting seedlings, he selected the following two types: Type 1, which was more similar to *V. riparia*, and Type 2, which was more similar to *Vitis rupestris* (Pospíšilová, 1981). This means that both were hybrids of *V. riparia* × *V. rupestris*. In the past, this rootstock was frequently used not only in the field of grapevine propagation but also when breeding new rootstock cultivars in the former Czechoslovakia. Schwarzmann results in medium scion vigour. Its resistance to active limestone is relatively low and does not exceed 10%. This rootstock is suitable for light, sandy, and less fertile soils with a good heat accumulation capacity. It also has a good affinity to all common cultivars of *V. vinifera*. This rootstock has been widely used in Australia and New Zealand.

After 1945, two rootstock cultivars were selected in the former Czechoslovakia, and both belonged to the group of French–American hybrids. In Velké Žernoseky, Vilém Kraus selected a rootstock named **K-1**. This was a hybrid of the following cultivars and species: [(*V. riparia* × *V. rupestris*) × Ortliebské] × Saint Laurent. This is a hybrid with a very vigorous growth habit. However, its resistance to the content of active limestone is low (<7%). Its drought resistance is good, and the affinity to different cultivars of *V. vinifera* is very good. The cultivar is phylloxera-tolerant. However, K-1 was not propagated and used to a great extent.

After the mid-1960s, the Czech rootstock breeding was concentrated in the Grapevine Breeding Station Polešovice. In this station, Václav Křivánek was an important breeder who contributed in a decisive manner to the selection of a new rootstock (Amos) and to several other clones of major rootstock cultivars. Amos was selected in 1990. Its originators were V. Křivánek and A. Tománek, and it was obtained by the crossing of [Severnyj × (*V. riparia* × *V. rupestris*)]. The vigour of this cultivar is high. Its resistance to the content of active limestone in soil is low, and it is suitable for cultivation in lighter soils. The affinity to *V. vinifera* cultivars is good. This rootstock cultivar is phylloxera-tolerant, but it is rarely used. Results of rootstock clonal selection are noteworthy. Most significant are clones of the following cultivars: Craciunel 2 PO 0/6, Kober 125 AA PO 0/3, Teleki 5C PO 3/7 and SO 4 PO 0/7. Křivánek (1989) described individual clones in detail. Data presented in Table 10.3 are based on his descriptions.

At present, the breeding of rootstocks continues in the Grapevine Breeding Station Perná. This new rootstock breeding is performed by Miloš Michlovský and Lubomír Glos. As far as the resistance to phylloxera is concerned, the breeding process is based on positive traits of *Vitis cinerea*. This species was widely used for rootstock breeding and is the basis for rootstocks Börner and the hybrid Bruci, which originated from the crossing [(*Vitis berlandieri* × *V. rupestris*) × *V. cinerea*].

Boubals (1966) was among the first to study phylloxera resistance and its heritability in both intraspecific and interspecific hybrids of *V. vinifera*, *V. berlandieri*, *V. riparia*, *V. rupestris*, *V. cinerea* and *Vitis labrusca*. In 1934, however, Carl Börner discovered total phylloxera resistance in *V. cinerea* Arnold and used this species in his breeding programme. *V. cinerea* shows a total resistance to this pest and was used to produce its hybrid with *V. riparia* 183 G, which was named Börner (Becker and Börner, 1988). Börner responds to phylloxera infestation with a hypersensitive reaction, which results in local necrosis on leaves and roots so that the damage caused

Table 10.3 **A detailed characterization of rootstock clones selected in the Grapevine Breeding Station Polešovice**

Rootstock and clone	Characterization
Craciunel 2 PO 0/6	This rootstock has a vigorous growth. The growth of scions grafted to this rootstock is also vigorous. As compared with the nonselected material, the grapevine stands are uniform. Resistance to drought and active lime is higher than that of 5 BB.
Kober 125 AA PO 0/3	This rootstock tolerates a higher content of active lime than 5 BB. Its growth is vigorous. The rootstock is not suitable for sites with a lack of humidity. It also does not tolerate shallow soils.
Teleki 5C PO 3/7	Vigorous growth but a little weaker than that of 5 BB. The tolerance of active lime is higher than that of 5 BB. This rootstock does not tolerate cold and wet soils and also sandy soils with a low content of nutrients. It is suitable for cultivars sensitive to blossom drop.
SO 4 PO 0/7	Medium growth intensity. This rootstock is very suitable for cultivars sensitive to blossom drop and for the medium height of stems.

According to Křivánek (1989).

by phylloxera is eliminated (Blank et al., 2009). Börner and Schilder (1934) and Hausmann et al. (2010) mentioned that the Börner rootstock showed a total resistance to phylloxera, so the formation of nodosities and tuberosities did not take place.

The commercial evaluation of phylloxera resistance was performed within the period of 2005–2006. Rootstock hybrids were produced on breeding plots of the firm Vinselekt in Břeclav, Czech Republic. The evaluation was performed in a glasshouse experiment and under laboratory conditions at the Faculty of Horticulture, Mendel University, in Lednice na Moravě, Czech Republic. A total of 59 rootstock hybrids were evaluated, and they originated from nine crossings (Table 10.4). Based on the evaluation of results obtained in the pot and laboratory experiments, seven hybrids were selected showing the highest degree of resistance. They are as follows: 16-1-7 (Group A), 16-10-1 (Group B), 17-2-7 (Group C), 17-3-1 (Group C), 17-3-6 (Group C), 17-2-10 (Group C) and 16-12-6 (Group E) (Pavloušek, 2012). According to the definition formulated by Kellow et al. (2000), these rootstock hybrids may be classified as resistant. The highest number of resistant hybrids originated from the crossing of Binova × Börner.

Börner shows a high degree of root resistance to all heretofore tested phylloxera races (Schmid et al., 2003). Zhang et al. (2009) mentioned that Börner disposed of a gene of resistance to phylloxera, and this resistance was successfully transferred also to the progeny. Börner seems to be an important source of phylloxera resistance in breeding. This fact is also confirmed in rootstock breeding in the Czech Republic.

Table 10.4 Hybrid combinations and hybrids assessed as phylloxera-resistant

Variant	Hybrid combination	Selected hybrids
A	(Teleki 5C × Börner) × [(*Vitis berlandieri* × *Vitis rupestris*) × *Vitis cinerea*]	16-1-6, 16-1-7, 16-2-5
B	**BV-9-20-4/**(Teleki 5C × Börner)/ × **BV-8-20-6/**{Peking 1 × [(*V. berlandieri* × *V. rupestris*) × *V. cinerea*]}/	16-10-1, 16-10-3
C	Binova × Börner	17-1-6, 17-1-9, 17-2-3, 17-2-7, 17-2-10, 17-3-1, 17-3-6, 17-6-2, 17-6-7, 17-6-9
D	Binova × [(Binova × Teleki 5C) × Börner]	17-8-2
E	(Binova × Aurelius) × {Peking 1 × [(*V. berlandieri* × *V. rupestris*) × *V. cinerea*]}	16-12-6
F	Teleki 5C × Börner	9-20-1
G	{Peking 1 × [(*V. berlandieri* × *V. rupestris*) × *V. cinerea*]}	
H	(Binova × Aurelius) × {Teleki 5C × [(*V. berlandieri* × *V. rupestris*) × *V. cinerea*]}	
I	**BV-9-21-6/**(Teleki 5C × Börner)/ × **BV-8-20-6/**{Peking 1 × [(*V. berlandieri* × *V. rupestris*) × *V. cinerea*]}/	17-12-1, 17-13-10

This was also specifically corroborated within the framework of this phenotypic evaluation performed in pot and laboratory experiments. In this study, Börner occurred in pedigrees of all selected resistant hybrids. In Groups A and B, there were even two sources of *V. cinerea* (Bruci and Börner). However, the significance of Börner for resistance to phylloxera seemed to be much more important than that of the hybrid Bruci. The highest numbers of hybrids resistant to the root form of phylloxera were found out in the combination C (Binova × Börner). Correlative relationships demonstrated the justification of combining results obtained in pot and laboratory experiments prior to the evaluation of plants under field conditions and their introduction into the viticultural practice. This means that when selecting rootstocks with regard to their resistance to phylloxera, it is suitable to test the hybrids in a pot experiment parallel with stricter conditions of a laboratory experiment with root bioassays (Pavloušek, 2012).

New, phylloxera-resistant hybrid rootstocks were assessed from the viewpoint of their capability to develop calluses after grafting with the cultivar Riesling. The visual evaluation of calluses was performed after grafts had hardened. The highest percentage of grafted plants with a ring-shaped callus was found out among hybrids 17-1-6 (78.57%), 9-20-1 (61.29%) and 17-6-7 (42.86%). Hybrids 17-1-6 and 17-6-7 resulted from the crossing Binova × Börner, while the hybrid 9-20-1 was the result of crossing Teleki 5C × Börner. The affinity and adaptability of the three best and the most prospective hybrids that demonstrated a very good capability of callus formation will be further evaluated under field conditions, that is in a field experiment established in a vineyard.

10.4 Breeding and selection of wine grape cultivars of *Vitis vinifera* L.

A long-term domestication of grapevines (*V. vinifera* L.) significantly influenced the development of grapevine genetic variability. In the course of evolution, plants of *V. vinifera* were propagated in three different manners: by sexual (seed) propagation, by asexual (vegetative) propagation and by somatic mutations. Nowadays, new cultivars are developed above all by sexual propagation, that is either by the cross-pollination or by self-pollination. As individual plants of grapevines show a high degree of heterozygosity, hybrid progeny results from new combinations of parental alleles.

Nowadays, very intensive breeding work takes place both in the Czech Republic and in Slovakia. The intensity of breeding work was negatively influenced by World War II. Intensive working activities were resumed in the 1950s, and they were coordinated from the Research Institute of Viticulture and Oenology in Bratislava. In the past, the main goal of European grapevine breeders was to develop cultivars with good soluble solids content and with as high as possible yields. In former Czechoslovakia, however, efforts of breeders were focused above all on the quality of grapes, so a number of new, very valuable cultivars were created, thanks to the application of new methods.

The main breeding goals can be therefore summarized as follows:

- White aromatic cultivars with a significant aromatic profile and high sensory qualities
- White cultivars with a good capability to accumulate sugars during the ripening period
- Red wine grape cultivars of the ‘Cabernet’ type
- Red wine grape cultivars showing a good capability to accumulate sugars
- Red wine grape cultivars with a distinctive aromatic profile
- Teinturiers

10.4.1 Heterosis as an innovative method of grapevine breeding

In Slovakia, the breeding and selection of grapevines were based on the activities of Dorota Pospíšilová, who intensively used heterosis as a method of breeding work and selection. The word ‘inbreeding’ is used to describe mutual pollination of closely related individuals ranging from the cross-pollination of closely related individuals to the self-pollination of individual plants. The term ‘heterosis’ (or hybrid vigour) is used to describe the improved or increased function of any biological quality in a hybrid offspring.

As stated above, heterosis means the subsequent significant improvement of performance and viability of heterotic individuals, especially of the inbred ones (Pospíšilová and Korpás, 1998). In plants, the self-pollination is often used also for the assessment of the genetic essence (basis) of certain traits. In grapevines, growth depressions of different intensities may occur in different cultivars (Todorov, 1983). When using the method of inbreeding in Slovakia, the most pronounced growth and fertility depressions were found in the cultivars Grüner Veltliner, Gewürztraminer and Valtelin rouge blanc (Pospíšilová and Korpás, 1998).

A schematic presentation of the application of inbreeding in *V. vinifera* (Pospíšilová and Korpás, 1998) is as follows:

Self-pollinated Gewürztraminer plants produce inbred seeds:

- I_1 Gewürztraminer$_n$ – inbred plants (I_1) with n traits;
- I_1 Gewürztraminer$_1$ × I_1 Gewürztraminer$_2$ – crossing within the framework of strict inbreeding;
- I_1 Gewürztraminer$_1$ × I_1 Gewürztraminer$_2$ + I_1 Gewürztraminer$_3$ + I_1 Gewürztraminer$_4$… + I_1 Gewürztraminer$_n$ – crossing within the framework of free inbreeding.

In the domain of plant breeding, heterosis is successfully used in different species; however, this method is generally evaluated as wrong when used in the breeding of woody plant species. In this case, the main disadvantage is a delayed manifestation of generative traits and thus a prolongation of the breeding cycle. This is why this method was not used in grapevine breeding (Pospíšilová, 1974a). In Slovakia, the heterotic breeding process of grapevines was based on principles used in the breeding of maize; the application of this method was based on the presumption that the interspecific crossing of individual grapevine lines could result in a desired heterotic effect (Pospíšilová, 1974b).

A mutual crossing of inbred lines of different grapevine cultivars resulted in the creation of two new cultivars (Hetera and Inzuchta).

Inzuchta – (I_1 Gewürztraminer 81/8 × pollen mixture of I_1 Valtelin rouge blanc plants (73/15 + 74/8 + 72/3 – 2/53)). Its clusters are of medium size, and berries are spherical and of wine-red colour. This cultivar ripens in the second half of October and its growth is vigorous. Yields and soluble solids content are high. These traits are the result of the heterosis effect. A great number of canes and leaves and the vigorous growth of plants are negative inbreeding consequences. However, the wine is of outstanding quality.

Hetera – (I_1 Gewürztraminer 76/10 × I_1 Valtelin rouge blanc 73/6 – 4/13). Its clusters are of medium size, and berries are also spherical and deep red. This cultivar is ripe at the end of October. Yields are consistently high. This cultivar shows an outstanding capability to accumulate sugars. These traits are also the result of the heterosis effect. Hetera is very suitable for making naturally sweet wines.

10.4.2 Breeding and selection of Vitis vinifera *L. wine grape cultivars in Slovakia*

In Slovakia, Mrs Dorota Pospíšilová and Mr Ondrej Korpás are the most important personalities in the domain of grapevine breeding and selection. Mr Korpás and his son are now working in a private breeding station. In Slovakia, there are altogether 13 cultivars that originate from the breeding process; of them, five and

Table 10.5 **Cultivars of *Vitis vinifera* L. bred and selected in Slovakia**

Cultivar	Type of wine	Year of registration	Pedigree
Devín	White	1997	Gewürztraminer × Valteline rouge blanc 15/4
Milia	White	2002	Müller Thurgau × Gewürztraminer
Noria	White	2002	Riesling × Semillon
Breslava	White	2011	(Chasselas × Gewürztraminer) × St Maria d'Alcantara 10/28
Hetera	White	2011	I_1 Gewürztraminer 76/10 × I_1 Rotweiss Veltliner 73/6 – 4/13
Dunaj	Red	1997	(Muscat Bouchet × Oporto) × Saint Laurent 6/10
Nitria	Red	2011	Castets × Abouriou noir 3/8
Rimava	Red	2011	Castets × Abouriou noir 3/12
Váh	Red	2011	Castets × Abouriou noir 3/13
Hron	Red	2011	Castets × Abouriou noir 3/22
Rudava	Red	2011	Castets × I-35-9 6/28
Torysa	Red	2011	Castets × I-35-9 9/17
Rosa	Teinturier	2011	(Picpoul × Lemberger) × Gewürztraminer 15/3

eight are white and red ones, respectively (Table 10.5). Of Slovak cultivars, the most interesting are Devín, Milia, Dunaj, Nitria Váh, Hron and an aromatic cultivar Rosa.

Devín is a cultivar that is suitable for making naturally sweet wine. Under favourable climatic conditions, its berries are usually infested with the noble rot *Botrytis cinerea*. This cultivar shows a high capacity to accumulate sugars. Devín wines are aromatic, with fruity, muscat and gentle spicy tones.

Milia is a cultivar that combines high yields with outstanding quality. It also shows a very good capability to accumulate sugars. Wines made of this cultivar are attractive and aromatic; they are of the 'Gewürztraminer' type.

Dunaj is a cultivar that is used for making both red wine and naturally sweet red wine. Its berries may be also infested by the noble rot *B. cinerea*. Dunaj grapes are ripe on the turn of September and October. It shows a very good capability to accumulate sugars. The sensitivity to blossom drop is its negative trait, which originates from the parental seedlings (Muscat Bouschet × Oporto). The wine is very attractive, with a pronounced fruity aroma with tones of blackberries, blueberries, cherries and sour cherries.

Nitria, Váh and Hron are cultivars of the 'Cabernet' type. It is recommended to cultivate them together. The combination of these cultivars makes wine of the 'Bordeaux' type. In spite of high yields, these cultivars produce grapes with high soluble solids content. They show a pronounced, fruity aroma and fine subtones that originate from the presence of methoxypyrazines.

Rosa is a cultivar with an interesting aroma. This cultivar belongs to the group of teinturiers. Its aroma is rather pronounced and resembles the nice smell of roses. The intensity of its colour is high. Rosa is a cultivar that can be used for making special and/or fortified (liquor) wines.

10.4.3 Breeding and selection of Vitis vinifera *L. wine grape cultivars in the Czech Republic*

Before World War II, the process of *V. vinifera* breeding and selection was very intensive. During the war, the major part of breeding material was devastated, and for that reason, it was necessary to resume the breeding work in the 1950s. In the Communist Era, the process of breeding and selection was realized in specialized breeding stations. After 1989, however, these stations were gradually privatized and became the property of private breeders. In the Czech Republic, the process of breeding and selection was performed above all in the following domains:

- Breeding and selection of white aromatic cultivars
- Breeding and selection of cultivars used for making of quality wines
- Breeding and selection of cultivars used for making of top quality red wines
- Breeding and selection of teinturiers

Before approval and registration, each newly bred cultivar must be thoroughly tested under different ecological conditions. This means that after the end of the testing process, it is possible to formulate recommendations concerning cultivation, habitats, management and wine-making procedures. Grapevine (*V. vinifera*) cultivars created in the Czech Republic are presented in Table 10.6.

10.4.3.1 Breeding and selection of white aromatic cultivars

The process of creating Czech aromatic grapevine cultivars was based, above all, on the world assortment of vines and the breeders used in their work (such cultivars as Gewürztraminer, Muscat Ottonel and Hárslevelű). In the period when these Czech cultivars were created, grapevine plants were grown using the Moser high-training system. This system of vine spacing was introduced into practice by the winemaker Lenz Moser from Rohrendorf in Austria (Moser, 1970). Higher yields were another objective of grapevine breeding and selection. Within the framework of this process, high-yielding cultivars were used (e.g. Müller Thurgau, Hárslevelű and even an old Austrian cultivar called Prachttraube).

At present, this group of white aromatic cultivars involves the parental cultivars Pálava, Muskat Moravsky and Lena. From the viewpoint of breeding and growing, most interesting are the cultivars Pálava and Muskat Moravsky. Muskat Moravsky is also used for breeding and the selection of cultivars with an increased resistance to fungal pathogens.

Pálava (Figure 10.1(a)) is a cultivar with grapes of medium size. Berries are red with greyish, purplish and/or orange shades. In this cultivar, an optimum relationship

Table 10.6 ***Vitis vinifera* L. cultivars bred and selected in the Czech Republic**

Cultivar	Type of wine	Year of registration	Pedigree
Pálava	White	1977	Gewürztraminer × Müller Thurgau
Aurelius	White	1983	Neuburger × Riesling
Muskat moravsky	White	1987	Muscat Ottonel × Prachttraube
Lena	White	2002	Harslevelü × Irsai Oliver
Veritas	White	2002	Roter Riesling × Bouvier
Vrboska	White	2005	Gewürztraminer × Pearl of Csaba
Florianka	White	2010	Frühroter Veltliner × Müller Thurgau
Tristar	White	2013	(Riesling × Grüner Sylvaner) × Pinot blanc
André	Red	1980	Lemberger × Saint Laurent
Alibernet	Teinturier	1975	Alicante Bouchet × Cabernet Sauvignon
Neronet	Teinturier	1991	(Saint Laurent × Blauer Portugieser) × Alibernet
Agni	Red	2002	André × Irsai Oliver
Ariana	Red	2002	(Riesling × Saint Laurent) × Zweigeltrebe
Cabernet Moravia	Red	2002	Zweigeltrebe × Cabernet Franc
Rubinet	Red	2005	(Revolta × Alibernet) × André
Fratava	Red	2008	Lemberger × Saint Laurent

between quality and yield was reached. The wine is full in taste, with a pronounced flowery and fruity aroma and subtones of tropic and subtropical fruits. Its aromatic structure is richer than that of Gewürztraminer. Pálava is a cultivar suitable for making naturally sweet wines.

Grapes of **Muskat Moravsky** (Figure 10.1(b)) are of medium to large in size. The colour of berries is yellow or yellow-green. This cultivar may be cultivated in localities with very different ecological conditions. Its growth characteristics are very good. Wine shows a marked muscat aroma with citrus subtones and fresh acid.

10.4.3.2 Breeding and selection of cultivars used for making wines of higher quality

This breeding objective was formulated in the 1960s. Climatic conditions of former Czechoslovakia forced breeders to develop new cultivars with an increased capability to accumulate sugars. After the year 2000, the frequency of warmer years also gradually increased in Czechoslovakia. That is why these cultivars are more likely suitable for making wines of a higher quality (above all in the

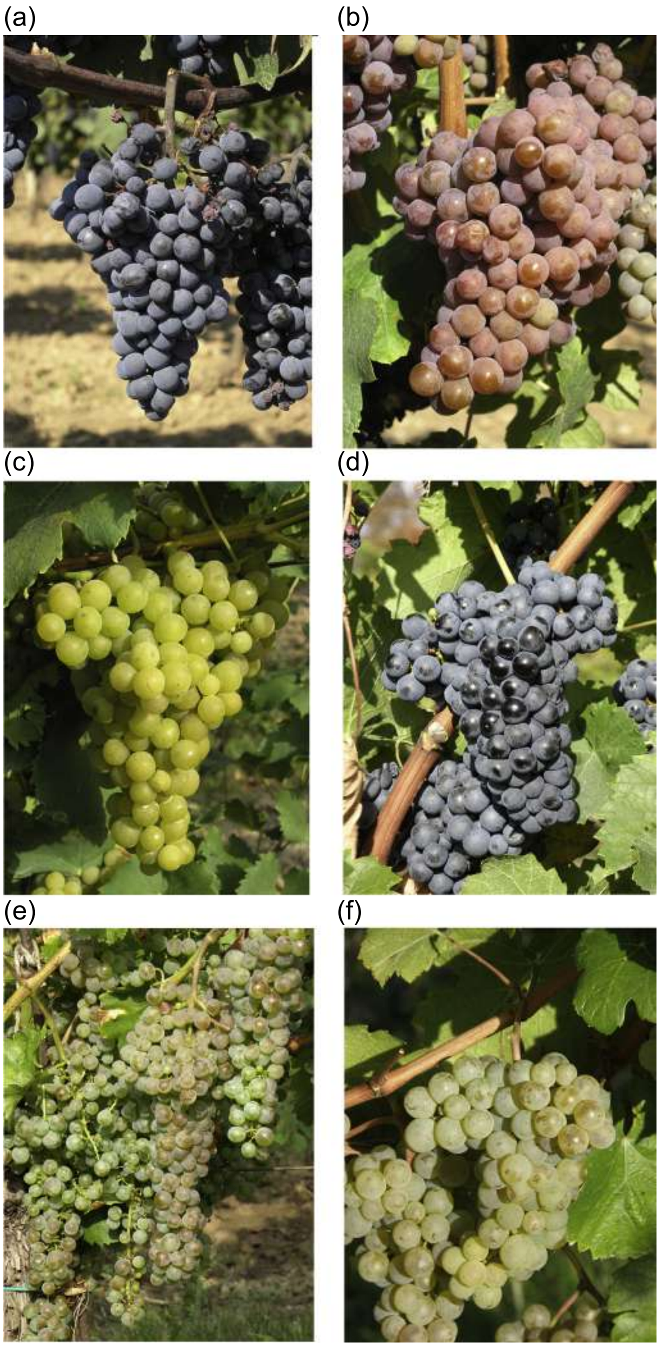


Figure 10.1 Cultivars introduced from Czech grape breeding programmes. (a) Neronet; (b) Pálava; (c) Muskat moravsky; (d) Cerason; (e) Savilon; (f) Vesna
Photographs by the author.

categories 'selection of grapes', 'selection of berries' and 'selection of raisins'). This group involves the cultivars Aurelius, Veritas and Florianka. Of them, probably the most interesting is the cultivar Florianka, which was characterized by its author Václav Křivánek as follows:

> *The growth of this new cultivar is very lush. Annual shoots grow uprightly (i.e. between wires). Canes ripen well and are frost resistant; in 1985, when temperatures dropped down to −27 °C, vines were damaged, but in spite of this, the yield was about 0.50 kg per plant. In 1987, the minimum temperature was −23 °C, but the yield of grapes was about 6 t/ha. Grapes are small or of medium size, dense and of green-yellowish colour. The sugar content of 17°–18° of the Czech standardised saccharimeter (i.e. 17–18 kg of sugar in 100 L of juice) is normally reached at the end of September. If harvested in the second half of October, the sugar content usually ranges from 22° to 26°. In warm localities, the sugar content may be as high as 30°. However, even with this high sugar content, that of acids ranges from 10 to 13 g/L. Wine made of late harvest grapes (Auslese) shows a fine bouquet that resembles Neuburger but is more pronounced. Because of its frost resistance, high sugar content in juice and high quality of wine, this cultivar can be grown in all wine-growing regions (including marginal ones).*

10.4.3.3 Breeding and selection of cultivars used for making top quality red wines

As far as red wines are concerned, the breeding goal was to select cultivars suitable for making full-bodied, extractive wines with a good tannin structure and capable of ripening well under the climatic conditions of the Czech Republic. As the parental material, cultivars typical for the region of Central Europe were used (i.e. Blaufränkisch and Saint Laurent).

André is a cultivar with grapes of medium to large size. Berries are of blue colour, and they have a frosty wax coating on the whole surface. André ripens to an optimum quality in the second half of October. Its terroir (site) demands are high. The wine is full-strength, extractive and full-bodied with a higher content of tannins. In its aroma and flavour (i.e. orthonasal and retronasal aromas), cherry and sour cherry tones predominate. André wines should be aged in wooden barrels.

Fratava is a cultivar with large clusters and berries. Berries are dark blue to black. Fratava ripens in the first half of October and shows average terroir demands. The wine is an intensive ruby colour, is full-bodied and contains nice tannins. Tones of sour cherry and forest fruits predominate in its aroma and flavour.

10.4.3.4 Breeding and selection of teinturiers

In the Czech Republic, Prof. Vilém Kraus was the first personality who intensively worked in the field of breeding and selection of teinturiers. Teinturiers grown in the Czech Republic at present are Alibernet, Neronet and Rubinet.

Alibernet is a cultivar that was selected in 1950 in Ukrainian Scientific and Research Institute of Viticulture and Oenology in Odessa. P.K. Ayvazyan and his colleagues were the originators of this teinturier (Pavloušek, 2007). In former Czechoslovakia, Prof. Vilém Kraus registered this cultivar, introduced it into viticultural practice and used it intensively in his breeding work and selection. This cultivar is also known as Odesskyi chernyi. The cultivar Alibernet is also characterized by 'Cabernet' tones that are caused by methoxypyrazines contained in its berries; however, this can be considered as a certain disadvantage for the cultivar that is used predominantly as a teinturier.

Further breeding work was focused on the utilization of positive traits of Alibernet and to the creation of a teinturier with neutral sensory tones. These efforts resulted in the creation of cultivars Neronet (Figure 10.1(c)) and Rubinet.

10.5 Breeding and selection of cultivars showing an increased resistance to fungal diseases and winter frosts

The process of breeding and the selection of cultivars with a better resistance to fungal pathogens takes place in the Czech Republic and also in Poland. Cultivars showing an increased resistance to fungal pathogens demonstrated clearly their positive properties in cultivar trials performed in different European countries. They produce wine of a high quality. In many European countries, these cultivars became one of the fundaments of organic and/or biodynamic viticulture. In German-speaking regions, fungus-resistant grape cultivars are called 'PIWI Sorten' (Pilzwidestandsfähige Rebsorten – PIWI). The term PIWI is a synonym and replaces terms such as 'own-rooted hybrids' and 'interspecific hybrids'. In the past, the first generation of these cultivars were often considered to be inferior and producing wine of a low quality.

10.5.1 Breeding and selection of cultivars showing an increased resistance to fungal diseases and winter frosts in the Czech Republic

In former Czechoslovakia, French own-rooted (interspecific) hybrids were tested as early as the 1920s to the 1930s. A wide assortment of these cultivars was tested by Mr Karel Neoral at the Breeding Station in Mutěnice. However, none of these cultivars were introduced into commercial viticulture. At the University of Agriculture (today's Mendel University) in Brno, a resumption of the interest in cultivars showing an increased degree of resistance took place in the 1960s. Prof. Vilém Kraus, who worked at that time in the research station Mendelelum in Lednice na Moravě, began to cross cultivars of *V. vinifera*, originating from different ecological and geographical groups, with the Amur grape (*V. amurensis*) and some Seibel hybrids. The cultivar Rondo was the result of this breeding work; later on, its breeding and selection were successfully finished in Geisenheim, and it was registered in Germany.

10.5.1.1 *Rondo: a resistant cultivar with* Vitis amurensis *in its pedigree*

Rondo is a red wine grape PIWI cultivar that is registered in Germany but with a very close relationship to the Czech Republic. This cultivar resulted from the crossing of the European grapevine *V. vinifera* with the Asian species *V. amurensis*. This crossing was performed by Prof. Vilém Kraus in Czechoslovakia in 1964, and thereafter, it was carried out by Prof. Helmut Becker in Geisenheim in Germany. Nowadays, it is also known under the breeding name Gm 6494-5. As far as Rondo is concerned, methods of molecular genetics played an important role in its genealogy. For a long time, cultivars Zarya Severa and Saint Laurent were presented as its parents. However, molecular studies clarified that its parents were the cultivars Severnyi and Saint Laurent. This conclusion was the result of studies performed by Schwander et al. (2012), who found (when mapping genes of resistance to *P. viticola*) that the cultivar Severnyi is the donor of the gene of resistance to *P. viticola*. This gene was named Rpv10. This gene also occurs in other cultivars, for example in Solaris, Rondo or Bronner. The gene of resistance to *P. viticola* (Rpv10) is located at the chromosome 9 (Schwander et al., 2012).

Thanks to this finding, the possibility to use the cultivar Rondo in grapevine breeding for resistance to *P. viticola* markedly increased. In combination with donors of the resistance gene Rpv3 (present in genomes of Bianca and Regent), it is possible to expect that it will be possible to obtain resistant progeny. Rpv3 is located at the chromosome 18. The crossing of cultivars that are donors of resistance genes Rpv10 and Rpv3 results in a combination of two genes of resistance located differently at this chromosome, and it can be expected that the resulting resistance will be of a more stable nature.

Rondo is a PIWI cultivar that is suitable for growing within the framework of organic viticulture when it is necessary to pay an increased attention to protection of plants against the powdery mildew. The colour of the produced wine is an intense, deeply ruby-colour and the taste of this wine is full-bodied (but sometimes with more pronounced tannins). Its aroma and flavour resemble tones of forest and red fruits. Overripened grapes show marked fruity and chocolate tones.

10.5.1.2 *Seibel 13666: an important donor of resistance to fungal pathogens*

In Czechoslovakia, the second wave of disease-resistance breeding was started in 1980s. The combination crossing began again at the Faculty of Horticulture in Lednice na Moravě. In cooperation with the scientific and research association ‘Rezistant’, represented by Mr Miloš Michlovský, it was possible to collect a very extensive gene pool of interspecific cultivars. This pool contained cultivars originating from the countries of the former Soviet Union and Yugoslavia, Hungary, Austria, Germany, Canada and the USA. This gene pool is being permanently maintained and evaluated. In the Czech Republic, the grapevine breeding for the resistance to fungal diseases was based on the cultivar Seibel 13666 (Figure 10.2). This cultivar is a very significant donor of resistance. It occurs in the pedigree of many new cultivars, and it is obvious that they show a very good resistance to diseases.

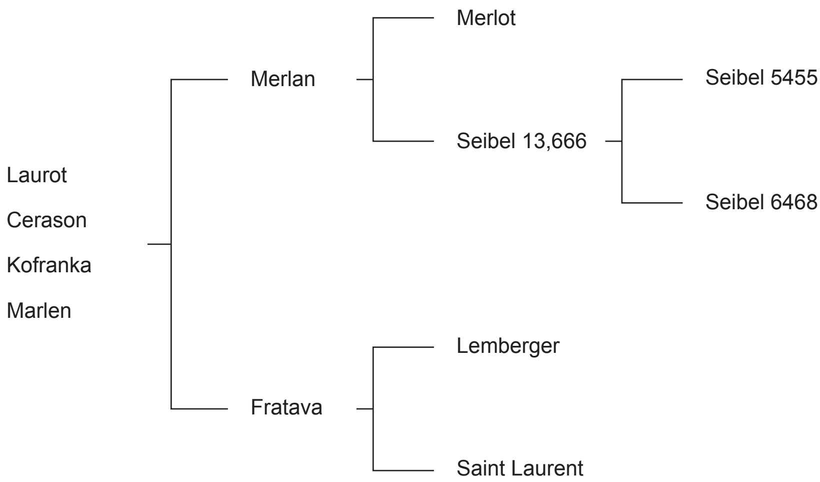


Figure 10.2 Seibel 13666 in the pedigree of red-wine cultivars.

According to Galet (1988), the origin of Seibel 13666 is Seibel 5455 × Seibel 6468 with the representation of particular *Vitis* spp. ($L^4Ru^{20}A^9C^3B^{40}V^{52}$). Seibel 13666 was used in breeding through the Moldavian cultivar Merlan (Merlot × Seibel 13666). This cultivar was used as a parent in the breeding of grapevine plants suitable for making both white and red wines.

10.5.1.3 Profiles of anthocyanin pigments in resistant cultivars

Anthocyanins are classified on the basis of the number of sugar molecules bound to the anthocyanidin portion of the molecule. The majority of species belonging to the genus *Vitis* spp. synthesize monoglucosides and diglucosides. Red wine cultivars of *V. vinifera* contain only acylated monoglucosylated anthocyanins, of which malvidin 3-glucoside is the most common (Mazza, 1995; García-Beneytez et al., 2002). Diglucosylated anthocyanins are more typical in grapes of other members of the *Vitis* genus (e.g. *V. riparia*, *V. labrusca*, *V. rupestris*, *Vitis rotundifolia*, etc.), and the interspecific hybrids of American grapevine species with *V. vinifera* means that this dominant diglucosylated trait is then also found in French–American hybrids (Goldy et al., 1986). Malvidin-3,5-diglucoside can be considered as an indicator of hybrid grapevine cultivars (Ribéreau-Gayon et al., 2000). Diglucosidic anthocyanins seem to be more stable than monoglucosidic ones; however, they are also more sensitive to oxidative browning (Robinson et al., 1966).

Due to a lack of dominant alleles controlling the formation of diglucosidic anthocyanins, cultivars of *V. vinifera* synthesize only monoglucosidic anthocyanins. The first generation of interspecific hybrids with *V. vinifera* produces both mono and diglucosidic anthocyanins. In the case that complex hybrids resulting from backcrossing with *V. vinifera* do not contain dominant alleles controlling the synthesis of diglucosides, they are able to synthesize only monoglucosidic anthocyanins (Van Buren et al., 1970).

Table 10.7 Percentages of mono- and diglucosides in some grapevine cultivars (Van Buren et al., 1970)

Cultivar	Monoglucosides	Diglucosides
Seibel 13666	100	0
Seyve Villard 12481	100	0
Isabella	45	55
Leon Millot	30	70
Vitis amurensis	40	60

Table 10.8 Contents of malvidin-3,5-diglucoside in berries (Balík et al., 2013) and in wine (Pavloušek and Kumšta 2014 unpublished)

Cultivar	Malvidin-3,5-diglucoside in berries (mg/L)	Malvidin-3,5-diglucoside in wine (mg/L)
Cerason	n.d.	1.53 ± 1.12
Laurot	n.d.	0.38 ± 0.53
Kofranka	n.d.	0.06 ± 0.08
Nativa	n.d.	0.62 ± 0.01

The evaluation of monoglucosides and diglucosides in *Vitis*, based on results by Van Buren et al. (1970), is presented in Table 10.7. Red wine cultivars were similarly evaluated for the presence of malvidin-3,5-diglucoside in berries (Balík et al., 2013) and in wine (Table 10.8). From the viewpoint of the Czech breeding of interspecific cultivars, these data are significant, because the resistance donor Seibel 13666 is exclusively a monoglucosidic cultivar. On the other hand, however, the fact that diglucosides predominate in *V. amurensis* is of a negative nature, because this species is also frequently used in the breeding process. However, from the viewpoint of anthocyanins and their structure, the resistance donor Seibel 13666 is very suitable for further breeding because it produces progeny with an anthocyanin profile that is typical for cultivars of *V. vinifera*.

10.5.1.4 Qualitative and quantitative data of new resistant cultivars

Qualitative and quantitative data of new resistant cultivars are regularly assessed and evaluated. Results were obtained in a study that was performed in an experimental vineyard of the Faculty of Horticulture (Mendel University in Brno) in the period from 2007 to 2009. The vineyard was established in 1992. Plants were grafted on Teleki 5C. Spacing of vines was 2.0 × 1.0 m and trunks were 80 cm high. The Guyot pruning system with flat canes was used to train experimental vines. The evaluation involved eight new resistant

Table 10.9 Fertility index (clusters per shoot), yield per vine (kg) and average dates of harvest, 2007–2009. Data followed by different letters in the same column are significantly different Tukey test at ($p > 0.05$) (Pavloušek et al., 2013). Standard cultivars are Riesling and Lemberger

Cultivar	Fertility index (clusters per shoot)	Yield per vine (kg)	Date of harvest
White wine cultivars			
Malverina	2.00 ± 0.19b	3.68 ± 0.50b	19.10.
Erilon	1.93 ± 0.21b	3.95 ± 0.50b	10.10.
Savilon	1.96 ± 0.18b	3.83 ± 0.39b	10.10.
Vesna	1.95 ± 0.09b	2.85 ± 0.43a	12.10.
Riesling	1.78 ± 0.17a	2.73 ± 0.20a	18.10.
	**	***	
Red wine cultivars			
Laurot	2.02 ± 0.12bc	3.89 ± 0.51c	17.10.
Cerason	1.82 ± 0.11a	3.31 ± 0.3b	12.10.
Kofranka	2.03 ± 0.25c	3.68 ± 0.41bc	11.10.
Nativa	1.87 ± 0.17ab	2.49 ± 0.54a	12.10.
Lemberger	1.73 ± 0.33a	3.55 ± 0.67bc	17.10.
	**	***	

cultivars and two control cultivars (i.e. Lemberger and Riesling) (Table 10.9). Results of this evaluation indicate a very good fertility and yielding capacity of new resistant cultivars. Yields of cultivars Malverina, Erilon and Savilon were markedly higher than that of the control (Riesling). The dates of harvest indicated that tested vines were mostly medium-late to late ripening cultivars (Table 10.9).

As far as the soluble solids and titratable acidity are concerned, new resistant cultivars showed a very good potential (Table 10.10). Even with relatively high yields, these cultivars produced grapes with high soluble solids. In white resistant cultivars, the soluble solids were higher than in the control Riesling, while in red ones they were comparable with the control Lemberger. The contents of tartaric and malic acid, as well as their mutual ratio, are considered to be the most important parameters of wine quality (Table 10.11). In warm years, the content of tartaric acid is important in white wine. When malic acid content in berries is low, the resulting wines are very flat and monotonous. The ratio between tartaric and malic acid is also an important variable, and its ideal value should range between 2:1 and 3:1 (Pavloušek, 2011).

Of cultivars used for making white wine, the highest content of both acids was recorded in Erilon. In other cultivars, these contents were lower than in Riesling. However, in cultivars used for making red wine, the contents of malic acid were higher than in the control cultivar Lemberger. The ratio of tartaric to malic acid nearly reached the ideal value. The evaluation of berry and wine composition revealed that all cultivars under study showed very good potential. Based on correlations existing

Table 10.10 **Soluble solids (°Brix), titratable acidity (g/L) and pH values for several cultivars, 2007–2009. Means in columns are separated by Tukey test ($p > 0.05$) (Pavloušek et al., 2013). Standard cultivars are Riesling and Lemberger**

Cultivar	Soluble solids (°Brix)	Titratable acidity (g/L)	pH
White wine cultivars			
Malverina	22.4	10.23±0.78bc	3.16±0.14
Erilon	22.0	11.42±1.20cd	3.14±0.03
Savilon	22.8	8.48±0.63a	3.27±0.04
Vesna	22.8	9.49±0.83ab	3.23±0.10
Riesling	21.5	12.34±0.83d	3.15±0.06
	n.s.	**	n.s.
Red wine cultivars			
Laurot	23.1	9.71±1.30	3.15±0.03
Cerason	22.8	11.03±0.96	3.09±0.11
Kofranka	21.3	11.21±1.07	3.13±0.05
Nativa	21.3	10.45±1.09	3.16±0.04
Lemberger	22.0	9.40±0.08	3.15±0.13
	n.s.	n.s.	n.s.

Table 10.11 **Contents of tartaric acid, malic acid and their ratios, 2007–2009. Means in columns are separated by Tukey test ($p > 0.05$) (Pavloušek et al., 2013). Standard cultivars are Riesling and Lemberger**

Cultivar	Tartaric acid (g/L)	Malic acid (g/L)	Tartaric acid/ malic acid ratio
White wine cultivars			
Malverina	8.16±0.57b	3.89±0.53a	2.14±0.41
Erilon	9.66±0.66c	5.44±1.50c	1.84±0.38
Savilon	6.43±0.11a	3.68±0.22a	1.75±0.12
Vesna	7.69±0.51b	3.29±0.21a	2.34±0.01
Riesling	9.44±1.16c	4.36±0.72ac	2.22±0.43
	**	*	n.s.
Red wine cultivars			
Laurot	8.57±0.27	3.17±0.31ab	2.72±0.17b
Cerason	8.85±0.35	3.94±0.39c	2.26±0.15a
Kofranka	9.16±1.41	3.68±0.41bc	2.48±0.13ab
Nativa	8.08±0.48	2.96±0.15a	2.73±0.03b
Lemberger	8.69±0.23	2.90±0.12a	3.00±0.18c
	n.s.	**	**

between yield and composition, it is possible to conclude that the lower the yields, the better quality of berries. This means that yields should be regulated by interventions performed during the growing season, especially by means of the method of cutting clusters in half.

*10.5.1.5 Assessment of grapevine resistance to powdery mildew (*Erysiphe necator*)*

The fungus *Erysiphe necator* Schw. (syn. *Uncinula necator* (Schw.) Burr.) that causes the occurrence of powdery mildew is an obligatory parasite that infests plant species belonging to the family *Vitaceae* (Gadoury et al., 2012). The fungus can attack all green parts of the host plants (i.e. leaves, berries and canes). In recent years, powdery mildew has very significantly damaged Czech vineyards. Under the climatic conditions of the Czech Republic, this pathogen overwinters most frequently as mycelium in dormant buds. This developmental stage is thereafter the source of the primary infection that results in the formation of conidia, which causes secondary infections of plants. Conidia are either blown by wind or transmitted by contact with infected parts of plants.

A good control of powdery mildew fungi is an important part of the management of vineyards and of all viticultural operations (Austin and Wilcox, 2012), because the majority of commercial grapevine cultivars are rather sensitive to this pest (Ramming et al., 2011; Miclot et al., 2011). Due to this fact, commercial grapevine growers use both fungicides and agrotechnical interventions to protect their plants against powdery

Table 10.12 Evaluation of resistance to powdery mildew (*Erysiphe necator*) in new cultivars. Standard cultivars are Riesling and Lemberger

Cultivar	Resistance donor	Leaf – evaluation with OIV 455	Cluster – evaluation with OIV 456
Lemberger	*Vitis vinifera*	1.43 ± 0.53	1.29 ± 0.49
Riesling	*V. vinifera*	2.43 ± 0.53	2.57 ± 0.53
Erilon	Seibel 13666	6.14 ± 0.69	5.43 ± 0.53
Malverina	Seibel 13666 SV 12375	6.00 ± 0.82	5.86 ± 0.38
Savilon	Seibel 13666 SV 12375	6.43 ± 0.53	5.86 ± 0.90
Laurot	Seibel 13666	6.71 ± 0.49	6.57 ± 0.53
Marlen	Seibel 13666	6.43 ± 0.79	6.57 ± 0.53
Kofranka	Seibel 13666	6.57 ± 0.53	6.57 ± 0.58
Cerason	Seibel 13666	6.86 ± 0.38	6.71 ± 0.49
Nativa	Seibel 13666	5.00 ± 0.06	5.29 ± 0.49
Seibel 13666	Seibel 13666	7.86 ± 1.07	8.43 ± 0.98
Seyve Villard 12375	SV 12375	8.14 ± 1.07	8.43 ± 0.38
Merlan	Seibel 13666	6.43 ± 0.79	6.71 ± 0.49

mildew (Cadle-Davidson et al., 2011). However, a systematic application of fungicides shows negative environmental effects. An improper application of these products may also affect grapes and produced wine, and it is well known that their residues may endanger human health. This means that the introduction of cultivars resistant to the fungus *Erysiphe necator* into viticulture and the wine-making industry represents an ecological method of control of this disease. Therefore, grapevine cultivars that show a resistance to powdery mildew infestation represent an important financial contribution and environmental improvement in the domain of the viticultural industry, with regard to widely grown sensitive commercial cultivars (Ramming et al., 2011).

At the end of the nineteenth century, grapevine breeders began to import genetically resistant North American species belonging to the genus *Vitis* spp. and gradually introduced this trait into the genome of *V. vinifera*, so many interspecific French–American hybrids were created in the years to follow (Gadoury et al., 2012). Breeding for the resistance to fungal diseases is also one of the major goals of the development of modern grapevine cultivars. The evaluation of grapevine gene sources showing the resistance to pathogenic fungi is, therefore, a suitable tool to breed and select donors of resistance to these infestations.

In a study performed at the Faculty of Horticulture in Lednice, the resistance of plants to powdery mildew was assessed and analysed under field conditions without any artificial infection within the period from 1996 to 2003. In the course of the experiment, no fungicides were applied. Pruning, crop load of vines, and vineyard management were identical during the whole experimental period. Depending on the intensity of powdery mildew infection, the degree of the infestation of plants was estimated within the period from July to September. The 25 leaves from the central part of the canopy (i.e. from the region between the sixth to the eighth nodes) were always evaluated. Leaves were sampled from seven randomly selected vines. The resistance to powdery mildew was evaluated using a scale published in the International List for Grapevine Varieties and Species Evaluation (OIV, 1983) (Table 10.12). Cerason, Laurot, Kofranka and Savilon showed the highest degree of resistance to this fungus. Under the climatic conditions of the Czech Republic, these cultivars can be grown either without the application of pesticides or only with minimum protection based on the application of sulphur products, preparations increasing the natural resistance of plants and/or preparations based on plant extracts.

10.5.1.6 Resistant grapevine cultivars from the Czech Republic

Of the registered PIWI cultivars, altogether 10 were bred and selected in the Czech Republic; the remaining two are from abroad (Table 10.13). Although the cultivar Marlen is not registered, it is already protected by copyright. In the current statistics of Czech vineyards, the PIWI cultivar Hibernal is mentioned in the first place with 96.7 ha. The following places are occupied by Solaris (15.9 ha), Johanitter (10.8 ha) and Malverina (9.0 ha). The most frequent red cultivar is Regent (6.5 ha).

Malverina

Its clusters are medium-sized and cylindrical or conical in shape. Berries are greenish-yellow; on the sunny side of the grape, they are of rosy colour. Sloped vineyards

Table 10.13 **PIWI grapevine cultivars registered in the Czech Republic to April 1, 2014**

Cultivar	Pedigree	Date of registration	Copyright date
Malverina	Rakisch × Merlan	16.07.2001	13.05.2002
Laurot	Merlan × Fratava	22.09.2004	05.10.2005
Cerason	Merlan × Fratava	14.11.2008	12.04.2011
Rinot	Merzling × (SV 12,375 × Pinot gris)	15.11.2008	27.11.2008
Sevar	Seyve Villard 12,358 × Sankt Laurent	19.11.2008	–
Nativa	Fratava × Merlan	8.07.2010	04.09.2010
Savilon	Rakisch × Merlan	31.12.2010	26.02.2011
Kofranka	Merlan × Fratava	26.01.2011	02.03.2011
Erilon	(Lemberger × Cabernet Franc) × Merlan	26.01.2011	02.03.2011
Vesna	Rakisch × Merlan	15.08.2012	15.08.2012
Marlen	Merlan × Fratava	–	20.03.2014

www.ukzuz.cz.

with plenty of sunlight and loamy-sand or sand soils represent an ideal locality for this cultivar. Malverina ripens in October. Most frequently, the colour of the wine is green-yellowish. In its aroma, it is possible to find interesting fruity tones (resembling apples, pears and quinces combined with pronounced floral subtones). In its aroma, it is possible to identify nice spicy tones, most frequently those of cinnamon. Acids are fresh but are sometimes more pronounced.

Laurot

Its clusters are medium to large-sized. Near the base of the rachis, the grape branching is relatively intensive. Berries are small to medium-sized and blue-black in colour. This cultivar is suitable for growing only in localities with a long tradition of the cultivation of red wine grapevine growing. Its successful cultivation is possible on slopes facing either south or southwest. The soil requirements of Laurot are not particular; it grows well also in vineyards with soils of medium to low quality. Laurot is a late-maturing cultivar and reaches an optimum stage of ripeness in the second half of October. This cultivar is suitable for the production of organic and varietal wines. Wine has an attractive ruby colour and shows a high content of tannins, with aromas predominated by tones of red fruit (cherry and sour cherry). In wine of higher degrees of ripeness, it is possible to also find tones of ripe forest fruits (strawberry, raspberry, etc.).

Cerason

Cerason clusters are medium to large-sized, conical and branch several times near the base of the rachis (Figure 10.1(d)). Berries are small, spherical, dark-blue or even black in colour and completely covered with a fine waxy coating. This cultivar requires localities of top quality, suitable for the growing of red grapevine cultivars. To reach a good quality of ripe grapes, it is necessary to have enough solar radiation. Cerason requires soils of medium quality and grows well in drier soils. Cerason is a late-maturing cultivar and ripens usually at the end of October. Thanks to this delayed ripening, this cultivar may be cultivated in Italian or French systems of organic viticulture. Cerason is a resistant (PIWI) cultivar of top quality, suitable for making a wide spectrum of different types of wine. It is especially suitable for making organic wines of top quality. The wine has an intense, dark red colour, with a good texture, full body and nice tannins. In its fruity aroma, it is possible to find not only accentuated tones of cherries and sour cherries, but also of small forest berries. In aged wine of older vintages, there are also interesting tones resembling the taste of chocolate.

Rinot

Rinot clusters are long and medium to large-sized. The berries are small, spherical green-yellowish; in the stage of full ripeness, it shows even golden shades. Rinot is suitable for growing in sloping vineyards that enable the aroma of ripe berries to intensify. Sandy-loams, loamy-sands and loams are those soil types that are most suitable for this cultivar. Dry soils, as well as wet and dense soils with high percentages of clay particles, are less suitable. Rinot ripens in the second half of September. The wine is aromatic with marked fruity-floral tones. Its aroma resembles green apples, quinces, peaches and citrus fruit.

Sevar

Clusters of this cultivar are small to medium-sized and branched near the base of the rachis. The berries are small and rounded. Their sunny and well-aerated sites are very suitable for growing the Sevar cultivar. It likes soils of medium quality with enough soil moisture. Excessively dry soils are not favourable because they may inhibit the growth and negatively influence the aromas of berries. The most suitable are sandy loams and loamy sand soils. The optimum ripeness of Sevar is reached in the middle of September. The aroma of this wine is very interesting and consists of a mixture of floral and fruity tones resembling small forest berries (raspberries, blackberries, strawberries, blueberries, etc.).

Nativa

Clusters of this cultivar are small to medium-sized. Berries are blue to blue-black with a marked waxy coating. Nativa should be planted on slopes. This cultivar does not like closed, unaerated and wet localities. Soil requirements of Nativa are not particular. On wet and fertile soils, Nativa produces very vigorous vines. Sandy loams and loamy sand soils are quite suitable for this cultivar. Nativa ripens at the end of September and the first half of October. This red wine is of very high quality and of a markedly 'European' type. It is full-bodied and extractive with a very intense colour. Its aroma is fruity, with tones of cherries and sour cherries. In older vintages, it is also possible to find tones of small forest fruit (resembling the taste of raspberries and blackberries) with a fine chocolate subtone. The content and character of tannin substances is also interesting.

Savilon

Clusters of this cultivar are medium to large-sized. Berries are small or medium-sized, slightly oval, and green-yellowish (Figure 10.1(e)). Fully ripened berries are gold-yellow, golden or even slightly rosy. The best localities for this cultivar are sunny, sloping tracts of land facing the south or the southwest. Soil requirements of Savilon are not particular, so it can be planted in a wide spectrum of localities. Drier soils are quite suitable, but the cultivar also tolerates wet soils with a high proportion of clay. Savilon ripens in October. The wine is aromatic, with a combination of fruity tones that are only finely tinged with 'green' subtones. Aromas of grapefruits, peaches, apricots and green peppers dominate this wine. Its taste is full-bodied and harmonic, with fresh acids.

Kofranka

Its clusters are medium-sized and conical, with a wing at the base of the rachis. Berries are medium-sized, rounded and of a deep blue to black colour with a fine waxy coating. Sufficient ripeness can be reached only in outstanding localities. It requires very sunny, sloping tracts of land. Kofranka requires soils of medium quality. It does not like dry sites because lack of water can inhibit its growth. However, too wet soils are also not suitable. Kofranka is a late cultivar and ripens in the second half of October. The wine is an intense, deep red colour. The aroma is dominated by dry plums, sour cherries and forest berries. It is a full-bodied and extractive wine.

Erilon

Erilon clusters are medium to large in size. The rounded berries are also medium to large. On the sunny side, the berries are a golden colour. The taste is finely aromatic. Well-aerated and sunny tracts of land are very suitable for this cultivar. Erilon does not require soils of higher quality. It gives good yields and grows well in gravelly or sandy soils. In such localities, the clusters are looser and the wine aroma is better. Erilon ripens in the first half of October. Intensive aromas of citrus fruit, peaches, black currant, gooseberry and green peppers dominate the wines.

Vesna

Vesna clusters are medium-sized and branched with small wings near the base of the rachis (Figure 10.1(f)). Berries are small and rounded. Skin colour is yellowish-green; in full ripeness, it is yellowish and slightly rosy on the sunny side of the berry. Vesna can be grown in the best localities that enable the growth of late grapevine cultivars (e.g. Italian Riesling, Rhein Riesling or Pinot blanc). It requires sunny and sloping sites that are able to harvest berries in the optimal stage of quality. Vesna does not need top-quality soils, and it tolerates dry conditions (but produces loose clusters). This cultivar reaches the optimum stage of quality in mid-October. The wine is of the top quality, of 'Riesling' type, full-bodied, extractive and with pleasant acids. The fruity-floral aroma of this wine is very interesting and attractive. One can find tones of green apples, peaches, apricots, citrus fruit, lime blossom and meadow flowers.

Marlen

Marlen is the result of the breeding work of Prof. Ing. Vilém Kraus and colleagues. It is a red grapevine cultivar with a high resistance to fungal pathogens. Grapes can be used for the making of red and rose wine. It is the result of crossing cultivars Merlan × Fratava. Clusters are either medium density or loose. Dark red berries are large, rounded and with a thin waxy layer on the surface. Ideal site requirements are sloped and sunny localities facing south to southwest. Windy sites are not recommended. Soil requirements are not specific. This cultivar also tolerates winter frosts. Its resistance to fungi is good. Marlen is ripe in the second week of October. Under favourable conditions, it can be harvested until the end of October to produce wine of very high quality. Berries contain relatively high amounts of methoxypyrazines, which may sometimes cause a marked 'grassy' taste in the wines. Sugar content and phenolic ripeness are very good. Wine is ruby coloured. In its smell and taste, it is possible to detect green pepper and fine subtones of forest berries and red fruit (strawberries, raspberries, ripe cherries and sour cherries). It is a full-bodied wine with a pleasant content of tannins. Marlen is also recommended for growing in systems of organic viticulture.

10.5.2 Breeding and selection of resistant cultivars in Poland

The process of growing and breeding grapevines also takes place in Poland. For the time being, the total acreage of Polish vineyards is ≈400 ha, and there is a tendency to increase it gradually in the near future (Kubal and Piziak, 2010). There is only one resistant cultivar that was bred and selected in Poland, and it is called Jutrzenka. The cultivar Jutrzenka is a hybrid that resulted from the crossing of cultivars Seyve Villard 12375 and Pinot blanc. It shows a very good resistance to winter frosts and also to fungal pathogens, especially to botrytis bunch rot (*B. cinerea*). It ripens in the second half of September. The taste of wine made of its grapes shows fruity and floral tones (Jelen et al., 2011).

10.6 Breeding and selection of table grapevine cultivars

10.6.1 Breeding and selection of table grapevine cultivars in the Czech Republic and Slovakia

In former Czechoslovakia, the breeding and selection of table grapevine cultivars were coordinated by people working in the Complex Research Institute of Viticulture and Oenology in Bratislava (Slovakia) and in the Viticultural Breeding Station in Polešovice (Moravia). At present, these activities are performed by the breeding firm managed by Mr Ondrej Korpás senior and his son in Slovakia and at the Faculty of Horticulture in Lednice na Moravě (Mendel University in Brno, Czech Republic). The breeding goal is to select seedless cultivars with large berries that are suitable for the climatic conditions of Central Europe.

When growing table grapevine cultivars, it is important to make use of types ranging from very early to very late (Korpás et al., 1990). The appearance of clusters plays an important role. This feature is dependent on the shape and density of berries, their uniform ripening and their colour. Berries with outstanding taste and a high content of aromatic substances are very popular and are demanded by consumers. In the stage of technological ripeness, their pulp should be crispy (Hajdu et al., 2000). Seedlessness is an attractive feature, and modern breeding and selection of table cultivars should be focused on the development of this feature because it definitely increases the demand for such grapes (Mattheou et al., 1995).

In Slovakia, the process of breeding and the selection of normal and seedless table grapevine cultivars were based on studies dealing with the world assortment of these cultivars (Pospíšilová, 1973; Korpás, 1989, 2010) (Table10.14). When breeding table grapevine cultivars, the following cultivars of *V. vinifera* are used: Aptiš Aga, Cardinal, Ceaus roz, Julski biser, Dunavski misket, Pannonia kincse, Katta Kurgan and Kossuth Lájos. The breeding and selection of seedless table cultivars is based on *V. vinifera*: for example Delight, Chibrid bezsemen V-6, Perlette and Beauty Seedless. As far as resistant cultivars are concerned, Talisman, Arkadia and Pölöskei muskotály are used above all.

The process of breeding seedless cultivars is relatively intensive, and its objective is to select not only parthenocarpic but also (and above all) stenospermocarpic cultivars. Rather interesting is the seedless cultivar ELMA that was created in the Slovak breeding firm Korpás in 2000. Elma is the result of crossing (Ceaus roz × Delight) × Kishmish moldavskyi. The skin of its berries is a dark violet to blue colour. Grapes of this cultivar ripen from the end of August to the beginning of September.

10.6.2 New trends in breeding seedless table grapevine cultivars in Slovakia

There are two different types of seedlessness in grapevines, viz parthenocarpy and stenospermocarpy. Parthenocarpy refers to the development of fruit without fertilization. The process produces a sterile fruit that lacks seeds. This means that the pollination results in a production of berries that are completely seedless (Colova-Tsolova et al., 2003). Parthenocarpic seedless berries are mostly small.

Fruit produced through the process called stenospermocarpy contain seeds that die at an early stage, causing the fruit to appear seedless. The ovules or embryos abort without producing mature seeds. Pollination and fertilization occur in stenospermocarpy but not in parthenocarpy. The size of stenospermocarpic berries is something between parthenocarpic and seed-containing berries. The ovules or embryos abort without producing mature seeds (Stout 1936, Pratt, 1971; Colova-Tsolova et al., 2003). The stenospermocarpy is a characteristic feature of the group of sultana-type raisin cultivars, for example Kishmish rozovyi (Pink Sultana), Black Kishmish, Black Monukka and Thompson Seedless grapes). Because the berries of sultanas are relatively big, these cultivars were intensively crossed and selected (Branas and Truel, 1965; Perl et al., 2000; Korpás, 2006). In *V. vinifera*, stenospermocarpy is the most significant form of seedlessness; this form enables to select cultivars that are successful both commercially and biologically. However, to breed and select cultivars with seedless and sufficiently big berries is a difficult task (Korpás, 2010). As far as the seed-containing grapevines are concerned, it is possible to expect the occurrence of many different types, varying

Table 10.14 Seeded and seedless table grape cultivars selected in the Czech Republic and Slovakia

Cultivar	Crossing	Type	Ripening date	Berry colour
Diamant	Julski biser × Pannonia kincse	Seeded	End of August	Green–yellow
Dóra	Julski biser × Pannonia kincse	Seeded	End of August	Green–yellow to yellow
Opál	Ceaus roz × Julski biser	Seeded	Beginning of September	Green–yellow to opaline
Ametyst	Aptiš Aga × Cardinal	Seeded	End of September	Red to orange red
Negra	Aptiš Aga × Cardinal	Seeded	Beginning of September	Blue–black
Onyx	Dunavski misket × Beauty seedless	Seeded	Beginning of October	Dark violet
Pastel	Katta Kurgan × Chibrid seedless V-6	Seeded	Beginning of October	Yellow–green to rosy
Rubanka	Julski biser × Pannonia kincse	Seeded	Beginning of September	Yellow
Bezsemenka	Ceaus roz × Delight	Seedless	End of August	Green–yellow
Heliotrop	Katta Kurgan × Chibrid bezsemen V-6	Seeded	Beginning of October	Rosy
Luna	Katta Kurgan × Perletta	Stenospermocarpic to seedless	Mid-September	Green–yellow
Premier	Dunavski misket × Cardinal	Seeded	Mid-September	Purple–red
Rhea	Ceaus roz × Chibrid Bezsemenn V-6	Stenospermocarpic to seedless	Mid-September	Red
Olšava	Kossuth Lájos × Boskolena	Seeded	2nd half of September	Purple–red
Pola	Poběda × Kossuth Lájos	Seeded	1st half of September	Purple–blue
Vitra	Poběda × Kossuth Lájos	Seeded	1st half of September	Purple–red

from individuals with soft seeds with minimal weight, without endosperm and with a green testa (that are acceptable for consumers), to individuals with hard seeds weighing 40–50 mg, without endosperm but with a brown testa (that are incapable of germinating under normal conditions; these are quite unacceptable for consumers). Because of their bitter taste, even seed traces are unacceptable for consumers, in spite of the fact that they can be easily chewed. They further complicate the process (Korpás, 2006).

Based on the results of performed analyses, it was possible to recommend for further breeding and selection Jupiter, Rusalka 3 and Neptune as maternal genotypes and seedless cultivars Edro bezseme, Elma, Kishmish luchistyi, Kishmish moldavskyi and Dawn seedless as paternal ones (Korpás, 2010).

Genetic studies for quantitative traits in grapevines have recently been greatly improved by the development of molecular markers and genetic maps. The markers were also scored in various Central and Eastern European stenospermocarpic seedless and seeded cultivars. This allowed comparison of the distribution of alleles responsible for seedlessness between the markers, as well as between the cultivars, and determination of seeded cultivars with increased potential to promote seedlessness. The results show that both *SCC8+* and *SCF27+* are linked to *sdI+*, a necessary but not sufficient *locus* for the seedless phenotype in grapevines. This supports the idea that, along with the *sdI locus*, there are probably other *loci* involved in seed development, a quite complex process. It is evident from allelic distribution that there are seeded cultivars with the potential to promote seedlessness. These cultivars can be divided into two groups. The first includes cultivars that harbour the *sdI+* allele and can be selected using appropriate markers, such as SCC8, SCF27 and VMC7f2 with great precision: Chaouch blanc, Chaouch rose, Luna and probably Helikon and Uraan. The presence of stenospermocarpic seeds, along with normal seeds in these cultivars, could aid their identification. In fact, all seeded individuals from crosses between *sdI−/sdI−* (or *sdI+/sdI−*) and *sdI+/sdI+* individuals belong to this group. The second group includes cultivars that do not harbour the *sdI+* allele but contain favourable operator genes as defined by Bouquet and Danglot (1996): Afus Ali, Diamant, Queen of the Vineyards and Yantar. There is a need for appropriate markers linked to these *loci*. As seen in the case of Merkur, if crossed together, these seeded cultivars from different groups can produce seedless individuals. However, the presence of null alleles and the genetic distance of markers from the *sdI locus* involved in seedlessness may produce complications. Even the promising *SCC8+/SCC8+ SCF27+/SCF27+* Jupiter can be heterozygous at the *sdI locus* due to recombination (Korpás et al., 2009).

The cultivar Talisman (Frumoasa albe × Vostorg) was also evaluated in these studies (Korpás, 2010, Figure 10.3). Talisman usually produces big berries with a small number of seeds. The inflorescence of this cultivar consists of functionally female flowers that (after isolation performed before flowering) develop only as parthenocarpic berries. Their mean berry weight was significantly higher than those originating from clusters with mixed berries (i.e. both seed-containing and parthenocarpic ones). The mean weight of parthenocarpic berries originating from clusters resulting from self pollination of early isolated inflorescences was not different from that of seed-containing berries resulting from the free (spontaneous) pollination of those inflorescences that were in blossom very early and were located on secondary shoots. In the case of self-pollination, Talisman not only produced parthenocarpic berries but also showed the loss of flowers, and its parthenocarpic berries developed only in the presence of pollen. The formation of seeds was not uniform. Further, it was found that Talisman represents an important source material for the breeding of vines producing both parthenocarpic and stenospermocarpic seedless berries (Korpás, 2010).

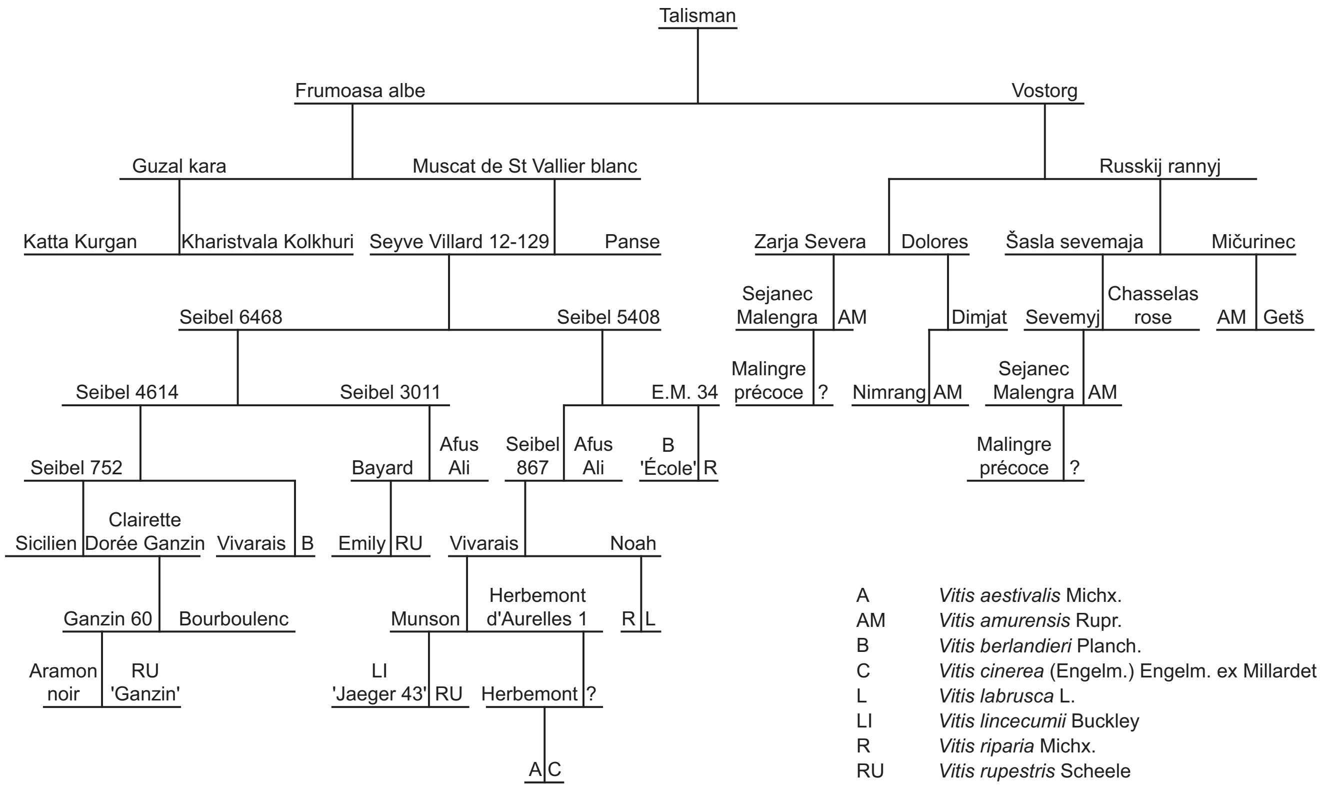


Figure 10.3 Pedigree of the cultivar Talisman (Korpás, 2010).

Acknowledgements

My sincere thanks for support belong to the Czech Republic Ministry of Agriculture. This publication arose as a part of research project 'National programme on plant genetic resources conservation and utilization' (206553/2011-Mze-17253).

References

Alleweldt, G., 1996. Genetics of grapevine breeding. Prog. Bot. 58, 441–454.

Austin, C.N., Wilcox, W.F., 2012. Effects of sunlight exposure on grapevine powdery mildew development. Phytopathology 102, 857–866.

Bakonyi, K., Bakonyi, L., Kocsis, L., 1997. Hungary's rootstock-breeding pioneer. Celebrating Zsigmond Teleki. Pract. Winery Vineyard 6, 9–13.

Balík, J., Kumšta, M., Rop, O., 2013. Comparison of anthocyanins present in grapes of *Vitis vinifera* L. varieties and interspecific hybrids grown in the Czech Republic. Chem. Pap. 67, 1285–1292.

Bareš, I., 1987. History of study of the genetic resources of plants (In Czech). In: Proceedings of 100th Anniversary of the Birth N.I. Vavilov. VURV, Praha-Ruzyně, pp. 19–22.

Becker, H., Börner, C., 1988. The first rootstock immune to all phylloxera biotypes. In: Smart, R.E., Thornton, R., Rodriguez, S., Young, J. (Eds.), Proceedings of the Second International Symposium for Cool Climate Viticulture and Enology. New Zealand Society for Viticulture and Enology, Auckland, pp. 54–55.

Blank, L., Wolf, T., Eimert, K., Schröder, M.B., 2009. Differential gene expression during hypersensitive response in phylloxera-resistant rootstock Börner using oligonucleotide arrays. J. Plant Interact. 4, 261–269.

Börner, C., Schilder, F.A., 1934. Beitrag zur Züchtung reblaus- und melthaufester Reben. II. Das Verhalten der Blattreblaus zu den Reben des Naumburger Sortimentes. Mitt. Biol. Reichsanst. Land-Forstwirt 12, 5–84.

Boso, S., Martínez, M.C., Unger, S., Kassemeyer, H.H., 2006. Evaluation of foliar resistance to downy mildew in different cv. Albarino clones. Vitis 45, 23–27.

Boso, S., Kassemeyer, H.H., 2008. Different susceptibility of European grapevine cultivars for downy mildew. Vitis 47, 39–49.

Boso, S., Alonso-Villaverde, V., Gago, P., Santiago, J.L., Martínez, M.C., 2011. Susceptibility of 44 grapevine (*Vitis vinifera* L.) varieties to downy mildew in the field. Aust. J. Grape Wine Res. 17, 394–400.

Boubals, D., 1966. Étude de la distribution et des causes de la résistance au phylloxéra radicicole chez la Vitacées. Ann. Amelior. Plantes 16, 145–185.

Bouquet, A., Danglot, Y., 1996. Inheritance of seedlessness in grapevine (*Vitis vinifera* L.). Vitis 35, 35–42.

Branas, J., Truel, P., 1965. Variétés de raisins de table: Nomenclature, description, sélection, amélioration. Le Progrès Agricole et Viticole, Montpellier, France.

Cadle-Davidson, L., Chicoine, D.R., Consolie, N.H., 2011. Variation within and among *Vitis* spp. for foliar resistance to the powdery mildew pathogen *Erysiphe necator*. Plant Dis. 95, 202–211.

Colova-Tsolova, V., Lu, J., Perl, A., 2003. Cyto-embryological aspects of seedlessness in *Vitis vinifera* L. and exploiting DNA recombinant technology as an advanced approach for introducing seedlessness into vinifera and muscadine grapes. Acta Hortic. 603, 195–200.

Eibach, R., Diehl, H., Alleweldt, G., 1989. Investigations on the heritability of resistance to Oidium tuckeri, *Plasmopara viticola* and *Botrytis cinerea* in grapes. Vitis 28, 209–228.

Gadoury, D.M., Cadle-Davidson, L., Wilcox, W.F., Dry, I.B., Seem, R.C., Milgroom, M.G., 2012. Grapevine powdery mildew (*Erysiphe necator*): a fascinating system for the study of the biology, ecology and epidemiology of an obligate biotroph. Mol. Plant Pathol. 13, 1–16.

Galet, P., 1988. Cépages et Vignobles de France, second ed. Les Vignes Américanes, Tome 1,Oenoplurimedia. 554 pp.

Garcia-Beneytez, E., Revilla, E., Cabello, F., 2002. Anthocyanin pattern of several red grape cultivars and wines made from them. Eur. Food Res. Technol. 215, 32–37.

Goldy, R.G., Ballinger, W.E., Maness, E.P., 1986. Fruit anthocyanin content of some Euvitis × *Vitis rotundifolia* hybrids. J. Am. Soc. Hortic. Sci. 111, 955–960.

Hajdu, E., Ésik, É., Borbás, É., Pernesz, G.Y., 2000. Gegen Plizkrankheiten resistente Traubensorten und ihre Qualität. In: Proceedings Sixth International Congress on Organic Viticulture. 25–26 August 2000. Basel, pp. 210–220.

Hausmann, L., Eibach, R., Zyprian, E., Töpfer, R., 2010. Sequencing of the phylloxera resistance locus Rdv1 of cultivar Börner. Abstracts. In: 10th International Conference on Grapevine Breeding and Genetics, Geneva, New York, USA, No. 26.

Jelen, H.H., Majcher, M., Dziadas, M., Zawirska-Wojtasiak, R., Czaczyk, K., Wasowicz, E., 2011. Volatile compounds responsible for aroma of Jutrzenka liquer wine. J. Chromatogr. A 1218, 7566–7573.

Kellow, A.V., Sedgley, M., McDonald, G., Van Heeswijck, R., 2000. Analysis of the interaction of phylloxera with susceptible and resistant grapevines using in vitro bioassays, microscopy and molecular biology. In: Proceedings of the International Symposium on Grapevine Phylloxera Management, Winetitles, Adelaide, Australia, pp. 22–31.

Korpás, A., 1989. Study of the New Wine and Table Grape Varieties in the Conditions of South Slovakia (Ph.D. thesis). 192 pp.

Korpás, A., 2006. Atlas of Seedless Table Grape Varieties. CD-ROM, Verze 1.0 http://tilia.zf.mendelu.cz/ustavy/556/ustav_556/atlas_bezsem_reva/.

Korpás, A., Baránek, M., Pidra, M., Hradilík, J., 2009. Behaviour of two SCAR markers for seedlessness within Central European varieties of grapevine. Vitis 48, 33–42.

Korpás, O., 2010. Plant Tissue Culture Cultivation of Seedless Varieties of Grapes (Ph.D. thesis). Mendel University, Brno, 162 pp.

Korpás, O., Pekárik, Š., Baranovič, R., 1990. Evaluation of the quality and economical efficiency of new table grape varieties (In Slovak). Vinohrad 28, 98–100.

Křivánek, V., 1989. New clones and new rootstock hybrids (In Czech). Moravin Proc. Viticultural Enological Actualities 54–57.

Kubal, M., Piziak, B., 2010. Wine tourism in rural areas – polish conditions after the transformation. J. Settlements Spat. Plan. 1, 135–144.

Mazza, G., 1995. Anthocyanins in grapes and grape products. Crit. Rev. Food Sci. Nutr. 35, 341–371.

Mattheou, A., Stavropoulos, N., Samaras, S., 1995. Studies on table grape germplasm grown in Northern Greece. I. Maturity time, bunch characteristics and yield. Vitis 34, 155–158.

Miclot, A.S., Wiedemann-Merdinoglu, S., Duchene, E., Merdinoglu, D., 2011. A standardized method for the quantitative analysis of resistance to grapevine powdery mildew. Eur. J. Plant Pathol. 133, 483–495.

Moser, L., 1970. High Training of the Grapevine (In Slovak). Príroda, Bratislava. 249 pp.

OIV, 1983. Descriptor List for Grapevine Varieties and *Vitis* Species. OIV, Paris. 135 pp.

Pavloušek, P., 2007. Encyclopaedia of Grapevine Cultivars (In Czech). Computer Press, Brno. 316 pp.

Pavloušek, P., 2011. Grapevine Growing – Modern Viticulture (In Czech). Grada Publishing, Praha. 333 pp.

Pavloušek, P., 2012. Screening of rootstock hybrids with *Vitis cinerea* Arnold for phylloxera resistance. Cent. Eur. J. Biol. 20, 708–719.

Pavloušek, P., Kumšta, M., 2014. Contents of malvidin-3,5-diglucoside in wine of resistant grapevine varieties. Unpublished results.

Pavloušek, P., Kumšta, M., Mateiciucová, P., 2013. Erfahrungen mit den anbautechnischen Eigenschaften bei den neuen PIWI Rebsorten. Book of Abstracts. Deutschen Weinbaukongresses. No. 61.

Perl, A., Sahar, N., Spiegel-Roy, P., Gavish, S., Elyasi, R., Orr, E., Bazak, H., 2000. Conventional and biotechnological approaches in breeding seedless table grapes. Acta Hortic. 528, 607–612.

Pospíšilová, D., 1973. Research of World Collection of the Grapevine Varieties. KVUVV, Bratislava. 135 pp.

Pospíšilová, D., 1974a. Heterosiszüchtung bei *Vitis vinifera* L. Vitis 13, 89–97.

Pospíšilová, D., 1974b. Heterosis in the breeding of *Vitis vinifera* L. varieties (In Slovak) Vinohrad 12, 106–108.

Pospíšilová, D., 1981. Ampelography CSSR (In Slovak). Príroda, Bratislava. 347 pp.

Pospíšilová, D., 1990. Evaluation and utilization of vine genetic resources in Czechoslovakia. In: Proceedings of the 5th International Symposium on Grape Breeding, 12–16 September 1989, St. Martin/Pfalz, FR of Germany, Vitis Special Issue, pp. 58–61.

Pospíšilová, D., Korpás, O., 1998. Grapevine Breeding and New Crossing in Slovakia (In Slovak). Bratislava, Slovakia, 222 pp.

Pratt, C., 1971. Reproductive anatomy in cultivated grapes – a review. Am. J. Enol. Vitic. 22, 92–109.

Ramming, D.W., Gabler, F., Smilanick, J., Cadle-Davidson, M., Barba, P., Mahanil, S., Cadle-Davidson, L., 2011. A single dominant locus, Ren4, confers rapid non-race-specific resistance to grapevine powdery mildew. Phytopathology 101, 502–508.

Ribéreau-Gayon, P., Dubourdieu, D., Doneche, B., Lonvaud, A., 2000. Handbook of Enology. The Chemistry of Wine Stabilization and Treatments, vol. II, John Wiley & Sons Ltd, Chichester, United Kingdom. 404 pp.

Robinson, W.B., Weirs, L.D., Bertino, J.J., Mattick, L.R., 1966. The relation of anthocyanin composition to color stability of New York State wines. Am. J. Enol. Vitic. 17, 178–184.

Schmid, J., Manty, F., Rühl, E.H., 2003. Utilizing the complete phylloxera resistance of *Vitis cinerea* Arnold in rootstock breeding. Acta Hortic. 603, 393–400.

Schwander, F., Eibach, R., Fechter, I., Hausmann, L., Zyprian, E., Töpfer, R., 2012. Rpv10: a new locus from the Asian *Vitis* gene pool for pyramiding downy mildew resistance loci in grapevine. Theor. Appl. Genet. 124, 163–176.

Stout, A., 1936. Seedlessness in grapes. New York State Agriculture Experimental Station Technical Bulletin, 238, Geneva, New York, USA.

Todorov, I., 1983. Study on grapevine seeds and seedlings obtained by inbreeding (In Bulgarian) Grad. Loz. Nauka 20, 85–91.

Töpfer, R., Hausmann, L., Harst, M., Maul, E., Zyprian, E., Eibach, R., 2011. New horizons for grapevine breeding. Fruit, Veg. Cereal Sci. Biotechnol. 5 (Special Issue), 79–100.

Van Buren, J.P., Bertino, J.J., Einset, J., Remaily, G.W., Robinson, W.B., 1970. A comparative study of the anthocyanin pigment composition in wines derived from hybrid grapes. Am. J. Enol. Vitic. 21, 117–130.

Zhang, J., Hausmann, L., Eibach, R., Welter, L.J., Töpfer, R., Zyprian, E.M., 2009. A framework map from grapevine V3125 (*Vitis vinifera* 'Schiava grossa' × 'Riesling') × rootstock cultivar 'Börner' (*Vitis riparia* × *Vitis cinerea*) to localize genetic determinants of phylloxera root resistance. Theor. Appl. Genet. 119, 1039–1051.

Grapevine breeding programs in Brazil

11

J.D.G. Maia[1], *U.A. Camargo*[2], *J. Tonietto*[3], *M.C. Zanus*[3], *V. Quecini*[3], *M.E. Ferreira*[4], *P. Ritschel*[3]

[1]Embrapa Grape and Wine, Tropical Viticulture Experimental Station, Jales, Brazil; [2]Vino Vitis Consulting Ltda., Bento Gonçalves, Brazil; [3]Embrapa Grape and Wine, Bento Gonçalves, Brazil; [4]Embrapa Genetic Resources and Biotechnology, Parque Estação Biológica, PqEB, Brasília, Brazil

11.1 Introduction

11.1.1 Grapevine: introduction and culture expansion in Brazil

Grapes are not only one of the most produced fruit species worldwide; they are also among the earliest domesticated crops. The genus *Vitis*, to which the grapevine belongs, originated in North America and Eurasia and probably evolved before the breaking of the Bering intercontinental bridge in the Quaternary Period (Mullins et al., 1992). *Vitis vinifera* is the most popular viticulture species in the world, being the only one originated in Eurasia 65 millions of years earlier. Seeds of domesticated grapevines were already found in archaeological sites from the Neolithic Period in Europe (This et al., 2006). Grapes and wine are mentioned by Egyptians, Phoenicians, Greeks, Romans and Etruscans, among others, for medical and ritualistic purposes (Johnson, 1989; McGovern et al., 2009).

In the 1400s, grapevine (*V. vinifera*) crops were introduced in the Canary and Madeira Islands and from there arrived to South Africa, Australia and South America. During the eighteenth century, the culture was introduced in North America via California. In contrast, hybrids between American species, such as *Vitis labrusca* and *Vitis bourquina* crossed to *V. vinifera*, started to be cultivated in the 1800s and played an important role in the establishment of viticulture in America (Alleweldt et al., 1990; Hedrick, 1908, 1919).

In Brazil, the grapevine was introduced from insular Portuguese regions on the very first expedition with colonizing purposes. The first vineyards were established on the coast, where the state of São Paulo is currently (Figure 11.1) (Sousa, 1969). The Portuguese brought *V. vinifera* grapevine varieties, selected based on personal information and the experience of European growers (Miranda, 2001). However, Brazilian climatic conditions, especially on the warm and humid coast, were not favourable for European varieties. The first Brazilian wine was made around 1551, with grapes from vineyards established in Piratininga plateau, in the surroundings of the current city of São Paulo. In the Northeast region, there are notes about grapevine growing in the 1500s in the state of Bahia, in the vicinity of the city of Salvador,

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00011-9

around 1549 and in the state of Pernambuco as early as 1542 (Figure 11.1) (Sousa, 1969). Portuguese grape varieties, such as Ferral and Dedo de Dama, along with Muscat grapes, were also established in drier areas, averting the possibility of successive vintages (Salvador, 1627).

In the state of Rio Grande do Sul (Figure 11.1), the first viticultural activities were recorded only after the arrival of the Jesuit mission to Brazil in 1626, but those initial vineyards were completely destroyed when the religious order was expelled from the country. In the current state of Santa Catarina, records from 1807 mention the growing of grapes and other European fruits, probably introduced by natives from the Azores and Madeira Islands that migrated to Southern Brazil in 1700s. Those immigrants also re-established viticulture in the state of Rio Grande do Sul (Sousa, 1969; Miranda, 2001).

However, although widespread in colonial Brazil, viticulture was not a commercially important activity, and instead it was restricted to backyards in the cities and farmhouses in the countryside (Sousa, 1969). Some historians present several economic reasons to explain the lack of importance of Brazilian viticulture in that period (Dickenson, 1995; Sousa, 1969). Others assign the restricted success of the crop to biological and technological factors, such as the typical susceptibility of *V. vinifera*, the nonfavourable Brazilian climatic conditions and the limitation of agricultural management techniques at that time (Sousa, 1969).

The failure in growing European grapes in the New World is not restricted to colonial Brazil, as it has also been recorded in the history of North American agriculture.

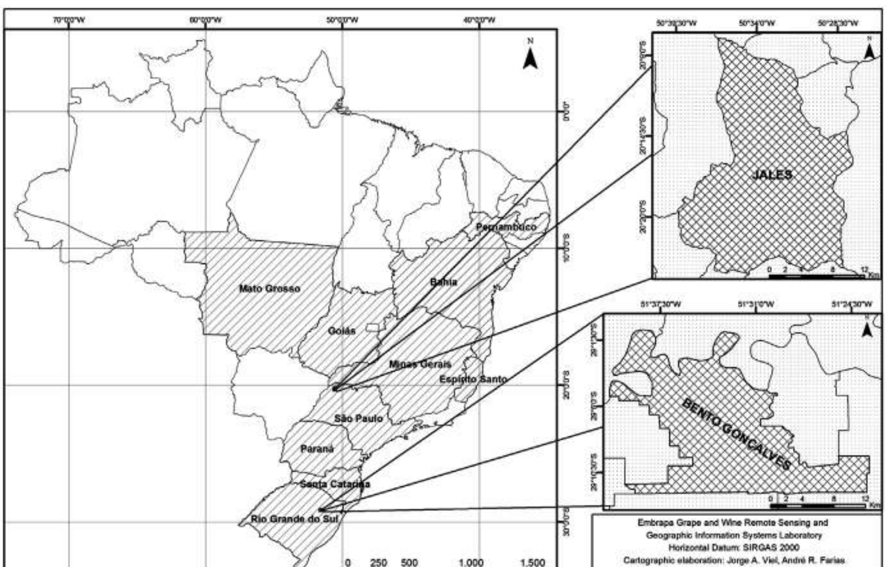


Figure 11.1 Map of the current viticultural regions in Brazil and the locations of Embrapa Grapevine and Wine Headquaters (Bento Gonçalves, RS) and Tropical Viticulture Experimental Station (TVES) (Jales, SP).

The problems were only overcome with the incorporation of other *Vitis* species, native of North America, into commercial production. These grapevine species are hardier than the European varieties and started to be used from the nineteenth century, when the Americans developed the first hybrid varieties Catawba, Isabella, Norton, Ives and Concord (Hedrick, 1908, 1919; Pinney, 1989).

The spread of American grapes in Brazil gained momentum with the arrival of Italian immigrants, from 1875 on, resulting in a quick replacement of the European grapevine cultivars. However, as occurred in Europe, the introduction of American grape species brought along new fungal diseases, such as downy mildew (*Plasmopara viticola* (Berk and Curt) Berl.) and powdery mildew (*Uncinula necator* (Schw.) Burr). The phytosanitary problems contributed to compromise the cultivation of European and even of American grapevine cultivars known to be resistant to the major fungal diseases. Thus, new technological goals were established for Brazilian viticulture in order to prevent the occurrence of fungal diseases, including the development of cultivars with increased tolerance and the use of chemical control (Sousa, 1969). The adoption and evolution of those cultural practices contribute to the success of tropical viticulture in Brazil 100 years later.

Until the middle of the 1900s, Brazilian viticulture was restricted to the cultivation of American grapes under temperate and subtropical climates in the South and Southeast. After the spread of Isabella from 1830 to 1840, other American cultivars became popular, such as Herbemont, Concord, Ives, Seibel 2, White Niagara, Rose Niagara and Jacquez. In the 1970s, the Brazilian white wine market was supported by Seyve Villard 5276 and Couderc 13, while the red wines were mainly made from Ives (synonym: Bordô) and Concord (Camargo et al., 2012c).

11.1.2 The current viticulture panorama in Brazil

The development of synthetic fungicides allowed the widespread cultivation of European grapes in Brazil to fresh fruit and wine making markets. The cultivation of European grapes, such as the Italian cultivars Barbera, Bonarda, Peverella, Marzemino, Trebbiano and also Cabernet Franc, Merlot and Riesling, was encouraged by the government in Southern Brazil from the 1940s. However, the real dissemination of European cultivars occurred only in the 1970s, with the establishment of international companies in the state of Rio Grande do Sul. The initial Italian cultivars were almost completely replaced by French ones, such as Pinot Noir, Cabernet Sauvignon, Chardonnay, Gamay and Sauvignon Blanc to varietal winemaking (Camargo et al., 2012c; Protas et al., 2002).

In contrast, commercial tropical viticulture was started in the 1960s with the introduction of European table grapes in the Valley of São Francisco River, in tropical semiarid Northeastern Brazil (Protas and Camargo, 2011). Lately, the development of new cultivars adapted to local soil and climatic conditions, along with the improvement of viticultural practices, allowed the cultivation of American grapes in tropical areas. Thus, currently, one can witness the expansion of grapevine cultivation to tropical regions in Brazil, mainly to the states of Goiás, Mato Grosso, Pernambuco and Bahia (Figure 11.1) (Camargo, 2005; Guerra et al., 2005; Maia and Kuhn, 2001; Ritschel et al., 2008).

In the Valley of São Francisco River (states of Pernambuco and Bahia), winemaking is based on traditional *V. vinifera* cultivars, such as Syrah, Alicante Bouschet, Chenin blanc and Moscato Canelli. Currently, new choices, such as Tempranillo, Petit Verdot, Touriga Nacional, Grenache and Verdelho, are spreading throughout the region. Several new Brazilian hybrid cultivars are increasingly being grown in both traditional and new viticulture areas (Camargo et al., 2012c).

Three periods of development of wine production have occurred since 1875, classified as First Generation – wines from American vines; Second Generation – wine diversification using hybrids and viniferas; and Third Generation – varietal wines. In the 1990s, Brazil entered the fourth stage (Tonietto and Mello, 2001), which involves the production of quality wines with Geographical Indications (GI). Since 1996, the Law of Industrial Property in Brazil (Law No. 9.279) paved the way for the recognition and legal protection of GI in two categories: GI and Appellation of Origin, at a nationwide level, under the authority of the Brazilian National Institute of Industrial Property.

In 1995, a small group of producers from the traditional Serra Gaúcha, a region in the surroundings of the city of Bento Gonçalves currently located at the Vale dos Vinhedos zone, became interested in having a GI for vinifera wines. In 2002, the region was recognized as the first GI in Brazil under the supervision of a growers association known as Aprovale. The development of the Vale dos Vinhedos GI resulted in several economic repercussions to wine production. From that point, other wine-producing regions became interested, resulting in several projects for GI development (Tonietto, 2012). In the Fourth Development Period of Brazilian winemaking, the recognized GIs, adding originality and value to the differential quality and typicality of products, are part of the conceptual and structural change strategies in sector policies for grape growers and wine producers to increase the competitiveness of Brazilian wines in national and international markets. The cultivars adapted to each region are valued for Brazilian regions with GIs, as in the case of the GI for Farroupilha (a county near Bento Gonçalves), with focus on muscatel vinifera-based wines due to the originality of the local production of cultivar Moscato Branco. Another example is the GI Vales da Uva Goethe, using American hybrid Goethe, which is traditionally cultivated in Santa Catarina.

Currently, Brazil is 13th worldwide in grape production (FAO, 2013). Despite the expansion tendency, Brazilian viticulture is still concentrated in the Central-southern regions of the country. The state of Rio Grande do Sul is the main producer, followed by Pernambuco, São Paulo, Paraná, Santa Catarina, Bahia and Minas Gerais (Figure 11.2). In 2012, 830,915 t, equivalent to approximately 57% of the national grape production, were industrialized to wine (257,980,767 L), juice (70,066,733 L) and other products, such as sparkling wine, dessert wine, concentrated must, and others (100,757,101 L) (Figure 11.3) (Mello and Machado, 2013). A large portion of Brazilian wine is made of grapes from American and hybrid cultivars. Although not accepted in Europe, these grapevines are broadly grown in Brazil, the US East Coast and Asia, due to the hardiness and yield of the plants.

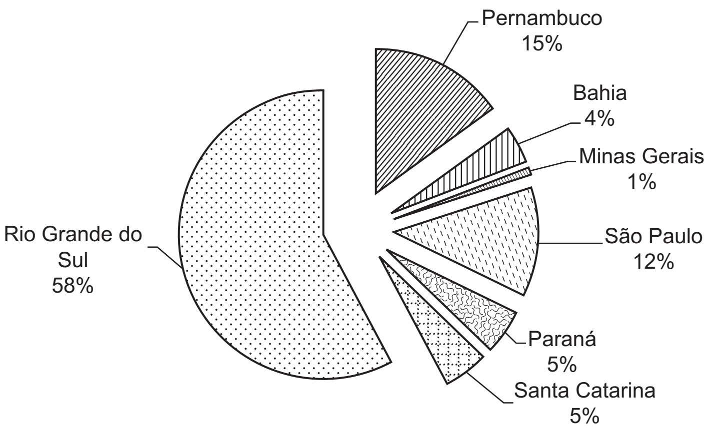


Figure 11.2 Grapevine production per state in Brazil. The most representative producing states are shown (Mello and Machado, 2013).

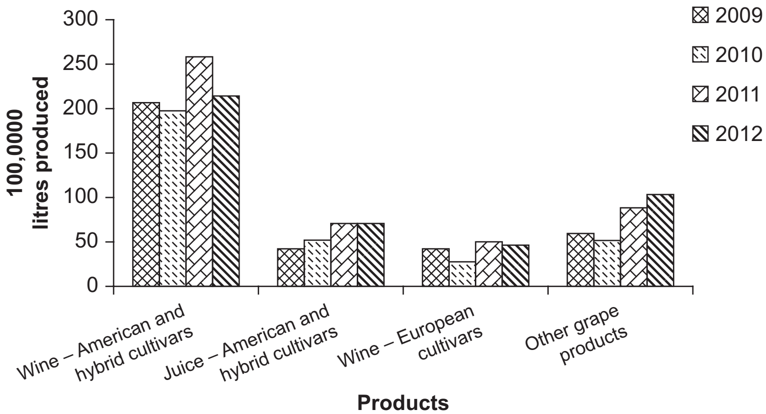


Figure 11.3 Grape products in Brazil from 2009 to 2011. Other grape products include sparkling wine, dessert wine and concentrated must, among others (Mello and Machado, 2013).

11.2 Germplasm banks

In South America, public research institutions conserve grapevine genetic resources in independent collections. In Brazil, the Grapevine Germplasm Bank (GGB), maintained by Embrapa Grape and Wine, is currently the main collection in South America, consisting of approximately 1400 accessions, including cultivars, interspecific hybrids and wild species of *Vitis* and *Ampelopsis* genera (Table 11.1). Other ampelographic collections, with a smaller number of accessions, are conserved by several public grapevine research Brazilian institutions, such as agricultural research companies of the states of Minas Gerais (Empresa de Pesquisa Agropecuária de Minas Gerais, EPAMIG), São Paulo (Instituto Agronômico de Campinas, IAC),

Table 11.1 Use of species of the *Vitis* genus in plant breeding during the last century and list of accessions from the Grapevine Germplasm Bank (GGB) at Embrapa Uva e Vinho

Species	GBB accessions	Uses in breeding		
		Novel varieties	Rootstocks	Interspecific hybrids
Ampelopsis cordata	1	–	–	–
Ampelopsis heterophylla	1	–	–	–
Ampelopsis vitifolia	1	–	–	–
Interspecific hybrids	561	+++*	++*	+++*
Non-classified accessions	52	–	–	–
Muscadinia rotundifolia	11	++	+*	+
Vitis aestivalis	–	–	–	++
Vitis ampelopsis	1			
Vitis amurensis	2	+	–	++
Vitis andersonii	1	–	–	–
Vitis arizonica	1	–	–	–
Vitis armata	1	–	–	*
Vitis berlandieri	2	+	+++	–
Vitis betulifolia	1	–	–	–
Vitis bourquina	12	–	–	–
Vitis candicans	1	–	+	–*
Vitis caribaea	2	–	–	+
Vitis caucasica	1	–	–	–
Vitis champinii	2	+	+	–
Vitis cinerea	1	–*	+	++*
Vitis cordifolia	1	–	+	+
Vitis coignetiae	1	–	–	*
Vitis davidii	1	–	–	–
Vitis del rioi	17	–	–*	–*
Vitis doaniana	3	–	–	–
Vitis embergerii	1	–	–	*
Vitis flexuosa	1	–	–	–
Vitis gigas	1	–	–	*
Vitis girdiana	1	–	–	–
Vitis hongijixin	1	–	–	–
Vitis jacquemontii	4	–	–	–

Continued

Table 11.1 Continued

Species	GBB accessions	Uses in breeding		
		Novel varieties	Rootstocks	Interspecific hybrids
Vitis labrusca and hybrids	64	+++*	++*	+++*
Vitis longii	1	+	++	–
Vitis montícola	2	–	–	–
Vitis novomexico	1	–	–	–
Vitis piaseskii#	–	–	–	*
Vitis riparia	1	++*	+++*	+++*
Vitis rupestris	4	++*	+++	+++
Vitis romanetii#	–	–	–	*
Vitis rubra	1	–	–	–
V. rupestris	4	–	–	–
Vitis simpsonii	1	–	+	–
Vitis shuttleworthii	1	–	–	*
Vitis silvestris	1	–	–	–
Vitis simpsonii	1	–	–	–
Vitis sinocinerea#	–	–	–	*
Vitis smalliana	1	–	–	*
Vitis slavinii	1	–	–	–
Vitis thunbergii	1	–	–	–
Vitis tiliifolia	1	–	+	–
Vitis vinifera	655	+++++*	+*	++++*
Vitis vulpina	1	–	–	–
Vitis yeshanensis	1	–	–	–

Frequent usage is indicated by larger numbers of plus signs (+), whereas subtraction signs (–) indicate lack of use ***(adapted from This et al., 2006)***. The number of accessions at the GGB at Embrapa Uva e Vinho is presented in the GBB column. The species used by the local breeding program are represented by * and lost accessions are indicated by #

Paraná (Instituto Agronômico do Paraná, IAPAR) and Santa Catarina (Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina, EPAGRI). The GGB at Embrapa Tropical Semiarid includes about 230 accessions and is the only collection kept in the Northeastern region of the country (Ferreira and Pádua, 2009).

11.2.1 Grapevine germplasm bank

GGB was initially assembled at the former Caxias do Sul Experimental station before Embrapa was founded. In 1975, upon the founding of Embrapa Grape and Wine, the collection contributed as a starting point for the development of the current GGB, formed by gathering smaller national grapevine germplasm collections and by the introduction of cultivars from several countries worldwide (Camargo, 1980). From the beginning, there has been a straight relationship between GGB and the Grapevine Breeding Program conducted at the institution. After evaluation, accessions introduced and maintained by the GGB can be directly used by growers and winemakers, also adding value to novel Brazilian GI. Alternatively, selected accessions presenting trait(s) of interest can be crossed to develop segregating populations and give rise to new cultivars. Table 11.1 summarizes the use of the germplasm, maintained by the Brazilian and other international collections, to develop new cultivars and form improved gene and genome banks for breeding purposes. A small part of the gene pool available in *Vitis* has been explored by breeders in Brazil and elsewhere.

11.2.1.1 Strategies for the conservation of grapevine germplasm

Grapevine germplasm comprises a large number of genotypes originated from environments with specific biotic and abiotic factors (This et al., 2006). The maintenance of grapevine collections in a uniform environment, safe from the occurrence of natural disasters, pest or disease attacks, is one of the greatest challenges of conservation. The maintenance of field grapevine collections requires extensive areas and large amounts of human and financial resources (Li and Pritchard, 2009). In contrast, in vitro conservation allows the maintenance of thousands of genotypes in small rooms, reducing the risks of extinction and genetic diversity losses (Walters et al., 2008; Volk, 2010; Bennelli et al., 2013). The advantages of in vitro culture include the higher propagation speed, the maintenance of fungus-, bacteria- and virus-free genotypes, small requirements for space, reduced costs per individual and the facilitation of germplasm transportation (Engelmann, 1991; Walters et al., 2008; Bennelli et al., 2013). In vitro conservation can also help the establishment of international agreements for germplasm exchange, mainly due to the improved phytosanitary conditions (Börner, 2006).

Until the end of the 1990s, the GGB was conserved in Bento Gonçalves, RS, in a region of temperate conditions (29°09′S, 51°31′W, 680 m high). Later, the bank was moved to the Tropical Viticulture Experimental Station (TVES), in Jales, SP, where the climate is classified as Aw Rainy Tropical with dry winters (20°09′S, 50°36′W, 480 m high). Currently, GGB is maintained as two field collections. The germplasm that has been characterized is maintained by Embrapa Grape and Wine at the TVES in dense plots with four replicates per accession. The germplasm undergoing characterization under temperate climate conditions is maintained at the headquarters of Embrapa Grape and Wine, in Bento Gonçalves, as four to six replicates per accession, in the field, in a vertical conducting system, grafted on the rootstock 101-14 Millardet et de Grasset.

Approximately 1000 accessions are conserved in vitro as duplicates in minimal growth conditions at 21°C and propagated every 4 months. In vitro introduction and establishment for the remaining accessions of GGB is underway. Cryopreservation, at temperatures lower than −196°C, allows accessions maintenance for long times without phenotypic or genotypic modifications (Volk, 2010; Bennelli et al., 2013). Currently, cryopreservation protocols are available to a limited number of grapevine genotypes, including scions and rootstocks (Wang et al., 2000; Bennelli et al., 2003; Matsumoto and Sakai, 2003; Wang et al., 2003), some exhibiting up to 80% of recovery efficiency (Matsumoto and Sakai, 2003). However, until now, cryogenic preservation of grapevine genotypes is not routinely employed (Bennelli et al., 2013). At Embrapa Grape and Wine, plant recovery after cryopreservation of 11 genotypes is currently under investigation, employing modified vitrification and encapsulation dehydration protocols.

11.2.1.2 Evaluation of GGB accessions

For 10 years, 1000 accessions of the collection were evaluated in Southern Brazil under temperate climate conditions using 23 Biodiversity International descriptors (IPGRI, 1997). The following data were recorded: phenology (start and end of bud flushing, flowering, maturation and leaf fall); yield; must composition (soluble solids, titratable acidity (TA) and pH); disease incidence (downy mildew, powdery mildew, anthracnose (*Elsinoe ampelina* (De Bary) Shear); viruses, grey mould (*Botrytis cinerea*, Pers.) and bunch rot (several agents)); features of cluster (size and shape) and berry (colour, shape, texture and flavour) and flower type (male, female or hermaphrodite). Data are available at Embrapa Grape and Wine webpage (Embrapa Uva e Vinho, 2009). Dried leaves of the accessions are kept in the herbarium.

Four hundred accessions are currently under evaluation in Bento Gonçalves, RS. Additionally, a sample of 200 accessions from the GGB was selected for traits associated to tropical adaptation, such as continuous growth, resistance to rust (*Phakopsora euvitis* Ono) and leaf blight, whose causal agent has not yet been determined and is currently under evaluation at the TVES, Jales (Camargo et al., 2012b). Berry total phenolics and anthocyanins are also being evaluated for the accessions (Caumo et al., 2012; Dall'agnol et al., 2013).

Genetic analysis of 1400 accessions from the GGB was initiated using 30 simple sequence repeats (SSR) markers selected from the literature and multiplexed for three or more loci per amplification reaction. The set includes the six SSR markers described by This et al. (2004) and used for genetic studies of other grapevine collections worldwide. Thus, it will allow the confirmation of the trueness-to-type of GGB accessions. Therefore, genotyping is contributing to the current knowledge of the genetic variation in the collection and is resolving genetic identity issues. It also contributes to the selection of parents for future crossings, along with phenotypic evaluation data (Camargo et al., 2012a).

As a result of GGB evaluations, two new cultivars, Early Isabella and Concord Clone 30 (Early Concord) (Camargo et al., 2000; Camargo, 2004), somatic mutations of original Isabella and Concord and described elsewhere in this text, were propagated and made available to growers. Currently, molecular comparisons of regular cultivars and their respective sports are underway to confirm the clonal relations between them.

The results from molecular and morphological characterization of GBB accessions are offering support to the further development of Brazilian GIs. The region of Farroupilha, in the state of Rio Grande do Sul, concentrates more than 50% of the Muscat grape production in Brazil, including the cultivar Moscato Branco, one of the most cultivated Muscat varieties in the country. Also known as 'Moscato Italiano', the origin of Moscato Branco is not known, although it has been described in Brazil since the 1930s. Preliminary ampelographic data suggested that Moscato Branco is a variety with expressive commercial cultivation restricted to Brazil, since no Italian cultivar with similar traits has been identified so far. Agronomic and phenological features of Moscato Branco were also compared with other Muscat grapes maintained in the GGB. Similarly, multiplex panels of SSR markers were used to compare the genetic profile of Moscato Branco with 636 accessions from the GGB and 4.370 accessions from the French grape germplasm collection. The results indicated that Moscato Branco exhibits a unique genetic profile, distinct from Muscat blanc, Moscato Giallo, Moscato de Hamburgo and Moscato de Alexandria. Its DNA fingerprint is also different from accessions of the 'Malvasia' group, as well as from that of 'Italia' and its sports. These results confirm Moscato Branco uniqueness and are adding value and supporting the development of the GI for the Farroupilha region. The sequencing of the Moscato Branco genome using Next Generation Sequencing technology was initiated to increase the knowledge on the genome context of the genotype, aiming the development of molecular tools to support further research on grape breeding and genetics in Brazil (Martins et al., 2013).

11.3 Brazilian grapevine breeding programs

The first notes on grapevine genetic breeding in Brazil were about private initiatives from the late nineteenth century (Paz, 1898; Sousa, 1969). In the 1940s, public institutions began these activities, first in the state of São Paulo and later in Rio Grande do Sul (Santos Neto, s.d.; Santos Neto, 1971; Sousa, 1969; Pommer, 1993; Camargo et al., 2009).

11.3.1 IAC breeding program

The grapevine breeding program maintained by IAC is a landmark for the beginning of the development of cultivars adapted to tropical climates. Several table grape cultivars, such as Piratininga and Patricia, fundamental to the development of tropical viticulture in São Francisco River Valley (Soares and Leão, 2009), were developed by the program.

However, the main results of the program were the development of rootstocks adapted to tropical conditions (Santos Neto, 1971). Those genotypes have been widely used in tropical viticulture with *V. vinifera* and American scions (Soares and Leão, 2009; Kuhn et al., 2003; Guerra et al., 2005; Regina et al., 2006). Rootstock IAC 313 (synonym: Tropical) was very important in the establishment of viticulture in the Valley of the São Francisco River and has also been used in the north of the state of Minas Gerais and in the Northwest of São Paulo. IAC 572 (synonym: Jales) is currently the most popular rootstock onto which American grapevines are grafted in tropical areas in Brazil. Another choice for tropical climates is IAC 766 (synonym: Campinas).

The fast spread of those rootstocks developed to warmer areas, virtually replacing the traditional rootstocks from temperate regions, is a proof of the great contribution of grapevine breeding programs to tropical viticulture (Camargo, 2002). The current tendency is the increasing usage of these rootstocks, along with the spread of tropical viticulture in Brazil (Camargo, 2008).

Regarding wine grapes, the program has developed the cultivars Rainha (IAC 116-31) and Máximo (IAC 138-22), interesting commercial choices for the states of São Paulo and Espírito Santo, where they are currently employed to make white and red 'vinifera'-type wines, respectively. The cultivation areas of those cultivars have remained stable in the country (Camargo, 2008).

11.3.1.1 Máximo (IAC 138-22)

Máximo is a hybrid producing red grapes, resultant from the cross between Seibel 11342 and Syrah, made by IAC researchers in 1946 in the state of São Paulo (Sousa and Martins, 2002). It is cultivated in São Paulo, Jundiaí and São Roque counties and also on the mountain regions of the state of Espírito Santo. There are records of its cultivation and use in winemaking also in the south of Brazil (Sousa and Martins, 2002). It is an early material, tolerant to the main grapevine diseases in Brazil (Gallo Neto, 2008; Pommer, 2009). It can be successfully grafted on IAC 313 and IAC 766 rootstocks (Terra et al., 1990). It can reach yields up to 30 t/ha, with soluble solids and TA of 16 °Brix and 150 meq/L, respectively (Embrapa Uva e Vinho, 2009). Máximo wine is distinguished by its deep characteristic colour and high acidity (Camargo and Maia, 2008; Sousa and Martins, 2002).

11.3.1.2 Rainha (IAC 116-31)

Rainha is a cultivar producing white grapes, a hybrid from the cross of Seibel 7053 and Burgunder Kastenholtz made in 1946 at IAC in the state of São Paulo (Sousa and Martins, 2002; Pommer, 2009). Currently, it can be found in the states of São Paulo, Santa Catarina and also on the mountain regions of Espírito Santo. The growth area of the cultivar in those states remains stable, showing no trend towards increase or reduction (Camargo, 2008; Camargo and Maia, 2008). The genotype is distinguished by its medium vigour and harvest in late January (Sousa and Martins, 2002). Soluble solids are typically around 22 °Brix and TA is 96 meq/L (Embrapa Uva e Vinho, 2009). The white wine made with Rainha is pleasant and well-balanced. It can be used as a blend in red wines (Pommer, 2009).

11.3.2 Embrapa Grape and Wine breeding program

Embrapa Grape and Wine conducts a grape breeding program mainly focused on hybridization aiming to develop novel grape cultivars for *in natura* consumption and processing for the wine and juice industries (Ritschel and Maia, 2009). Despite the existence of specific lines of interest for each usage, the program has common goals, such as the development of novel cultivars with greater fecundity in warm conditions and/or increased tolerance to the major grapevine pests and diseases. Specific objectives for each product are also pursued. Concerning the development of wine grapevine cultivars, the program pursues three main objectives: for *V. vinifera* grapes, the main purposes are the development of novel white Muscat cultivars with resistance to bunch rot and red grape cultivars to give rise to wines with intense colour. The development of novel grape cultivars totally adapted to tropical conditions in order to make truly 'labrusca'-type wines is also a goal, since the Brazilian market favours this type of wine. Finally, one of the main interests is to develop cultivars displaying the hardiness of American grapes and the flavour of *V. vinifera*.

Basic germplasm used by the program includes *V. vinifera* and hybrids from *V. labrusca*, along with tropical wild species such as *Vitis caribaea*, *Vitis gigas*, *Vitis smalliana* and *Vitis schuttleworthii*. Complex, interspecific hybrids obtained in Europe after phylloxera dissemination (e.g., Seibel and Seyve Villard, among others) and resulting from crosses between *V. vinifera* and several American species, such as *Vitis rupestris*, *Vitis riparia*, *Vitis aestivalis*, *Vitis cinerea*, *Vitis berlandieri*, *V. bourquina* and *V. labrusca*, are also used by the program, mainly as source of resistance genes for the most important diseases and pests (Table 11.1) (Camargo, 1998).

Evaluations are performed at TVES located in Jales, in the Northwest of the state of São Paulo. During initial selection, the features carefully considered include resistance to the main diseases, especially downy (*P. viticola*) and powdery mildew (*U. necator*), flower bud fecundity, yield, sugar content, acidity and flavour. Colour intensity is also taken into consideration in selections of grapes for red winemaking.

About 1000 hybrids, resulting from crosses between the before mentioned species and with the purpose of developing novel wine cultivars, are evaluated each year. Chosen individuals are propagated to selection fields, where they are evaluated for two to three years. Promising selections are then propagated to validation fields, where their performances are evaluated further for 3–4 years. The evaluation step includes sensory analysis of the wine made at a microscale. Advanced selections are subsequently tried on growers' fields for about 2 years. Novel cultivars are released in accordance to the growers' evaluations.

Recently, three novel wine grape cultivars displaying the *V. vinifera* flavour and the hardiness of American grapes and hybrid grapes were developed and released by Embrapa Grape and Wine. Seven new 'labrusca'-flavour, double-purpose cultivars for juice and wine were also released. High yields and tolerance to the main grape diseases, such as downy and powdery mildew, are the main features of those cultivars. Hybrids from crosses between *V. vinifera* accessions are still under evaluation. For the development of white grapes, progenies are resulting from different combinations of the following cultivars: Muscat Frontignan, French Colombard, Moscato di Hamburg, Green Malvasia, Moscato di Canelli, Palomino, Moscato di Alexandria, Petit Manseng and Muscat Frontignan. For the red ones, hybrids were generated using Cabernet Franc, Alicante Bouschet, Tannat and Merlot.

11.3.2.1 Hardy hybrids with V. vinifera *flavour*

Two novel, white-grape producing, interspecific hybrids were released by Embrapa Grape and Wine with the purpose of making aromatic white wines: Moscato Embrapa in 1997 and BRS (which identifies all new materials [including cultivars] released by Embrapa)

Lorena in 2001. The main objective was to develop a hybrid grapevine for standard wines, indistinguishable from those made with *V. vinifera* cultivars, to offer an alternative to vinifera-like products with high quality and competitive prices. Both cultivars present high yields, high sugar levels and good tolerance to the main diseases. Thus, they have quickly spread throughout the state of Rio Grande do Sul. They have been well-accepted by growers, due to their agronomical qualities, and by consumers, due to the balanced flavour and Muscat-like characteristics of their wines (Camargo, 2008). In 2011, the state of Rio Grande do Sul processed approximately 7.700 t of BRS Lorena and 11.200 t of Moscato Embrapa, confirming the significance of those cultivars (Mello and Machado, 2013). With the same purpose, the red grape cultivar BRS Margot was released in 2007. It consists of an interspecific hybrid for red winemaking with sensory properties indistinguishable from those of *V. vinifera* wines along with low production costs. BRS Margot is currently under dissemination at Serra Gaúcha, and it is an interesting alternative to compete with low-price, imported wines in Brazil. Due to its high tolerance to the main diseases, the cultivar has the potential to be employed in organic production systems (Camargo, 2008).

11.3.2.2 Moscato Embrapa

Moscato Embrapa (Camargo and Zanus, 1997) is a Muscat white grape, obtained from the cross between Couderc 13 and July Muscat, made in 1983. The hybrid was selected in 1990. From 1991 on, the selection has been propagated in semicommercial scale and evaluated by growers, winemakers, wineries and growers' cooperatives. It was released in 1997.

Plant vigour and flower bud fecundity are high, with an average of two clusters per cane. It also displays a high level of bud flushing; thus, it requires green pruning practices to allow light penetration in the vegetative canopy. The recommended spacing ranges from 2.5 to 3.0 m between lines and 1.8–2.5 m between plants on the rootstocks 101-14 Millardet et de Grasset or Paulsen 1103. The recommended pruning system is mixed, and the most effective conduction system is the pergola system, where it can reach yields up to 35 t/ha. The reaction to downy mildew is similar to that of the cultivar Isabella, but it is susceptible to anthracnose. It is tolerant to powdery mildew and to grey mould.

The berries are light green with semifleshy pulp and Muscat flavour. Average soluble solids is 19 °Brix and TA varies from 90 to 100 meq/L. The wine has a light yellow colour, intense aroma, with a light Muscat flavour, low acidity and medium or long aftertaste, which is preferred by Brazilian consumers.

Moscato Embrapa is classified as a cultivar of the late group, it is recommended to be grown in the region of Serra Gaúcha region for white table wine that is typically aromatic with low acidity. Although it was originally developed to be grown under temperate conditions, it has also been successfully grown in tropical areas.

11.3.2.3 BRS Lorena

BRS Lorena (Camargo and Guerra, 2001) is a white Muscat grape, resulting from a cross between Malvasia Bianca and Seyval made in 1986. It was grafted in 1990, in Bento Gonçalves, and selected for its performance to be cultivated in the region of

Serra Gaúcha. Among its qualities, the proper growth vigour for the region, the potential for high yields, good tolerance to the main grapevine diseases and also for high soluble solids and balanced acidity can be mentioned. It started to be propagated in Serra Gaúcha in a semicommercial scale in 1994. In the following years, those initial observations were confirmed, and the cultivar was released in 2001.

It presents medium vigour and high fecundity of buds, except for the basal ones, thus, long pruning is recommended. The growth habit is erect, showing proper adaptation to vertical systems and to pergola. The recommended rootstocks are 1103 Paulsen and 101-14 Millardet et de Grasset and spacing ranges from 2.5 to 2.8 between lines and 1.5 between plants. BRS Lorena has high-yield potential, reaching up to 25–30 t/ha. The cultivar also presents a good reaction to the main grapevine diseases, with few occurrences of anthracnose, grey mould and powdery mildew. It displays medium susceptibility to downy mildew. In rainy years, it may exhibit losses caused by the ripe grapes rot (*Glomerella cingulata* (Ston.) Sapuld and Schrenk).

Berries are green-yellowish, with resistant peel, fusing pulp and Muscat flavour. The grapes easily reach 20–21 °Brix and TA is between 100 and 110 meq/L. Two different wines can be made with the grapes of BRS Lorena, a table white wine and a sweet sparkling wine. The white wine made by the classical system exhibits the following chemical characteristics: pH 3.4, TA of ≈80 meq/L and dry extract about 20 mg/L. The wine colour is straw-yellow, with greenish reflections, a light and delicate pronounced aroma, a medium Muscat-like flavour and a complex taste that can be described as balanced and complemented by the delicate and lingering aftertaste. It is suitable for consumption from bottling up to 24–36 months, depending on storage conditions. The differential winemaking of BRS Lorena grapes results in a white wine with greater antioxidant content, in comparison to regular white wines (Camargo, 2008).

The sweet sparkling wine made from BRS Lorena has a sugar content of 60 g/L and carbonic gas pressure of 4 atm, at 20°C. The sweet sparkling wine is straw-yellow in colour, with greenish reflections; it presents good foam and persistent perlage, an excellent aroma that can be described as pleasant and delicate, mixed with the floral varietal trait and the proper level of acidity, along with carbonic gas effects. It has a delicate and pleasant taste with fruit notes and is able to retain its sensory qualities for up to 24 months from bottling.

BRS Lorena is an early Muscat grape cultivar recommended to Serra Gaúcha for white and sparkling winemaking. It has also been successfully evaluated in tropical regions and organic systems.

11.3.2.4 BRS Margot

BRS Margot (Camargo and Guerra, 2007) is a cultivar producing red grapes obtained from the crossing between Merlot and Villard Noir made in 1977 at Embrapa Grape and Wine. Its pedigree consists of 74.22% *V. vinifera* genomic context and 25.78% from other species (14.84% *V. rupestris*, 4.69% *V. aestivalis*, 3.52% *V. labrusca*, 1.95% *V. riparia* and 0.78% *V. cinerea*). The genotype was selected in 1995 for its yield, sugar contents and resistance to the main fungal diseases. From 2003 to 2005, it was evaluated under commercial scale production systems, confirming the initial observations. The cultivar was released in 2007. BRS Margot presents high fecundity of flower buds, including the basal structures. Yields of the cultivar are up to 25–30 t/ha. The berries display soluble solid contents of 20–21 °Brix, TA of ≈90 meq/L and average pH 3.30. It tolerates the main fungal diseases, especially powdery mildew and grey mould.

The wine made from BRS Margot has sensory features of a typical *V. vinifera* wine with no detectable 'foxy' flavour. It can be used in blends in hybrid-type wines, contributing to the alcoholic content, besides representing an alternative to reduce the costs of *V. vinifera*-winemaking (Ritschel and Sebben, 2010). In the vintages 2004, 2005 and 2006, BRS Margot was used to make a red wine in semi-commercial scale at Embrapa Grape and Wine (Camargo and Guerra, 2007). The main features of the average chemical composition of the wines are shown in Table 11.2. The key sensory characteristics of these wines are the visual aspects (ruby-red colour with violet reflections). In the end of 2006, it was observed that the violet hue turned to brownish-orange in the wine made in 2004, which indicates a good durability potential. It has an average intensity of aroma and it is delicate, resembling wild berries (cherry, blackberry and currant). A 'foxy' or bitter taste is absent; the aftertaste is balanced and pleasant. It is suitable for young wines, with the potential to be consumed up to three years after elaboration. BRS Margot is recommended to be cultivated in the South of Brazil, under temperate conditions, to be used in red vinifera-like winemaking.

11.3.2.5 Forthcoming selections

Currently, approximately 20 selections for winemaking are under evaluation, and two advanced selections are under validation in growers' areas in the south of Brazil and in tropical regions, supporting the perspective of the release of novel grapevine cultivars for wine making in the forthcoming years. The advanced selections produce white Muscat berries with fusing pulp. The selection under testing in the south of Brazil is tolerant to bunch rots (acid rot and grey mould). The cluster is cylindrical–conical in shape with shoulder, medium in size and has loose berries. The must composition is 23.6 °Brix with TA of 115 meq/L and pH 3.3. The wine, resulting from winemaking at microscale, presents alcohol contents of 14.2%, reducing sugar of 2.3 g/L and TA of 106.1 meq/L with a pH of 3.2. It has a straw colour and gives rise to a clear wine with intense Muscat aroma, reminiscent of papaya and cloves, with lower acidity and a sweet attack. The flavour exhibits high persistence and no defects of bitterness or astringency. The other grapevine selection is tolerant to grey mould but susceptible to acid rot. The cluster is more compact than that of the first selection. Must exhibits 20.1 °Brix, TA of 103 meq/L and pH 3.3. The chemical composition of the wine consists of 12.9% alcohol, reducing sugar contents of 4.5 g/L, TA of 83.8 meq/L and pH 3.4. The wine is clear, light straw-green in colour, with a fine aroma of vinifera wine, medium intensity, delicate and slightly fruity. It tastes fresh and balanced, displays correct acidity and is considered harmonious, with no defects of bitterness or astringency. It is described as having medium persistence.

Table 11.2 **Physicochemical parameters of 'BRS Margot' wine (Camargo and Guerra, 2007)**

Must yield (%)	Alcohol (°GL)	Total acidity (meq/L)	pH	Reduced dry extract (g/L)	Anthocyanins (g/L)	Colour (intensity)	Total polyphenols	Total tannins (g/L)
70.00	12.04	70.00	3.52	21.35	465.20	0.50	37.30	1.64

11.3.2.6 Dual purpose 'labrusca' or strawberry flavoured hybrids (wine and juice)

Grapes with 'labrusca' (typical strawberry) flavour are the greatest group of novel cultivars released by Embrapa Grape and Wine. They can be used for juice and wine production, thus being considered double purpose. Five of those cultivars were obtained from crosses, and all of them gave rise to wines and juices with intense purple colour, appreciated by Brazilian consumers. Moreover, they present distinct productive cycles and, with the exception of BRS Rúbea, have high sugar contents. In contrast, Concord Clone 30 (Early Concord) and Early Isabella were obtained from clonal selections. They were introduced and evaluated by the GGB in order to confirm the distinct phenological behaviour in comparison to that of the original cultivars, Concord and Isabella. The cultivars are spreading throughout Serra Gaúcha because their features meet the demands of several wineries, which recommend them to the growers to expand the harvesting and processing periods by the combined use of early and late cultivars (Figure 11.4) and also to improve the quality (colour, sugar/alcohol) of the wines and juices made from traditional cultivars (Camargo, 2008).

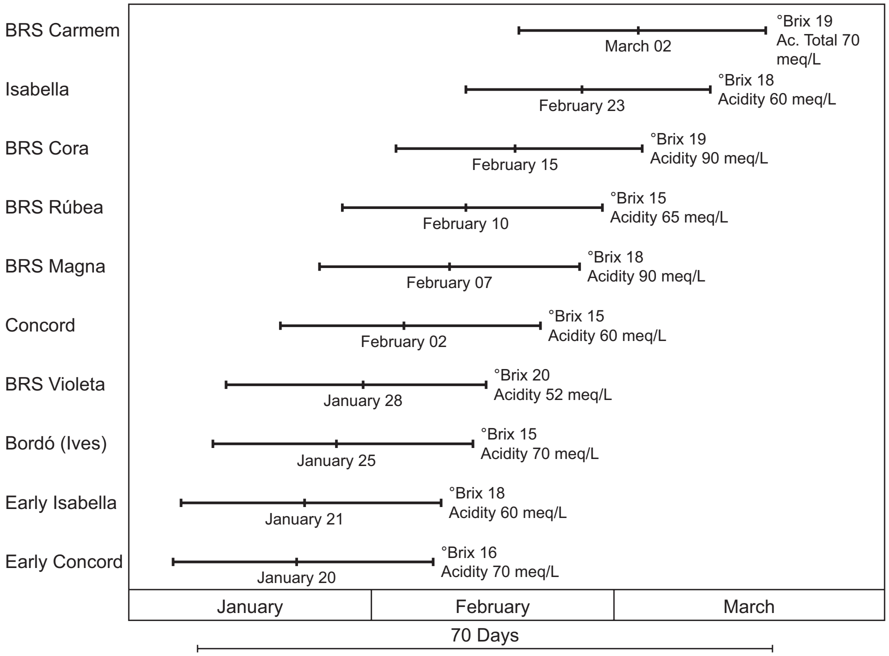


Figure 11.4 Must composition and harvesting period under temperate climate conditions of Brazilian hybrid grapevine cultivars exhibiting 'labrusca' or 'strawberry' flavour. The berries from the cultivars are considered dual purpose, i.e. wine- and juice-making. It is noteworthy that novel cultivars exhibit an extension of approximately 40 days in the harvesting period under temperate conditions, in comparison to the harvesting period of traditional cultivars (Isabella, Concord and Bordô/Ives). The extended harvesting allows better distribution of the labour force and facility resources in the vineyard and winery (Ritschel et al., 2012).

11.3.2.7 BRS Rúbea

BRS Rúbea (Camargo and Dias, 1999), obtained from a cross between Rose Niagara and a plant from a seed of Ives, is a typical teinturier red grape, for primary use in juice blends with Isabella and Concord. It can also be used to make 'labrusca'-type wines. The cluster is small, 100 g on average, the berries length is 19 mm in average and 15 °Brix. The plants are vigorous, disease resistant and well-adapted to Southern Brazilian conditions. It reaches yields of approximately 20 t/ha. Although the cultivation under warm/hot climates may present problems, the cultivar is currently grown in the state of Goiás as an alternative to teinturier grapes.

11.3.2.8 BRS Cora

BRS Cora (Camargo and Maia, 2004) is a high-yield cultivar producing red grapes for juice with excellent colour and high levels of sugar (18–20 °Brix). It is a result of a cross between 'Muscat Bailey A' and BRS Rúbea. It is moderately vigorous, with determinate growth habit. It was released as an alternative to juice and table winemaking in tropical regions to improve the colour of Isabella and Early Isabella products. It can also be grown under temperate climate in South Brazil.

11.3.2.9 BRS Violeta

BRS Violeta (Camargo et al., 2005) is a hybrid grape cultivar, resulting from a cross between BRS Rúbea and IAC 1398-21, that includes *V. vinifera* and *V. labrusca* germplasm. It is very fecund (25–30 t/ha) and suitable to elaborate juice and table wine. It is adapted to a wide range of climates and can be grown in South Brazil and also in tropical regions, such as the Northwest of the state of São Paulo and Mato Grosso. Its main advantage is the excellent quality of the berries, resulting from the combination of high sugar levels (19 °Brix) and intense violet colour.

11.3.2.10 BRS Carmem

BRS Carmem (Camargo et al., 2008) originated from a cross between Muscat Bailey A and BRS Rúbea. It displays high fecundity, good berry flavour and the must from its grapes is purple in colour. It also shows a good tolerance to the main fungal diseases. Based on evaluation data, the novel cultivar can be recommended for cultivation in Serra Gaúcha and the Northern region of the state of Paraná.

11.3.2.11 BRS Magna

BRS Magna (Ritschel et al., 2012) is also a result from the cross between BRS Rúbea and IAC 1398-21. It is a teinturier grape with labrusca flavour. BRS Magna is a novel cultivar for juice and winemaking with an intermediate productive cycle and wide climatic adaptation. It is recommended to be grown in tropical and temperate climates. It exhibits the typical labrusca or strawberry flavour, resulting in a wine with intense red colour, proper alcoholic grade, and low level of acidity.

11.3.2.12 Concord Clone 30

Concord Clone 30's (Early Concord) (Camargo et al., 2000) main characteristic is the earliness, since the harvest can be carried out with approximately 15 days of anticipation, in comparison to the harvest dates of traditional Concord. Moreover, Early Concord maintains the features of traditional Concord, mainly its strawberry flavour. Early Concord is recommended to be grown in the south of Brazil, where it can reach yields of 30 t/ha. Currently, its cultivation area is increasing in the region of Bento Gonçalves and in the Western region of Santa Catarina (Camargo, 2008). Based on the performance of the original Concord in tropical regions, the precocious cultivar displays less vigorous growth and poor bud flushing; however, it has the potential to be cultivated in subtropical climates with a single harvest per year (Camargo and Maia, 2008).

11.3.2.13 Isabel Precoce (Early Isabella)

Early Isabella (Camargo, 2004) has the agronomic features of regular Isabella, but presents an early maturation and harvest period of approximately 1 month earlier (Camargo, 2004). As Isabella, it exhibits a typical labrusca or strawberry flavour and can be used to several purposes. Early Isabella is recommended to the south of Brazil. Under warmer climates, such as in the Northwestern of São Paulo, Mato Grosso and Goiás states, Early Isabella is recommended for juice and winemaking, allowing two harvests during the dry season.

11.4 Future trends

The continuous enrichment of the grapevine germplasm collection, followed by evaluation and use of the accessions by the Breeding Program, is an important perspective for Brazilian breeding programs. Moreover, these resources are also likely to contribute to the establishment of further Brazilian GIs, such as those of Farroupilha. The sequencing of the Moscato Branco genome will contribute to the development of molecular tools to support further research on grape breeding and genetics in Brazil.

Phenotyping activities are likely to provide tools to meet the future demands of growers and consumers, and new traits will be considered in the forthcoming years, as genotype profiling and evaluation of health-related compounds. Based on SSR molecular marker analysis, coupled with morphological characterization, the classification and identification of accessions will become more precise, and it will result in a better organization and use of the collection. It will also contribute to confirm the nature of Isabella and Concord to their respective sports. Moreover, the evaluation of health-related compounds will allow the development of novel selections appealing to health-oriented consumer markets.

The scenery for the release of novel Brazilian wine grape cultivars in future years is promising, considering the number of hybrids and selections currently under evaluation. Based on the available data, at least one hardy hybrid with Muscat flavour for winemaking will be released in the near future.

11.5 Sources of further information and advice

The vast majority of literature and websites mentioned and commented here are in Portuguese. They are listed in the end of this section.

11.5.1 The Embrapa grape and wine public page

This page is in Portuguese, as is the vast majority of the literature and databases and general information; however, a translator may allow recovering the information.

One exception in English is the book 'Embrapa Grape & Wine – International relations', by Jorge Tonietto and coauthors, which can be downloaded for free and is recommended to those interested in learning more about the research at Embrapa Grape and Wine. It describes the institution history and the facilities (including the laboratory and field researches) and stresses the main technologies, such as a brief description of novel grape cultivars.

Data from Brazilian viticulture can be easily accessed at the Embrapa Grape and Wine page that also hosts the VitisBrasil page. Also on the web, information on the Brazilian GGB and the novel Brazilian grape cultivars are available. Books and papers about current Brazilian viticulture are also present, and the majority can be downloaded for free. 'Vitivinicultura Brasileira - Panorama Setorial em 2010' by José Fernando Protas and Umberto A. Camargo presents a detailed snapshot of the Brazilian grape production and winemaking with data from the main productive regions in the country. In regard to the breeding program at Embrapa Grape and Wine, 'Novas cultivares brasileiras de uvas' by Patricia Ritschel and Sandra Sebben (editors) is available and presents a quick description of the breeding program and a detailed description of novel grape cultivars.

11.5.2 Books, book chapter and articles

A very complete panorama of the historical aspects of Brazilian viticulture, remounting the introduction of the grapevine in Brazil, can be found in the books by Julio S. Inglês de Souza, especially 'Uvas para o Brasil', from 1969.

On the topic of tropical viticulture, 'A viticultura no semiarido brasileiro', by José Monteiro Soares and Patricia C. de S. Leão is recommended. It compiles the research efforts of Embrapa Semiarid and partners over the past 30 years and their contribution to the consolidation of viticulture and the wine industry in the semiarid region of Brazil. Specifically on the development and evolution of tropical viticulture, there is also a chapter about grapes by Patricia Ritschel and coauthors in the first volume of the book 'Agricultura Tropical: quatro décadas de inovações tecnológicas, institucionais e políticas'.

To learn more about the grape breeding program at IAC, one can refer to 'O melhoramento de plantas no Instituto Agronômico' and also to 'Uva: tecnologia de produção, pós-colheita, mercado', by Celso Pommer and coauthors.

A series of papers by Umberto Camargo and coauthors were presented in 'International Society for Horticultural Science' and in 'Office International de la Vigna et du Vin' meetings and are available, in English, in the Annals of the Events. The evolution of the Brazilian Grape Breeding Programs can be recovered by consulting the documents.

References

Alleweldt, G., Spiegel-Roy, P., Reisch, B., 1990. Grapes (*Vitis*). In: Moore, J.N., Ballington Junior, J.R. (Eds.), Genetic Resources of Temperate Fruit and Nut Crops. The International Society for Horticultural Science, Wageningen, pp. 289–327.

Bennelli, C., de Carlo, A., Engelmann, F., 2013. Recent advances in the cryopreservation of shoot-derived germplasm of economically important fruit trees of *Actinidia*, *Diospyros*, *Malus*, *Olea*, *Prunus*, *Pyrus* and *Vitis*. Biotechnol. Adv. 31, 175–185.

Bennelli, C., Lambardi, M., Fabbri, A., 2003. Low temperature storage and cryopreservation of the grape rootstock ‘Kober 5BB’. Acta Hortic. 623, 249–253.

Börner, A., 2006. Preservation of plant genetic resources in the biotechnology era. Biotechnol. J. 1, 1393–1404.

Camargo, U.A., 1980. Banco ativo de germoplasma de uva. In: Simpósio de Recursos Genéticos Vegetais, Brasília, DF, 1979. EMBRAPA-CENARGEN, Brasília, DF.

Camargo, U.A., 2004. ‘Isabel Precoce’: alternativa para a vitivinicultura brasileira, vol. 54. Comunicado Técnico (online). Available from: http://www.cnpuv.embrapa.br/pesquisa/pmu/cultivares.html#precoce (accessed 03.07.13.).

Camargo, U.A., 1998. Grape breeding for the subtropical and tropical regions of Brazil. In: Symposium International sur la Genetique et L’amelioration de la Vigne, 7, Montpellier, 1998. INRA: Agro-Montpellier, Montpellier.

Camargo, U.A., 2008. Impacto das cultivares brasileiras de uva no mercado interno e potencial no mercado internacional. In: Congresso Brasileiro de Viticultura e Enologia 12, Bento Gonçalves, 2008. Embrapa-CNPUV, Bento Gonçalves.

Camargo, U.A., Bernd, R.B., Revers, L.F., 2009. Melhoramento genético da videira. In: Soares, J.M., Leão, Souza (Eds.), A Vitivinicultura No Semi-árido Brasileiro. Embrapa Semiárido, Petrolina, pp. 109–147.

Camargo, U.A., Maia, J.D.G., Machado, C.A.E., Ritschel, P., 2012a. Evaluation of grapevine germplasm under tropical conditions in Brazil. In: International Crop Science Congress 6, Bento Gonçalves, 2012. International Crop Science Society, Bento Gonçalves.

Camargo, U.A., 2005. Suco de uva: matéria-prima para produtos de qualidade e competitividade. In: Congresso Latino-Americano de Viticultura e Enologia 10, Bento Gonçalves, 2005. Embrapa Uva e Vinho, Bento Gonçalves.

Camargo, U.A., Dias, M.F., 1999. BRS Rúbea, vol. 33. Comunicado Técnico (online). Available from: http://www.cnpuv.embrapa.br/pesquisa/pmu/cultivares.html#rubea (accessed 03.07.13.).

Camargo, U.A., Guerra, C.C., 2001. ‘BRS Lorena’: cultivar para elaboração de vinhos aromáticos, vol. 39. Comunicado Técnico (online). Available from: http://www.cnpuv.embrapa.br/pesquisa/pmu/cultivares.html#lorena (accessed 03.07.13.).

Camargo, U.A., 2002. Novas cultivares de videira para vinho, suco e mesa. In: Simpósio Mineiro de Viticultura e Enologia 1, Andradas, MG, 2002. EPAMIG, Caldas.

Camargo, U.A., Guerra, C.C., 2007. ‘BRS Margot’: nova cultivar de uva para vinho tinto, vol. 73. Comunicado Técnico (online). Available from: http://www.cnpuv.embrapa.br/pesquisa/pmu/cultivares.html#margot (accessed 03.07.13.).

Camargo, U.A., Kunh, G.B., Czermainski, A.B.C., 2000. ‘Concord Clone 30’ – uva precoce para suco. In: Congresso Brasileiro De Fruticultura 16, Fortaleza. Embrapa Agroindústria Tropical, Fortaleza.

Camargo, U.A., Maia, J.D.G., 2008. Cultivares de uvas rústicas para regiões tropicais e subtropicais. In: Uvas Rústicas de Mesa, Cultivo e Processamento em Regiões Tropicais. Jales, pp. 63–90.

Camargo, U.A., Maia, J.D.G., 2004. 'BRS Cora': nova cultivar de uva para suco, adaptada a climas tropicais, vol. 53. Comunicado Técnico (online). Available from: http://www.cnpuv.embrapa.br/pesquisa/pmu/cultivares.html#cora (accessed 03.07.13.).

Camargo, U.A., Maia, J.D.G., Nachtigal, J.C., 2005. 'BRS Violeta': nova cultivar de uva para suco e vinho de mesa, vol. 63. Comunicado Técnico (online). Available from: http://www.cnpuv.embrapa.br/pesquisa/pmu/cultivares.html#violeta (accessed 03.07.13.).

Camargo, U.A., Maia, J.D.G., Revers, L.F., Leão, P.C. De S., Quecini, V., Ferreira, M.E., Ritschel, P.S., 2012b. Grape genetics and breeding in Brazil. In: XV Congreso Latinoamericano de Genética, Rosário, 2012. Buenos Aires: Journal of Basic and Applied Genetics.

Camargo, U.A., Maia, J.D.G., Ritschel, P.S., 2008. 'BRS Carmem': nova cultivar de uva tardia para suco, vol. 84. Comunicado Técnico (online). Available from: http://www.cnpuv.embrapa.br/pesquisa/pmu/cultivares.html#carmem (accessed 03.07.13.).

Camargo, U.A., Tonietto, J., Hoffmann, A., 2012c. Progressos na viticultura brasileira. Revista Brasileira de Fruticultura 144–149 Volume Especial.

Camargo, U.A., Zanus, M.C., 1997. EMBRAPA 131-'Moscato Embrapa': nova cultivar para a elaboração de vinho branco, vol. 24. Comunicado Técnico (online). Available from: http://www.cnpuv.embrapa.br/pesquisa/pmu/cultivares.html#moscatoembrapa (accessed 03.07.13.).

Caumo, M., Galzer, C., Dalagnol, L., Poloni, T., Perissutti, G., Maia, J.D.G., Ritschel, P., 2012. Avaliação do potencial funcional em uvas tintas e rosadas mantidas no Banco Ativo de Germoplasma de Uva. In: Encontro de Iniciação Científica 10; Encontro de Pós-Graduandos da Embrapa Uva e Vinho 6, Bento Gonçalves, 2012. Embrapa Uva e Vinho, Bento Gonçalves.

Dall'agnol, L., Caumo, M., Poloni, T., Comachio, V., Camargo, U., Maia, J.D.G., Ritschel, P., 2013. Características do mosto e de compostos relacionados à saúde de acessos mantidos pelo Banco de Germoplasma de Uva (BAG-Uva). In: Encontro de Iniciação Científica, 11; Encontro de Pós-Graduandos da Embrapa Uva e Vinho 7, Bento Gonçalves, 2013. Embrapa Uva e Vinho, Bento Gonçalves.

Dickenson, J., 1995. Viticulture in pre-independence Brazil. J. Wine Res. 6, 195–200.

Embrapa Uva e Vinho, 2009. Banco Ativo de Germoplasma de Uva (online) Embrapa Uva e Vinho, Bento Gonçalves. Available from: http://www.cnpuv.embrapa.br/prodserv/germoplasma (accessed 23.02.13.).

Engelmann, F., 1991. In vitro conservation of tropical plant germplasm: a review. Euphytica 57, 227–243.

FAO, 2013. Statistical Databases - FAOSTAT. FAO, Rome. Available from: http//apps.fao.org/page/collections?subset=agriculture (accessed 19.02.13.).

Ferreira, F.R., Pádua, J.G., 2009. Fruteiras e ornamentais. Embrapa Recursos Genéticos e Biotecnologia, Brasília, DF.

Gallo Neto, C., 2008. Um brinde ao vinho paulista. J. da Unicamp 416, 6. (online). Available from: http://www.unicamp.br/unicamp/unicamp hoje/ju/novembro2008/ju416 pag06.php (accessed 24.06.13.).

Guerra, C.C., Hickel, E.R., Kuhn, G.B., Nachtigal, J.C., Maia, J.D.G., Fráguas, J.C., Vargas, L., Mello, L.M.R. de, Garrido, L. da R., Conceição, M.A.F., Botton, M., Oliveira, O.L.P. de, Sônego, O.R., Naves, R. de L., Soria, S. de J., Camargo, U.A., 2005. Sistema de produção de uvas rústicas para processamento em regiões tropicais do Brasil. Sistemas de Produção, vol. 9, (online). Available from: http://sistemasdeproducao.cnptia.embrapa.br/FontesHTML/Uva/UvasRusticasParaProcessamento/index.htm (accessed 25.02.13.).

Hedrick, U.P., 1919. Manual of American Grape-Growing. The Macmillan, New York, (online). Available from: http://archive.org/stream/manualofamerican29659gut/29659.txt (accessed 05.02.13.).

Hedrick, U.P., 1908. The Grapes of New York. J. B. Lyon, Albany, (online). Available from: http://archive.org/details/cu31924080184165 (accessed 05.02.13.).

IPGRI, 1997. Descriptors for Grapevine: *Vitis* spp. IPGRI, UPOV, OIV, Paris.

Johnson, H., 1989. The Story of Wine. Mitchell-Beazley, London.

Li, D.-Z., Pritchard, W., 2009. The science and economics of ex situ plant conservation. Trends Plant Sci. 14, 614–621.

Kuhn, G.B., Melo, G.W., Nachtigal, J.C., Maia, J.D.G., Protas, J.F. Da S., Mello, L.M.R. de, Garrido, L. da R., Conceição, M.A.F., Botton, M., Sônego, O.R., Naves, R. De L., Soria, S. de J., Camargo, U.A., 2003. Cultivo da videira Niágara rosada em regiões tropicais do Brasil. Sistemas de Produção, vol. 5, (online). Available from: http://www.cnpuv.embrapa.br/publica/sprod/UvaNiagaraRosadaRegioesTropicais (acessed 01.03.13.).

Maia, J.D.G., Kuhn, G.B., 2001. Cultivo da Niágara Rosada em áreas tropicais do Brasil. Embrapa Uva e Vinho, Bento Gonçalves.

Martins, A.M., Anjos, L.M. dos, Longhi, P., Maia, J.D.G., Boursiquot, J.-M., Legrand, D., Zanus, M.C., Tonietto, J., Ferreira, M.E., Ritschel, P., 2013. Comparative agronomical, phenological and molecular analyses between the grape variety 'Moscato Branco' and accessions of Brazilian and French Grape Germplasm Banks. In: Simpósio de Genética Molecular de Plantas 4, Bento Gonçalves, 2013. Sociedade Brasileira de Genética, Riberão Preto.

Matsumoto, T., Sakai, A., 2003. Cryopreservation of axillary shoot tips of in vitro-grown grape (*Vitis*) by a two-step vitrification protocol. Euphytica 131, 299–304.

McGovern, P.E., Mirzoianb, A., Halla, G.R., 2009. Ancient Egyptian herbal wines. Proc. Natl. Acad. Sci. USA 106, 7361–7366.

Mello, L.M.R., Machado, C.A., E. VitiBrasil: dados da vitivinicultura. (online). Available from: http://vitibrasil.cnpuv.embrapa.br (acessed 14.02.13.).

Miranda, F., 2001. Arte & Vinho. Axcel Books do Brasil, Rio de Janeiro.

Mullins, M.G., Bouquet, A., Williams, L.E., 1992. The grape vine and its relatives. In: Mullins, M.G., Bouquet, A., Williams, L.E. (Eds.), Biology of the Grapevine. Cambridge University, Nova York, pp. 17–36.

Paz, C. da, 1898. Manual Prático Do Viticultor Brasileiro. Imprensa Nacional, Rio de Janeiro.

Pinney, T.A., 1989. History of Wine in America: from the Beginnings to Prohibition. University of California, Los Angeles, (online). Available from: http://ark.cdlib.org/ark:/13030/ft967nb63q (accessed 14.02.13.).

Pommer, C.V., 2009. Melhoramento da Videira. (online). Available from: http://www.iac.sp.gov.br/UniPesquisa/Fruta/Melhoramento/Videira.asp (accessed 25.11.09.).

Pommer, C.V., 1993. Uva. In: Furlani, A.M.C., Viegas, G.P. (Eds.), O melhoramento de plantas no Instituto Agronômico. Instituto Agronômico, Campinas, pp. 489–524.

Protas, J.F. da S., Camargo, U.A., Mello, L.M.R. de, 2002. A viticultura brasileira: realidade e perspectivas. In: Simpósio Mineiro de Viticultura e Enologia 1, Andradas, 2002. EPAMIG, Andradas.

Protas, J.F.S., Camargo, U.A., 2011. Vitivinicultura brasileira: panorama setorial de 2010 (online) SEBRAE, Brasília, DF. Bento Gonçalves: IBRAVIN: Embrapa Uva e Vinho. Available from: http://www.cnpuv.embrapa.br/publica/livro (accessed 14.07.13.).

Regina, M. de A., Fráguas, J.C., Alvarenga, A.A., Souza, C.R. de, Amorim, D.A. de, Mota, R.V. da, Fávero, A.C., 2006. Implantação e manejo do vinhedo para produção de vinhos de qualidade. Informe Agropecuário 27, 16–31.

Ritschel, P., Camargo, U.A., Mello, L.M.R., Leão, P.C. de S., Soares, J.M., 2008. Uva. In: Albuquerque, A.C.,S., Silva, A.G. da (Eds.), Agricultura Tropical: quatro décadas de inovações tecnológicas, institucionais e políticas, 1, Produção e produtividade agrícola, pp. 537–543.

Ritschel, P.S., Gomes, F.G.G., Ceriotti, I., Longhi, P., Maia, J.D.G., Zanus, M.C., Tonietto, J., Ferreira, M.E., 2012. Genetic analysis of Moscato Branco and other Muscat grapes held by the grape germplasm bank in Brazil. In: International Crop Science Congress 6, Bento Gonçalves, 2012. International Crop Science Society, Bento Gonçalves.

Ritschel, P.S., Maia, J.D.G., (coord.), 2009. Uvas do Brasil: Programa de Melhoramento Genético. (online). Available from: http://www.cnpuv.embrapa.br/pesquisa/pmu (accessed 24.02.13.).

Ritschel, P.S., Maia, J.D.G., Camargo, U.A., Zanus, M.C., Souza, R.T., Fajardo, T.V.M., 2012. 'BRS Magna': nova cultivar de uva para suco com ampla adaptação climática, vol. 125. Comunicado Técnico (online). Available from: http://www.cnpuv.embrapa.br/pesquisa/pmu/cultivares.html#magna (accessed 04.07.13.).

Ritschel, P.S., Sebben, S. de S. (Eds.), 2010. Embrapa Uva e Vinho: novas cultivares brasileiras de uva. Embrapa Uva e Vinho, Bento Gonçalves.

Salvador, V. do, 1627. História do Brazil. Biblioteca Nacional, Rio de Janeiro, (online). Available from: http://purl.pt/154 (accessed 14.02.13.).

Santos Neto, J.R.A. (s.d.). Cartilha Do Viticultor. Belo Horizonte: Uvale.

Santos Neto, J.R.A., 1971. O melhoramento da videira no Instituto Agronômico. Ciência e Cultura 23, 700–710.

Soares, J.M., Leão, P. C. de S. (Eds.), 2009. A Viticultura No Semi-árido Brasileiro. Embrapa Semi-árido, Petrolina, PE.

Sousa, J.S.I. de, 1969. Uvas para o Brasil. Melhoramentos, São Paulo.

Sousa, J.S.I. de, Martins, F.P., 2002. Viticultura Brasileira: principais variedades e suas características. FEALQ, Piracicaba.

Terra, M.M., Pires, E.J.P., Coelho, S.M.B.M., Passos, I.R. da S., Santos, R.R. dos, Pommer, C.V., Silva, A.C.P. da, Ribeiro, I.J.A., 1990. Porta-enxertos para o cultivar máximo iac 138-22 de uvas de vinho em Monte Alegre do Sul, SP. Bragantia 49, 363–369.

This, P., Lacombe, T., Thomas, M.R., 2006. Historical origins and genetic diversity of wine grapes. Trends Genet. 22, 511–519.

This, P., Jung, E.A., Boccacci, E., Borrego, E.J., Botta, E.R., Costantini, L., Crespan, E.M., Dangl, E.G.S., Eisenheld, E.C., Ferreira-Monteiro, F., Grando, E.S., Ibañez, E.S., Lacombe, T., Laucou, E.V., Magalhães, E.R., Meredith, C.P., Milani, E.N., Peterlunger, E.E., Regner, E.F., Zulini, L., Maul, E.E., 2004. Development of a standard set of microsatellite reference alleles for identification of grape cultivars. Theor. Appl. Genet. 109, 1448–1458.

Tonietto, J., Hoffmann, A., Zanus, M.C. Embrapa Grape & Wine – International Relations. Available from: http://www.cnpuv.embrapa.be/publica/livro.

Tonietto, J., 2012. Vale dos Vinhedos and the development of geographical indications in Brazil. In: Worldwide Symposium on Geographical Indications, Lima, 2011. WIPO, Geneva.

Tonietto, J., Mello, L.M.R., 2001. La Quatrième Période Évolutive de la vitiviniculture brésilienne: changements dans le marché consommateur du pays. In: 26 Congreso Mundial & 81 Asamblea General de la Organización Internacional de la Viña y el Vino, Adelaida 2001. Organización Internacional de la Viña y el Vino – OIV, Adelaida.

Volk, G.M., 2010. Applications of functional genomics and proteomics to plant cryopreservation. Curr. Genomics 11, 24–29.
Walters, C., Volk, G.M., Richards, C.M., 2008. Genebanks in the post-genomic age: emerging roles and anticipated uses. Biodiversity 9, 68–71.
Wang, Q., Mawassi, M., Li, P., Gafny, R., Sela, I., Tanne, E., 2003. Elimination of grapevine virus A (GVA) by cryopreservation of in vitro-grown shoot tips of *Vitis vinifera* L. Plant Sci. 165, 321–327.
Wang, Q., Tanne, E., Arav, A., Gafny, R., 2000. Cryopreservation of in vitro-grown shoot tips of grapevine by encapsulation-dehydration. Plant Cell, Tissue Organ Cult. 63, 41–46.

Grapevine breeding in China

12

J. Lu[1], *C. Liu*[2]
[1]China Agricultural University, Beijing, China; [2]Zhengzhou Pomology Research Institute, Zhengzhou, China

12.1 General introduction to the grape and wine industry in China

China is one of the original centres of *Vitis* species. It has been reported that the Chinese used grapes as food from earliest times (Sun, 1979). The domestic grapevine, *Vitis vinifera* L., has been grown in China for more than 2000 years. The acreage of grapevine, following apple, citrus, banana, pear, jujube and peach, ranks sixth among fruit cultivation in China, Moreover, grape production comprises 5% of the total fruits in China. In recent years, China has achieved great success in the establishment of many large production zones (Figure 12.1), and new grape planting technology has been developed, especially since the 1980s. There are at least 13 national and local grape research institutes involved in programmes of breeding and genetic improvement of grapevines as well as National Grapevine Repositories (Figure 12.2). More than 20 universities and colleges are engaging in education and research concerning grape breeding. Although most grape-breeding programmes are performed by public institutions sponsored by the government, more and more private ones have been established in recent years. More than 50 table grape cultivars were released from 1960 to 1999, in the approximately 40 years of breeding effort before the new century, and releases of new grape cultivars have accelerated since 2000 because a total of 38 table grape cultivars, including 12 seedless ones, have been released in the twenty-first century (Figure 12.3).

12.2 History and major viticultural areas in China

Grape growing in China dates back to 2300–2500 years ago. However, the beginning of modern grape production can be linked to the establishment of the Zhangyu Winemaking Company in 1892. The Chinese government paid great attention to the development of viticulture and grape breeding after 1949 when the People's Republic of China was established. The acreage and production of grape increased steadily since then. The major viticulture areas are located in Northern China. For quite a long time, the five leading provinces and autonomous regions are Xingjiang, Hebei, Shandong, Liaoning and Henan, which accounted for more than two-thirds of total grape production in China. The absolute minimal temperature of −17 °C is generally considered the limit for vineyards without winter protection. Unfortunately, the main viticulture areas

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00012-0

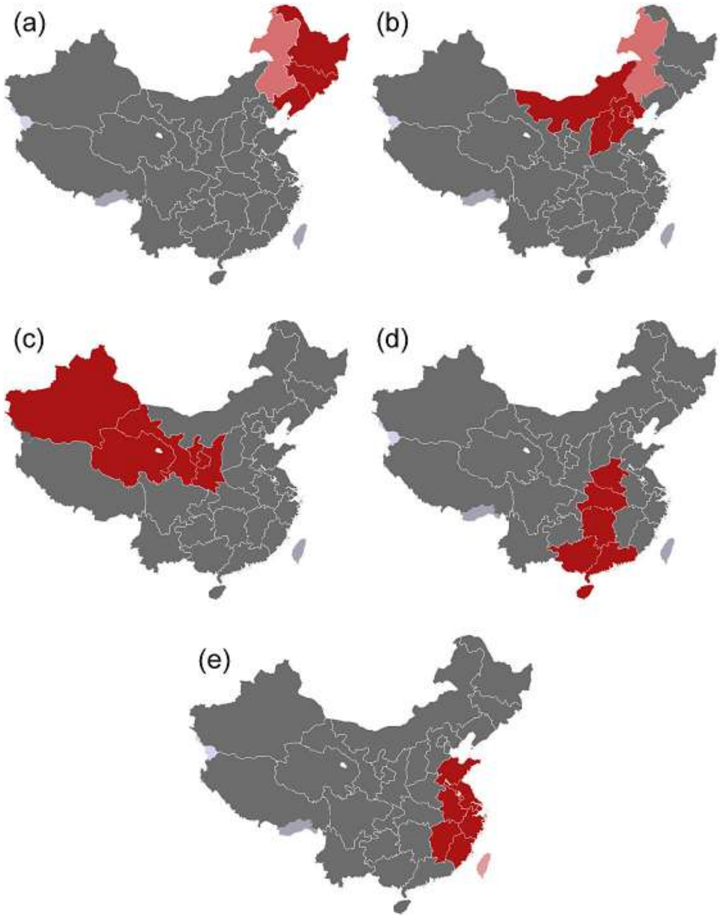


Figure 12.1 Chinese grape-growing regions (specified zones in red): (a) Northeast China, (b) northern China, (c) northwestern China, (d) South Central China and (e) East China. The map was adopted from http://en.wikipedia.org/wiki/.

in China are distributed in winter temperatures often lower than −17 °C, which means winter protection is necessary for the grapevine to survive.

12.2.1 Main grape production areas with protection in winter

Northeast: The wine grapes growing successfully in the Northeast are cultivars selected from *Vitis amurensis*, a wild species native to China, and the hybrids derived from crosses between *V. amurensis* and *V. vinifera*.

North China and Bohai Ocean Bay: This region is the oldest and the most important grape-producing zone in China, including production areas in Tianjin, Beijing, Hebei Province (Langfang, Zhangjiakou, Qinhuangdao) and Shanxi Province (Qingxu).

Figure 12.2 (a) National grapevine repository in Zhengzhou, Henan Province. (b) National repository for *Vitis amurensis* in Zuojia, Jilin Province.

Ningxia: Grape production in this region started in the 1980s. The wine industry has been expanding rapidly since the 1990s of the last century. Many vineyards have been established east of Helan Mountain, a semiarid to arid area where there is usually ample water for irrigation.

The Hexi Corridor: The Hexi Corridor is along the ancient silk route in Gensu Province. Grape production in this region is largely concentrated in Wuwei, Jiuquan and Zhangye. This is one of the premier wine grape production areas in China.

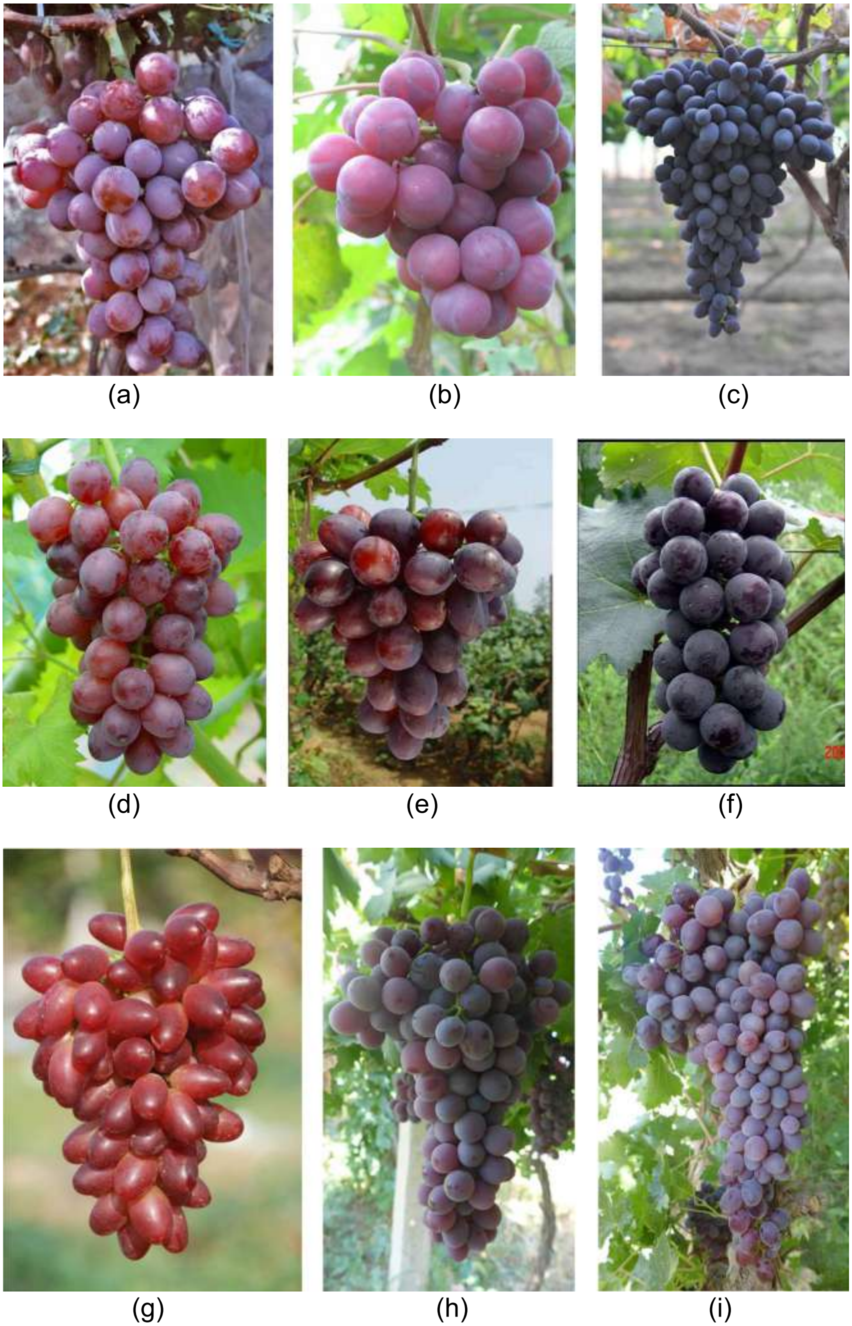


Figure 12.3 Selected table grape cultivars released by breeding programmes in China: (a) Fenghong, (b) Fenghuang No. 51, (c) Heimeiren, (d) Hongshuangwei, (e) Hongbiaowuhe, (f) Hutai No. 8, (g) Jintianmeizhi, (h) Jingfeng, (i) Jingkejing. (j) Shennongjinhunaghou, (k) Shennongxiangfeng, (l) Wuhecuibao, (m) Wuizaohong, (n) Xiazhihong, (o) Xinyu, (p) Yanhong, (q) Zaoheibao and (r) Zaomanao.

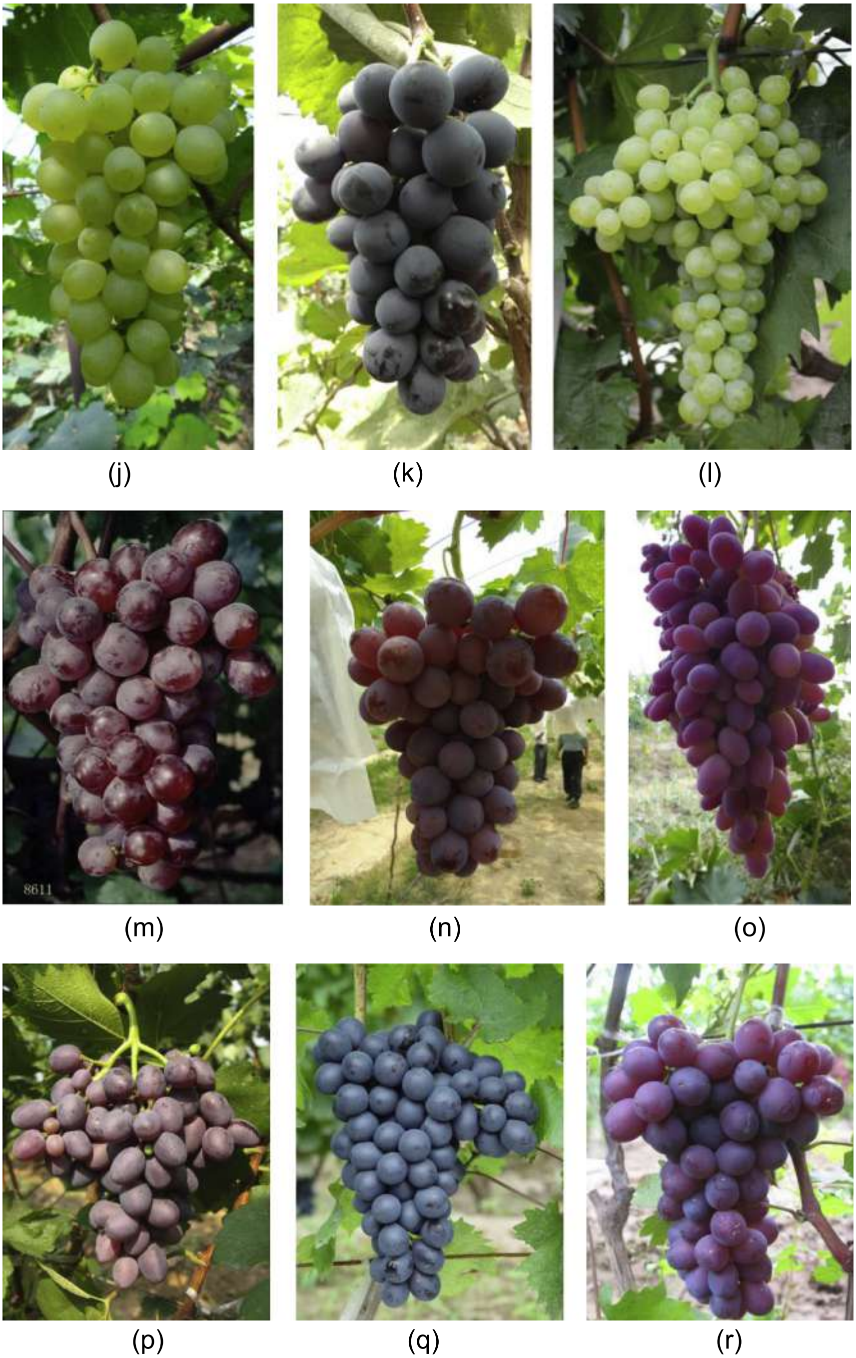


Figure 12.3 Continued.

Xinjiang: Chinese grape culture began in the Xinjiang Uygur Autonomous Region. Its acreage and annual production of grape rank first in China. With annual precipitation ranging from 16 to 200 mm, Xinjiang has fewer disease issues than other viticulture regions in China.

12.2.2 Main viticulture areas without winter protection

Shandong Peninsula: This region is located south of Bohai Ocean Bay. It is the most important wine grape-producing region in China. The Changyu Winemaking Company, the first and the largest (thus far) Chinese winery, was established in 1892 in this region.

The Loess Plateau: This region includes the west part of Henan and Shanxi Provinces and most of Shaanxi Province. Scattered vineyards are found in this region.

The old course of the Yellow River: This region is the alluvial plain of the Yellow River along the Longhai Railway. Several wineries were established in the 1950s and more in recent years. However, wet and hot summer weather conditions in this region are not favourable for producing good-quality wine grapes.

Southwest Plateau: This region includes some high-altitude areas of Yunnan and Sichuan Provinces. Rose Honey, an old cultivar introduced by missionaries 100 years ago, is a major grape cultivar in this area. Some *V. vinifera* and hybrid cultivars have been planted in recent years.

12.3 Wild *Vitis* germplasm and utilization in China

12.3.1 Distribution of Chinese Vitis *species*

Survey and collection of wild *Vitis* has been performed throughout China on a large scale by most research institutes since the mid-1950s (Kong, 2004; Liao, 1988a,b; Lin, 1988; Qiu, 1990, 1992; Shen, 1989; Shi, 1995; Wang, 1978; Wei, 1991; Wen, 1989; Yu, 1994; Zhou and Guo, 1995). The most comprehensive collection and evaluation among the Chinese grape species is *V. amurensis* Rupr. Since the 1970s, more collection trips were performed, especially in Xinjiang and Tibet (Zhou and Fang, 1986). This effort resulted in the discovery of a new species, *Vitis piasezkii*, in Xinjiang Region (Lin, 1998). According to *The Chinese Flora* (Vol.48 (2), *Vitaceae*) (Li, 1998), there are 37 species, one subspecies and 10 variation species of wild grape in China, and nearly 30 species were investigated and named in the last 20 years. Of course, whether all of these are true species is still under debate.

Wild *Vitis* species are distributed throughout China (Table 12.1). Of these, 80% are found in central China and 20% of them are in restricted and scattered areas. Zuo and Yuan (1981) classified 31 species and cultivars according to geographical distribution and found that Hunan, Hubei, Guangxi and Jiangxi Provinces were the most abundant in *Vitis* species. Regions further away from these provinces have fewer grape species. For example, only two species are found in the Northeast Region, three in Tibet, three in Hainan Island and four in Taiwan. Of the 42 species/subspecies known before 1986,

Table 12.1 **Provincial distribution of East Asiatic species in China**

Species	Gd	Gx	Jx	Fj	Zj	Hn	Hb	Ah	Js	Yn	Gz	Sc	Sx	Sd	Hn	Shx	Hb	Gs
Vitis adenoclada		*	*			*												
Vitis adstricta	*	*	*	*	*	*	*	*	*	*		*	*			*	*	
Vitis amurensis					*			*						*		*	*	
V. amurensis var. *baihuashanensis*																	*	
Vitis balanseana	*	*																
V. balanseana var. *ficifolioides*		*																
V. balanseana var. *tomentosa*		*																
Vitis bashanica													*					
Vitis bellula							*					*						
V. bellula var. *pubigera*	*																	
V. bellula var. *pubigera*	*	*				*												
Vitis betulifolia						*	*			*		*	*		*			
V. bryoniaefolia var. *ternate*					*													
Vitis chunganensis	*	*	*	*	*	*		*										
Vitis chungii	*	*	*	*														
Vitis davidii	*	*	*		*	*	*	*	*	*	*	*	*					*
V. davidii var. *ferruginea*	*		*	*	*													

Continued

Table 12.1 Continued

Species	Gd	Gx	Jx	Fj	Zj	Hn	Hb	Ah	Js	Yn	Gz	Sc	Sx	Sd	Hn	Shx	Hb	Gs
V. davidii var. *cyanocarpa*							*	*		*								
Vitis erythrophylla			*		*													
Vitis fengqingensis										*								
Vitis flexuosa	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			*
Vitis hekouensis										*								
Vitis heyneana						*												
V. heyneana	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*		*
V. heyneana subsp. *Ficifolia*									*				*	*	*	*	*	*
Vitis hancockii			*	*	*			*										
Vitis hui (Lushan)			*		*													
Vitis jinggangensis			*			*												
Vitis lanceolati-foilosa	*		*			*												
Vitis longquanensis			*	*	*													
Vitis luochengensis		*																
Vitis menghaiensis										*								
Vitis mengziensis										*								
Vitis piasezkii					*						*	*	*		*			

V. piasezkii Var. *pagnucii*													*		*	*	*	*
Vitis piloso-nerva	*		*	*														
Vitis pseudoreticulata	*	*	*	*	*	*	*	*	*						*			
Vitis retordii	*	*									*							
Vitis romaneti							*	*	*			*	*		*			*
Vitis ruyuanensis	*																	
Vitis shenxiensise													*					
Vitis silvestrii							*						*					
Vitis sinocinerea			*	*	*	*	*		*	*								
Vitis tsoii	*	*		*														
Vitis wenchouensis					*													
Vitis wilsonae				*	*	*	*	*	*	*	*	*	*		*			*
Vitis wuhanensis			*				*								*			
Vitis yunnanensis										*								
Vitis zhejiang-adstricta					*													
Total	16	15	18	13	18	14	13	11	8	13	6	9	13	4	10	5	5	7

Materials come from *The Chinese Flora* (Vol. 48(2), *Vitaceae*) (Li, 1998) and *The Guangxi Vitaceae* (Wang, 1988). * Denotes distribution of species in this province. Some species or variations of species that are most limited in scope are not listed in this table.
Gd, Guangdong; Gx, Guangxi; Jx, Jiangxi; Fj, Fujian; Zj, Zhejiang; Hn, Hunan; Hb, Hubei; Ah, Anhui; Js, Jiangsu; Yn, Yunnan; Gz, Guizhou; Sc, Sichuan; Sx, Shanxi; Sd, Shandong; Hn, Henan; Xhx, Shanxi; Hb, Hebei; Gs, Gansu.

Kong (1986) found that 33 were distributed in Henan, Hunan, Hubei, Jiangxi and Guangxi Provinces.

The wild *Vitis* species are formed through long-term natural selection. Although fruits from the wild species fall short of expectations for human consumption, explorers always selected better ones for domestic cultivation and further breeding for new grapes with better qualities.

12.3.2 Grape germplasm preservation in China

Although a good number of regional/provincial research institutes and universities maintain various *Vitis* germplasm throughout the country, Zhengzhou Grape Germplasm Repository (Henan), Taigu Grape Germplasm Repository (Shanxi) and Zuojia *V. amurensis* Grape Repository (Jilin) are three national *Vitis* germplasm repositories collecting and preserving grape materials designed by the Chinese Agricultural Ministry.

12.3.3 Utilization of Chinese wild grapes

12.3.3.1 Uses as table grapes

Among the Chinese wild *Vitis* species, *Vitis davidii* has relatively large berry size (average 1.6 cm in diameter). It is also resistant to disease and tolerant to hot climates. Clonal selections of *V. davidii* have been used as table grape cultivars (Hu, 1956; Liao, 1988a). The people who live in Fujian, Jiangxi, Jiangsu, Hunan and Guizhou Provinces usually cultivate this wild *Vitis* species as a table grape. *V. davidii* Tangwei and Xuefeng are perfect flower cultivars with good viticulture characteristics. The former was originally found in Yushan County of Jiangxi Province (Wang, 1980; Zhang and Fan, 1985) whereas the latter was found in Xupu County of Hunan Province (Yu, 1994). Residents living in the mountain area of Anhui, Henan and Shaanxi Provinces also plant this wild species in their courtyards as a table grape (Wang, 1978, 1980). In 2008, the *V. davidii* grape cultivation reached 6800 ha in Hunan Province and produced 2.55 million tons of fruit. Approximately 99.8% of the fruit was used for table consumption whereas only 0.2% was used for making wine and juice.

12.3.3.2 Uses as wine grapes

The fruit of several wild *Vitis* species have been used in winemaking in China, among which *V. amurensis* is the most valuable one. There are plenty of *V. amurensis* resources on Changbai Mountain. Tonghua Winery and Changbaishan Winery in Jilin Province and Yimianpo Winery in Heilongjiao Province have used *V. amurensis* berries for winemaking for over 80 years. The wine made from *V. amurensis* has a dark ruby colour, unique flavour and is locally popular. As the most cold-hardy species, *V. amurensis* is distributed in Jilin, Heilongjiang and Liaoning Provinces in Northeast China, including Changbai, Da and Xiao Hinggan Mountains. Its distribution extends to the far eastern part of Russia and the Korean Peninsula. China has a long history in studying and using *V. amurensis* germplasm resources, and it has acquired great achievements in its utilization (Luo, 2011). Jilin Province conducted research on domestic cultivation as early as 1957 (Lin, 1982). Tonghua, Jilin Province has fermented *V. amurensis* wine since the 1930s.

In contrast to the cold-hardy *V. amurensis*, *Vitis quinquangularis* Rehd. is widely distributed in Guangxi Province in southern China. Local people have been using *V. quinquangularis* berries to make wine for a long time. In recent years, more selected clones from wild *V. quinquangularis* have been planted, and the productive area in Guangxi has reached 5800 ha with a total annual production of 2100 tonnes (Zhu et al., 2006). In addition, Zaoyang County of Hubei Province and Danfeng County of Shaanxi Province also process the fruit (Wang, 1993) into wine. Wineries in Feixian County of Shandong Province and Zuopgong County of Tibet use the local wild grapes for wine (Hu and Wang, 1986).

12.3.3.3 Use for rootstock

In Northeast China, *V. amurensis* is also used as rootstock to increase cold hardiness and disease resistance for local cultivars. Using *V. amurensis* rootstock can reduce the soil depth for winter covering and thus save labour and burying soil. Grafting of tender shoots on rootstocks of *V. amurensis* can also improve the success of propagation. However, it is notable that this species does not root well from hardwood cuttings and grafting affinity between the scions, and *V. amurensis* rootstock is generally weak. As a result, it is more common to use Beta (*V. riparia* × Concord) as rootstock to propagate *V. amurensis* cultivars in Northeast China.

Vitis pseudureticulata, which is very hardy to biotic and abiotic stress, is used as rootstock for *Vitis davidii* Tangwei. *Vitis balanseana* was used as rootstock for Golden Muscat to increase the productivity and disease resistance (Miao et al., 1999). Wild *V. piasezkii* was used as rootstock for cold hardiness, and its affinity with scions was good (Zhang et al., 2009).

12.3.3.4 Cultivar development from clonal selections among the wild Chinese Vitis *species*

Since the 1950s, there have been many achievements on utilizing the wild grape germplasm for new cultivar development. *V. amurensis* is the most commonly known and used for grape varietal development. Selection of superior clones from natural variation, followed by cross-pollination, is the common approach used by many breeding programmes in China. Since the 1950s, Institute of Botany, Chinese Academy of Sciences (CAS), Institute of Pomology of Chinese Academy of Agricultural Sciences (CAAS) and Northeast Institute of Agricultural and Forestry Sciences started comprehensive grape-breeding programmes using cold-hardy *V. amurensis* germplasm from Northeast China. Clonal selection of *V. amurensis*, such as Shuangqing, Shuangyou and Changbai No. 4, were among a dozen *V. amurensis* cultivars selected directly from the wild clones. Crosses between *V. amurensis* and *V. vinifera* were also made, and several new F1 hybrids such as Beichun, Gongniang No. 1 and Gongniang No. 2 were developed as new grape cultivars (Figure 12.4).

Figure 12.4 Selected wine grape cultivars released by breeding programmes in China: (a) Beichun, (b) Beifeng, (c) Beihong, (d) Beiquna, (e) Gongning No. 2, (f) Heijianiang, (g) Zuoshan No. 2, (h) Zuohongyi and (i) Beibinghong.

Cultivars developed from *V. amurensis*

V. amurensis is the peculiarly valuable resource of Changbai Mountain in the North-east, where the grape can sustain temperatures as low as −40 °C. Fruits have been used for making wine for many years. *V. amurensis* is characterized by small clusters and berries, low yields and soluble solids content (Brix) and high titratable acidity (TA) and tannins. *V. amurensis* is dioecious, and because of its inherently low yields and difficulty in rooting, domestic cultivation is limited. One important objective of genetic improvement is to select highly productive clones with high Brix, low TA, large clusters and large berries (Hao, 1982). In 1957, Professor Shen-Jun, the former president

Table 12.2 Some superior clonal selections of *Vitis amurensis*

Selections	Sex of flower	Units	Year of selection	Year of naming
Changbai No. 6	♀	Special Plant and	1963	
Changbai No. 9	♀	Animal Research	1963	
Changbai No. 11	♂+♀perfect	Institution of CAAS	1963	1975
(Shuangqing)		Changbaishan Winery		
Zuoshan No. 1	♀	Special Plant and	1973	1984
Zuoshan No. 2	♀	Animal Research	1974	1989
		Institution of CAAS		
Tonghua No. 3	♀	Tonghua Winery	1977	1991
Tonghua No. 7	♀		1977	1991
Tonghua No. 10	♀		1977	1991

of the Society of Chinese Horticultural Science, led the effort to make clonal selections from wild *V. amurensis* in the Changbai Mountain area. Subsequently, Tonghua Winery and Changbai Winery in Jilin Province and the Special Animals and Plants Research Institute of Chinese Academy of Agricultural Sciences also joined the same effort in 1961 (Lin, 1982; Lin et al., 1993). A series of new selections with large clusters and berries, such as Tonghua No. 1, Tonghua No. 2, Tonghua No. 3, Changbai No. 6, Changbai No. 9, Zuoshan No. 1 and Zuoshan No. 2, were selected and released for commercial production (Lin et al., 1991) (Table 12.2). Among them, the most valuable one was a hermaphroditic clone Changbai No. 11, which was originally discovered by Changbai Winery in Jiaohe County of Jinlin Province in 1963. The hermaphroditic character is stable and its clusters are small (mean 43.2 g). In 1975, the selection was renamed as Shuangqing in 1975 (Lin, 1982). The prefix *shuang* means 'both' in Chinese, and many perfect flowered selections are named with the prefix *shuang*.

The selection of superior clones of *V. amurensis* promoted commercial planting on a large scale. Since the discovery of superior hermaphroditic *V. amurensis*, higher yields and more stable production have been achieved. By using perfect flowered parents, breeding hermaphroditic *V. amurensis* hybrids/new cultivars became possible.

In1975, Shen Yu-Jie at the Institute of Special Animal and Plant Sciences of CAAS found an individual with abnormal growth from the intraspecific hybridization of *V. amurensis* (Tonghua No. 3 × Shuangqing). It has large and thick leaves and more clusters, and the mean berry weight is 1.1 g. This line was proved as tetraploid by chromosome counting ($2n = 4X = 76$). This is the first tetraploid *V. amurensis* grape in the world.

In 1995, Mudanjiang Fruit Research Institute of Heilongjiang Province selected Mushan No. 1 from the natural seedlings of *V. amurensis*. The cluster is conical with a mean weight of 195 g, the berry is black with green fresh, 16.0 Brix and it has a 60.0% juice extraction rate, of which the flesh and the peel are easy to separate. It ripens in early September in the middle and southern parts of Heilongjiang Province, and it does not need burying in soil for winter protection (Shan et al., 2011).

Cultivars developed from *V. quinquangularis*

Since the 1980s, the wineries in Luocheng, Duan and Yongfu Counties of Guangxi Province made wines with *V. quinquangularis* Rehd. In the 1990s, the Horticultural Research Institute of Guangxi Academy of Agricultural Sciences made a systematic selection of *V. quinquangularis* in Guangxi, and 15 superior individuals were selected with high Brix and yield. After evaluation for many years, two superior individuals, GSH-2 and ZHJ-5, were selected as wine grape cultivars.

Since 1995, the Science Committee of Duan County of Guangxi Province and the Horticulture Institute of Guizhou Provincial Academy of Agricultural Sciences selected two well-adapted cultivars, Zhonggu No. 2 and Zhongjiu No. 5, from *V. quinquangularis* (Huang et al., 2003). On the basis of the abundant germplasm resources of *V. quinquangularis* in Guangxi, the Biotechnology Institute of Guangxi Academy of Agricultural Sciences selected Yeniang No. 1 as a new wine grape cultivar, but it has shortcomings of low yield and susceptibility to diseases. They then selected a hermaphrodite strain Yeniang No. 2 in 2011. The drought and disease tolerance was strong, and it was suitable for hot and humid environments. It had been planted widely in the mountainous regions in Guangxi. The combination of the Luocheng Administration of Fruit Production, Guangxi and Guangxi Fruit Production Technical Guidance Station selected the pistillate flower cultivars Shuiyuan No. 1 and Shuiyuan No. 11 from *V. quinquangularis*. In 2012, they passed Guangxi cultivar registration, and they bloomed in the beginning of July and ripened in the end of September. The fruit of Shuiyuan No. 1 is reported to have light strawberry flavour.

Clonal selections of *V. davidii*

The origins of *V. davidii* are the Hunan, Jiangxi, Fujian and Zhejiang Provinces south of the Yangtze River. In 1985, Professor Zhang of Jiangxi Agricultural University found that 80% of the grapes in Yushan County of Jiangxi Province were clonal progeny from the domestication and cultivation of *V. davidii.* The centralized growth was in Tangwei Village of Yushan County; thus, he named it as Tangwei grape, which was the first reported hermaphroditic *V. davidii* in the world (Zhang and Fan, 1985). Its mean cluster weight is 905 g, mean berry weight is 2.9 g, mean Brix is 15.1, TA is 6.2 g/L and juice rate is 64.7%. It is a good grape used for table consumption and winemaking. Another hermaphrodite cultivar, Xuefeng, was selected from *V. davidii* in Xupu County of Hunan Province (Zhang et al., 1989). Later on, *V. davidii* Gaoshan No. 1, Ziqiu and Jinzhi Ciputao were selected. (Xiong et al., 2006; Shi et al., 2008). *V. davidii* is another good example of the successful domestic cultivation of Chinese wild grape species. Its popularity and acreage is just behind that of *V. amurensis.*

12.4 Grape-breeding programmes in China

Table grape breeding in China began in the 1950s. Red berry skin, muscat flavour, early maturity and large berry size were the main breeding objectives for table grape breeding in the 1950s and 1960s. Muscat Hamburg and Pearl of Csaba were the main parents used in many table grape-breeding programmes at that time (Figure 12.3).

For example, in 1955, the Chinese Pomology Institute of CAAS in Liaoning Province selected an early-maturing seedling with strong muscat flavour from an open-pollinated population of Muscat Hamburg and named it as Zaotian Meiguixiang. Unfortunately, it did not become a main grape cultivar because of its low yield. In 1958, the Special Plant and Animal Institute of Hubei Academy of Agricultural Sciences developed Zijixin from the cross between Baijixin and Pearl of Csaba. Since then, many early-maturing cultivars such as Zhengzhou Zaohong, Zaomeigui, Zaojinxiang, Jingzaojing, Jingkejing, Zaohong, Zaohuang, Honglianzi and Hongxiangjiao were subsequently developed by the Zhengzhou Pomology Institute of CAAS, Northwest Agricultural University, Beijing Botanical Garden of CAS and Shangdong Grape Research Institute. Different grape-breeding programmes based on geographical regions in China will be introduced in the rest of the chapter.

12.4.1 Grape-breeding programmes in Northeast China

Northeast China includes Heilongjiang, Jilin and Liaoning Provinces as well as part of Eastern Inner Mongolia. The climate in Northeast China is cold and dry in the winter and warm and humid in the summer because rainfall appears mainly in the summer months. The precipitation greatly changes from year to year.

12.4.1.1 Wine grape breeding in Northeast China

V. vinifera grapevines in northern China need to be buried in winter for cold protection. This practice is laborious and is getting more and more expensive. This is indeed a limiting factor for the extension of the local grape industry. Therefore, breeding cold-hardy grape cultivars that do not require burying is a major goal in this region, and the same is true for the major viticulture areas in China (Yang and Wu, 1959; Pu, 1960). *V. amurensis*, which is distributed mostly in northern China and can tolerate −40 °C, is a valuable resource for breeding cold-hardy grapes (Hu, 1956).

Intraspecific hybridization of *V. amurensis*

Selecting and breeding for perfect flowered cultivars is the objective of intraspecific crosses of *V. amurensis*. The first perfect flower *V. amurensis* clone is Changbai No. 11 (named Shuangqing). The selection of this hermaphroditic *V. amurensis* made breeding for perfect flowered *V. amurensis* grape cultivars possible. For example, a joint effort between the Institute of Special Animal and Plant Sciences of CAAS and the Tonghua Winery led to the release of two superior hermaphroditic hybrids from the cross between Tonghua No. 1 × Shuangqing in 1975, Shuangyou (released in 1988; mean cluster weight 132 g) and Shuangfeng (released in 1995; mean cluster weight 118 g), respectively (Huang et al., 1998; Wang et al., 1996). In 1977, a superior hermaphroditic cultivar Shuanghong was released, which was derived from an intraspecific cross between *V. amurensis* Tonghua No. 3 × Shuangqing. Shuanghong also showed cold resistance, high and stable yields, good winemaking quality and resistance to downy mildew, and it passed the cultivar certification in 1998 (Song and Li, 1998). Zuohong No. 1 was another *V. amurensis* cultivar with perfect flowers being released for dry and semi-dried red winemaking (Huang et al., 1994, 1998) (Table 12.3).

Table 12.3 Perfect flowered *Vitis amurensis* cultivars bred from 1975 to 1998

Cultivars	Parents	Unit	Year of cross	Year of release
Shuangyou	Tonghua No. 1 × Shuangqing	Special Plant and Animal Institution of CAAS	1975	1988
Shuangfeng	Tonghua No. 1 × Shuangqing		1975	1995
Shuanghong	Tonghua No. 3 × Shuangqing	Tonghua Winery	1977	1998

Table 12.4 Characteristics of perfect flowered cultivars of *Vitis amurensis*

Cultivars	Cluster weight (g)	Berry weight (g)	Brix	Titratable acidity (g/L)	Tannin (g/L)	Juice (%)	Downy mildew resistance
Shuangyou	132.0	1.19	14.6	22.3	0.68	64.7	Resistant
Shuangfeng	117.9	0.81	14.3	20.3	0.46	57.0	High resistance
Shuanghong	127.0	0.83	15.6	19.6	0.62	55.7	Resistant

Another hermaphroditic cultivar with superior fruit characters and berry quality developed from intraspecific cross of *V. amurensis* is Shuangfeng, which is characterized by high yield, high Brix and strong disease resistance (Wang et al., 1996). The breeding of hermaphroditic cultivars of *V. amurensis* played an important role in grape production in Northeast China, with an increase of 22.4–31.6% of yield (Song et al., 1999) (Table 12.4).

Interspecific hybridization between *V. amurensis* and *V. vinifera*

At an early stage, the main objective of breeding wine grape cultivars in Northern China was to develop cold-hardy red-coloured cultivars. A lofty goal is to develop new grape cultivars that can tolerate temperatures as low as −25°C without burying. In 1951, the Pomology Institute of Jilin Academy of Agricultural Sciences initiated a breeding programme of making crosses between *V. amurensis* and *V. vinifera*/*V. labrusca*. From approximately 15,000 hybrid seedlings, they selected Gongniang No. 1 (Muscat Hamburg × *V. amurensis*) and Gongniang No. 2 (*V. amurensis* × Muscat Hamburg). These cultivars were highly tolerant to cold stress, being able to survive through winter without burying (temperatures could be as cold as −20 to −29 °C). They had high Brix, and the wines were evaluated as having good quality with some degree of *V. vinifera* alike. Since their release, these two cultivars have been widely planted in Northeast China (He et al., 1981, 1990). In the 1970s, these cultivars were used for making crosses with *V. vinifera* cultivars. A new high-quality white wine cultivar named Gongzhubai (Gongniang

No. 2 × Golden Muscat) was released from this effort. Gongzhubai was obviously a better grape in terms of berry size, fruiting habit, berry flavour and cold hardiness (Fang et al., 1993) (Table 12.5).

The Pomology Institute of Chinese Academy of Agricultural Sciences started research on cold-resistant grape cultivars in 1951. They selected Heishan from crosses of Black Hamburg × *V. amurensis* and Shanmeigui from Muscat Hamburg × *V. amurensis,* respectively. They could sustain temperatures as low as −26 °C and showed no cold injury without burying. These selections had high Brix and low TA and they were more suitable for winemaking than *V. amurensis* (Yang and Wu, 1959; Pu, 1960). Huapu No. 1 is a new wine grape hybrid cultivar of Zuoshan No. 1 × White Malaga. It has strong cold and disease resistance, high yield and good wine quality. It was also used as a rootstock, and grafting affinity with some table grapes was quite good (Wang et al., 2012a,b,c) (Tables 12.5 and 12.6).

In 1967, the Liaoning Agronomy College (in Xiongyue County) bred a cold-resistant cultivar Xiongyuebai by crossing Longyan with a hybrid selection of Muscat Hamburg × *V. amurensis*. This cultivar was suitable for making high-quality white wine (Zhang, 1987). The Pomology Institute of the Liaoning Academy of Agricultural Sciences also released a white wine grape cultivar named Xiongyuehong, which was selected from an F1 hybrid crossed between *V. amurensis* with Longyan, a Chinese native grape cultivar.

At present, repeated crosses and backcrosses to make F2 and F3 hybrids are the strategy to screen progenies with superior wine quality at the Special Plant and Animal Institution of CAAS. In 1998, the cold-resistant wine grape Zuohongyi was selected from the hybrids of the female parent 79-26-58, which was the F1 hybrid between *V. amurensis* × *vinifera* and the male parent *V. amurensis* 74-6-83 (Lu et al., 2000). Zuoyouhong was also selected from a hybrid of *V. amurensis* × *Vitis vinifera* and then backcrossed *to V. amurensis*. It was approved by the cultivar releasing committee of Jilin Province in 2005. The period from berry setting to harvesting was 119–128 days. It was considered as an early ripening, very cold hardy and resistant to disease and high-yield cultivar (Song et al., 2005).

A cultivar named Beibinghong ((*V. amurensis* × *V. vinifera*) F2 × (*V. amurensis* × *V. vinifera*) F2) was released in 2008 (Figure 12.4). The Brix at maturity ranged from 17.6 to 25.8. It is used for making icewine, and the Brix of the frozen fruit in early December was 35.2–37.0. This cold-hardy cultivar is also resistant to disease and high yield (Song et al., 2008). Xuanlanhong (also called Zuohongsan), derived from Zuoyouhong × Beibinghong and released in 2012, is another cultivar for dry red wine. The Brix ranges from 16.2 to 21.8. It ripens in the end of September, and the period from blooming to harvesting is 137–145 days. Its cold hardiness is similar to Beta rootstock (Song et al., 2012).

12.4.1.2 Table grape breeding in Northeast China

Dalian is a major region and seaport in the south of Liaoning Province. It is the southernmost city of Northeast China. The Dalian Agricultural Science Institute started a table grape-breeding programme in the 1970s and selected Fenghuang No. 12 (Muscat of Alexandria × (Flame Tokay × Pobeda)), and Fenghuang No. 51 (Muscat of Alexandria × Cardinal) (Wu et al., 1989). Fenghuang No. 51 is an early-maturing cultivar that has large berries and is purple-red in colour. It has thin skin and thick pulp, and it is high quality and high yield. From the 1980s to 1990s, Fenghuang No. 51 had been cultivated

Table 12.5 **Interspecific cultivars derived from hybridization between *Vitis amurensis* and *Vitis vinifera* in Northeast China**

Cultivars	Parentage	Unit	Year of cross	Year of release	References
Gongniang No. 1	Muscat Hamburg × *V. amurensis*	Pomology Institute of Jilin Academy of Agricultural Sciences	1951	1981	He et al. (1981, 1990)
Gongniang No. 2	*V. amurensis* × Muscat Hamburg		1951	1981	He et al. (1981, 1990)
Gongzhubai	Gongniang No. 2 × Golden Muscat		1970	1993	Fang et al. (1993)
Heishan	Black Hamburg × *V. amurensis*	Pomology Institute of Chinese Academy of Agricultural Sciences	1951	1959	Yang and Wu (1959) and Pu et al. (1960)
Shanmeigui	Muscat Hamburg × *V. amurensis*		1951	1959	Yang and Wu (1959) and Pu (1960)
Huapu No. 1	Zuoshan No. 1 × White Malaga		1979	2011	Wang et al. (2012)
Xiongyuebai	Longyan × (Muscat Hamburg × *V. amurensis*)	Liaoning Agronomy College	1967	1987	Zhang (1987)
Zuohongyi (84-15-21)	79-26-58 (*V. amurensis* × *V. vinifera*) × *V. amurensis* 74-6-83	Special Plant and Animal Institution of CAAS	1984	1998	Lu et al. (2000)
Zuoyouhong	(*V. amurensis* × Muscat rouge de Frontignan) × *V. amurensis*		1987	2003	Song et al. (2005)
Beibinghong	Zuoyouhong × 84-26-53 (*V. amurensis* × *V. vinifera*)		1995	2008	Song et al. (2008)
Xuanlanhong	Zuoyouhong × Beibinghong		2001	2012	Song et al. (2012)

Table 12.6 **Table grape cultivars developed in Northeast China**

Cultivars	Parentage	Units	Year of cross	Year of release	References
Zaotian Meiguixiang	Muscat Hamburg	Pomology Institute of CAAS	1955	1963	Kong (2004)
Fenghuang No. 12	Muscat of Alexandria × (Flame Tokayx Pobeda)	Dalian Agricultural Science Institute	1970	1989	Wu et al. (1989)
Fenghuang No. 51	Muscat of Alexandria × Cardinal		1970	1989	Wu et al. (1989)
Jumeigui	Shenyangmeigui × Kyoho		1993	2002	Wang et al. (2003)
Mihong	Shenyang Meigui × Black Olympia		1993	2009	Zong et al. (2009a)
Heiguixiang	Shenyangmeigui × Kyoho		1993	2009	Zong et al. (2009b)
Zifeng	Black Hamburg × Niagara	Liaoning Provincial Saline-Alkali Land Utilization and Research Institute	1960	1985	Li et al. (1985)
Zhuosexiang	Delaware × Royal Rose		1961	2009	Yang et al. (2012)
Zizhenxiang	Muscat Hamburg Mutant (7601) × Zixiang Shui Mutation (8001)	Horticultural Institute of Liaoning Academy of Agricultural Sciences	1981	1991	Xu et al. (1992)
Xiyanghong	Muscat Hamburg Mutation (7601) × Kyoho		1981	1993	Xu et al. (1994)
Guixiangyi	Muscat Hamburg Mutation (7601) × Kyoho		1981	1993	Xu et al. (1994)
Zuijinxiang	Muscat Hamburg Mutation (7601) × Kyoho		1981	1997	Wang (1999)
Xiangyue	Muscat Hamburg Mutation (7601) × Zixiangshui		1981	2005	Zhang et al. (2006)
Zhuangyuanhong	Kyoho × Guixiangyi		1991	2006	Jin et al. (2007)
Tianfeng	Kyoho	Pomology Institute of Jilin Academy of Agricultural Sciences	1975	1988	He et al. (1989)
Bixiang Wuhe	18-5-1 × Pearl of Csaba	Jilin Agricultural College	1994	2004	Li at al. (2008)

as the main early-ripening cultivar in most table grape-growing regions throughout China. In 2002, two *vinifera*×*labrusca* hybrid cultivars were released – Jumeigui and Mihong Putao – which were derived from crosses between *V. vinifera* Shenyang Meigui and American hybrids Kyoho and Black Olympia (Wang et al., 2003; Zong et al., 2009a). Other cultivars released by the same institution include Heiguixiang, Jumeigui, Mihong Putao and Heimeixiang. These mid-season varieties have muscat flavour, high yield and are resistant to disease. Among them, Jumeigui has been expanded rapidly and has become one of the main table grape cultivars growing in China today (Table 12.6).

Liaoning Provincial Saline-Alkali Land Research Institute made crosses in 1960 and selected Zifeng from Black Hamburg×Niagara (Li et al., 1985). Zhuosexiang was selected from Delaware×Royal Rose in 2009, which was early maturing with strawberry flavour; it was tolerant to salt, cold hardy, and resistant to disease (Yang et al., 2012) (Table 12.6).

From the 1980s to 1990s, the Horticultural Institute of Liaoning Academy of Agricultural Sciences selected hybrid cultivar Zizhenxiang by crossing a Muscat Hamburg Mutant (7601)×Zixiangshui Mutant (8001) (Xu et al., 1992). In the meantime, hybrid cultivars Zuijinxiang, Xiyanghong and Guixiangyi were released from selections in a cross of Muscat Hamburg Mutant 7601×Kyoho (Xu et al., 1994a,b; Wang, 1999, 2000). Among those hybrid cultivars, Zuijinxiang has good quality and good appearance, and it can easily become a seedless cultivar by treating with plant growth regulators. Zuijinxiang is now accepted by many grape growers in south China. In 2005, Xiangyue, a mid-season ripening, large-berry, good-quality, high-yielding, disease-resistant cultivar was bred by crossing Shenyangmeigui and 8001(Xu et al., 2003). Zhuangyuanhong (Kyoho×Guixiangyi), a mid-season cultivar with muscat flavour, was selected in 2006 (Jin et al., 2007) (Table 12.6).

In 1988, the Pomology Institute of Jilin Academy of Agricultural Sciences selected an elite hybrid cultivar from natural seedlings of Kyoho and named it Tianfeng (He et al., 1989). Jilin Agricultural College bred Bixiang Wuhe from a cross between *V. vinifera* 18-5-1 and Pearl of Csaba. Bixiang Wuhe is green, seedless and early ripening with muscat flavour (Li et al., 2008) (Table 12.6).

12.4.2 Grape breeding in North China

Northern China includes Beijing Municipality, Tianjin Municipality, Hebei Province, Shanxi Province and Inner Mongolia Autonomous Region. The climate of North China is cold and dry in the winter and warm in the summer, with a substantial diurnal temperature fluctuation. Rain appears mainly in the summer, but the precipitation pattern greatly changes from year to year.

12.4.2.1 Wine grape breeding in North China

In 1954, the Beijing Botanical Garden of the Chinese Academy of Sciences made a cross of *V. amurensis* and Muscat Hamburg from which the cultivars Beichun, Beihong and Beimei were selected and released. These Va×Vv hybrid cultivars are cold hardy (−25 °C) and resistant to disease with high yield and high Brix. They do not need burial for winter protection (Yu, 1959; Luo and Zhang, 1990; Li et al., 1983; Fan et al., 2010).

In addition, their juice is brightly coloured, and they show good winemaking potential. Of all of the hybrid cultivars, Beichun is the most widely planted wine grape. Total cultivation areas of Beichun reached 6600 ha over 30 counties in the early 1980s. The Shandong Wine Grape Research Institute crossed *V. amurensis* × Sweet Water, a European cultivar, in 1964 and released a new cultivar, Baotuhong (Kong, 2004). These cultivars are used for making wine or blending to enhance the colour of wines. In addition to cold hardiness, Beichun is also resistant to fungal diseases; therefore, it has been introduced to South China, where the climate is warm but too humid to grow *V. vinifera* (Table 12.7).

In recent years, the Beijing Botanical Garden crossed F1 hybrids of *V. amurensis* with European cultivars and released a new white wine grape cultivar, Beiquan, which is cold hardy with excellent quality, high yield, and disease resistance.

12.4.2.2 Juice grape breeding in North China

Since 1953, the Beijing Botanical Garden of CAS made crosses between *Vitis adstricta* and *V. vinifera* cultivars and successively released several juice grape cultivars such as Beizi, Beixiang and Beifeng. Among them, Beizi was released in 1965 from the interspecific cross between *V. adstricta* and Muscat Hamburg. With many years of planting tests, comparative tests and producing and processing tests, it had outstanding performance and passed the cultivar certification of Beijing in 2006. Beizi is late-maturing, cold- and drought-tolerant and disease-resistant grape cultivar (Fan et al., 2006). Beifeng was another juice cultivar derived from *V. adstricta* × Muscat Hamburg. In 1959, the processing tests were performed. With many years of planting tests, comparative tests and producing and processing tests, the merits of it had outstanding performance, especially the strong resistance to cold and disease. In 2006, it passed the cultivar certification of Beijing. Beifeng was late maturing, high yielding, drought resistant and disease resistant (Fan et al., 2007b). Juice cultivar Beixiang was also derived from hybridization between *V. adstricta* × Muscat of Alexandria. It was very late maturing, high yielding and strongly stress resistant. In 2006, it got through the certification of the Beijing Crop Cultivar Certification Committee. It is cultivated in Beijing, Zhejiang, Jiangsu, etc. (Fan et al., 2007a).

12.4.2.3 Table grape breeding in North China

The Beijing Botanical Garden of CAS began a table grape-breeding programme in 1960. Through 1994, a total of 10 cultivars were released by the Institute of Botany of CAS. Four of them are seedless grapes: Jingzaojing (Queen of the Vineyard × Thompson Seedless) (Fan et al., 2004a), Jingkejing (Blue French × Hongwuzilu), Jingzijing (Queen of the Vineyard × Hongwuzilu) and Jingdajing (Queen of the Vineyard × Hongwuzilu). Four are early ripening with large berries, which are named as Jingxiu (Pannoniavinesa × 60-33 (Muscat Hamburg × Hongwuzilu)) (Yang et al., 2003), Jingyu (Italia × Queen of the Vineyard), Jingyou (Black Olympia seedlings) (Fan et al., 2004b) and Jingya (Black Olympia seedlings) (Yang, 1990). Two are early to mid-season cultivars: Jingfeng (Queen of the Vineyard × Hongwuzilu) and Jingchao (Kyoho natural seedlings). Jingxiu is an elite early-ripening and good-quality cultivar, and it has been grown in China fairly extensively. The fruit ripening time of Jingzaojing is 20 days earlier than Thompson Seedless. Jingzaojing has been widely

Table 12.7 **Table grape cultivars released by Beijing Botancial Garden of CAS**

Cultivars	Parentage	Year of cross	Year of release	References
Jingzaojing	Queen of the Vineyard × Thompson Seedless	1960	2001	Fan et al. (2004)
Jingkejing	Blue French × Hongwuzilu	1960	1984	Kong (2004)
Jingzijing	Queen of the Vineyard × Hongwuzilu	1960	1983	Kong (2004)
Jingdajing	Queen of the Vineyard × Hongwuzil	1960	1983	Kong (2004)
Jingxiu	Pannoniavinesa × 60-33 (Muscat Hamburg × Hongwuzilu)	1981	1994	Yang et al. (2003)
Jingyu	Italia × Queen of the Vineyard	1960	1992	Kong (2004)
Jingyou	Black Olympia seedlings	1981	1994	Fan et al. (2004)
Jingya	Black Olympia seedlings	1981	1990	Yang (1990)
Jingfeng	Queen of the Vineyard × Hongwuzilu	1960	1983	Kong (2004)
Jingcha	Kyoho natural seedlings	1960	1984	Kong (2004)
Jingmi	Jingxiu × Xiangfei	1997	2007	Fan et al. (2008)
Jiangxiangyu	Jingxiu × Xiangfei	1997	2007	Fan et al. (2008)
Jingcui	Jingxiu × Xiangfei	1997	2007	Fan et al. (2008)
Jingyan	Jingxiu × Xiangfei	1997	2010	Fan et al. (2012)

grown in Gansu, Inner Mongolia, Jilin and Beijing. In the new century, Jingmi (Fan et al., 2008c), Jiangxiangyu (Fan et al., 2008b), Jingcui (Fan et al., 2008a) and Jingyan (Fan et al., 2012) were selected from a cross of Jingxiu and Xiangfei (Table 12.7).

In 1973, the Forestry and Pomology Institute of Beijing Academy of Agricultural Sciences started to breed table grape cultivars. The objective was to produce early-maturing or seedless cultivars. They successively bred a series early-maturing cultivars with good quality, such as Zizhenzhu (Muscat Hamburg × Pearl of Csaba), Zaomeiguixiang (Muscat Hamburg × Pearl of Csaba), Aishenmeigui (Muscat Hamburg × Jingzaojing), Yanhong (Muscat Hamburg × Jingzaojing), Zaomanao (Muscat Hamburg × Jingzaojing), Cuiyu (Muscat Hamburg × Jingzaojing) (Li et al., 1987; Tang et al., 1992; Xu and Liu,1994), Xiangfei (Cardinal × 73-7-6 (Muscat Hamburg × Pearl of Csaba)) (Xu et al., 2001) and Ruiducuixia (Jingxiu × Xiangfei) (Xu et al., 2008). A series of mid- and late-maturing cultivars with large berry size and muscat flavour as well as being seedless and good for storage and transportation were also released. These include Ruiduxiangxu (Jingxiu × Xiangfei) (Xu et al., 2009) and Ruiduwuheyi (Xiangfei × Ruby Seedless) (Xu et al., 2001). Fenghou (a seedling of Kyoho) is a late-ripening cultivar with large berry size, good appearance and storageability, and good eating quality (Xu et al., 2000) (Table 12.8).

Changli Pomology Institute of Hebei Academy of Agricultural Sciences (in Changli County of Hebei Province) started a table grape-breeding programme in 1979. They selected the early-ripening cultivars – Chaokangmei, Chaokangfeng and Chaokangzao – from an open-pollination seedling population of Campbell Early (Kong, 2004). Wuhezaohong (8611) and Hongbiao Seedless are triploid seedless cultivars derived from Zhengzhou Zaohong (a diploid seeded cultivar) × Kyoho (a tetraploid seeded cultivar) in the 1990s (Zhao et al., 2000, 2003). They ripen very early, 30 days earlier than Kyoho, with large berries. They are black purple in colour, high in quality, productive and disease resistant, and they have been planted widely in most grape regions. In recent years, this institute has released Yueguang Wuhe (Muscat Hamburg × Kyoho) and Xiaguang (Muscat Hamburg × Jingya), which are early ripening, with large berry size, high yields, and they are disease resistant (Tao et al., 2012) (Table 12.9).

In the past 5 years, Hebei Normal University of Science and Technology (in Changli County of Hebei Province) released several table grape cultivars. Jintian 0608 is a new late-ripening cultivar. Its mean cluster weight is 905 g. Its berry looks like a chicken heart in shape, and it is purple-black in colour. The mean berry weight is 8.1 g, Brix is 22.0 and the flesh tastes sweet with a light aroma. The overall quality is excellent. The fruit matures in late September in the east of Hebei (Xiang et al., 2008c). Jintian Meigui is derived from Muscat Hamburg × Red Globe. Its mean cluster weight is 608 g. The berry, average weight of approximately 7.2 g, is round, purple-red to dark purple-red in colour, with a Brix of 20.5. The flesh is juicy and tastes sweet. The fruit matures in late August in the east of Hebei (Xiang et al., 2008b). Jintianmi (9603 × 9411) has a mean cluster weight of 616 g. Its berry is round and green-yellow in colour, the mean berry weight is 7.2 g and the Brix is 14.5%. It tastes sweet with aroma. The quality is excellent (Xiang et al., 2008a). Jintian Feicui is a late-ripening cultivar derived from Fenghuang No. 51 (maternal plant) × Victoria (paternal plant). Its mean cluster weight is 920 g. Its berry is near orbicular. The mean berry weight is 10.6 g, and Brix is 17.5. The flesh is white in colour with fragrance, the pulp is

Table 12.8 **Table grape cultivars released by the Forestry and Pomology Institute, Beijing Academy of Agricultural Sciences**

Cultivars	Parentage	Year of cross	Year of release	References
Zizhenzhu	Muscat Hamburg × Pearl of Csaba	1973	1986	Li et al. (1987)
Zaomeiguixiang	Muscat Hamburg × Pearl of Csaba	1973	1994	Xu and Liu (1994)
Aishenmeigui	Muscat Hamburg × Jingzaojing	1973	1994	Xu and Liu (1994)
Yanhong	Muscat Hamburg × Jingzaojing	1973	1986	Li et al. (1987)
Zaomanao	Muscat Hamburg × Jingzaojing	1973	1986	Li et al. (1987)
Cuiyu	Muscat Hamburg × Jingzaojing	1973	1986	Li et al. (1987)
Fenghou	A seedling of Kyoho	1983	1999	Xu et al. (2000)
Xiangfei	Cardinal × 73-7-6 (Muscat Hamburg × Pearl of Csaba)	1982	2000	Xu et al. (2001)
Ruiducuixia	Jingxiu × Xiangfei	1998	2007	Xu et al. (2008)
Ruiduxiangyu	Jingxiu × Xiangfei	1998	2007	Xu et al. (2009)
Ruiduwuheyi	Xiangfei × Ruby Seedless	1997	2009	Xu et al. (2011)

Table 12.9 **Table grape cultivars released by Chanli Pomology Institute, Hebei Academy of Agricultural Sciences**

Cultivars	Parentage	Year of cross	Year of release	References
Chaokangmei	Campbell Early seedling	1979	1987	Kong (2004)
Chaokangfeng	Campbell Early seedling	1979	1987	Kong (2004)
Chaokangzao	Campbell Early seedling	1979	1987	Kong (2004)
Wuhezaohong (8611)	Zhengzhou Zaohong × Kyoho	1986	1998	Zhao et al. (2000)
Hongbiao Seedless	Zhengzhou Zaohong × Kyoho	1986	2003	Zhao et al. (2003)
Yueguang Wuhe	Muscat Hamburg × Kyoho	1991	2009	Tao et al. (2012)
Xiaguang	Muscat Hamburg × Jingya	2001	2009	Tao et al. (2012)

crisp and succulent and the quality is excellent. Harvest is in early September (Wang et al., 2012). Jintian Meizhi is a late-ripening cultivar derived from Niunai (maternal plant) × Minicure Finger (paternal plant). Its mean cluster weight is 802 g, and its berry is a long ellipsoid in shape that is bright red in colour with a mean berry weight of 10.5 g and Brix of 19.0. The quality is excellent. Harvest is from late September to early October in east Hebei Province (Wang et al., 2012) (Table 12.10).

The Pomology Institute of Shanxi Academy of Agricultural Sciences started a table grape-breeding programme in the 1970s. They first released Guibao (Ispissar × Vera Rose) in 1988 (Ouyang et al., 1989) and several new ones after the year of 2000. They are very early-ripening Zaoheibao (Guibao × Zaomeigui), which has big berry size, fine quality and high yield (Chen et al., 2001). Qiuhongbao is a mid- to late-season table grape cultivar derived from a cross between Guibao and Taifi Meigui. It is very vigorous and productive, with good adaptability to environmental adversities, and it has moderate disease resistance. Clusters can hang on the vine for a very long period of time and have good shipping and storage characteristics. The clusters are large (508 g), conical and well filled. The berries are uniform, large and short/oblong with a mean weight of 7.1 g, and they are reddish purple in colour. The flesh is firm, crisp and sweet, with a pleasant lychee-like flavour. Its fruits have a Brix of 21.8, a TA of 2.5 g/L, and a sugar:acid ratio of 8:7 (Chen et al., 2007). Zaokangbao is another early-season seedless grape cultivar derived from the cross between Guibao and Centennial Seedless made in 1998. The clusters are conical, with a mean weight of 216 g, but they can attain 417 g. The berries are obovate and uniform in size, with a mean weight of 3.1 g, and the potential to attain 5.8 g. The berry skin colour is purple-red. The flesh is firm, crisp, juicy and seedless or with one to two aborted seeds; the flavour is sweet with a muscat aroma, and it has high eating quality. It matures in early August. The vines have good adaptability, but the disease resistance is medium (Chen et al., 2009). Qiuheibao is a new mid-maturing tetraploid grape cultivar that was selected from the cross Guibao × Christmas Rose and then doubling the chromosome number by colchicine treatment. Its cluster is large and conical, with a mean weight of 437 g. The berries are oblong, with a mean weight of 7.13 g, and they are black purple in colour. The flesh is soft and sweet with a rose flavour. Its fruit quality is rather good, with one to two big seeds, a Brix of 23.4, and a TA of 4.0 g/L. The sugar:acid ratio is 4.9:1. The maturity of fruit is in mid- to late August. Its vines are normal and fruitful, with good adaptability to the environment and high disease resistance (Ma et al., 2010). Lihongbao is a new grape cultivar that is bred by crossing Guibao and Centennial Seedless. Its clusters are large and conical, with a mean weight of 300 g. The berries are chicken-heart shaped, with a mean weight of 3.9 g, and they have a purple-red skin colour. The flesh is crisp, with rose aroma, and it is seedless. It has a Brix of 19.40 and a TA of 4.7 g/L. The sugar:acid ratio is 3.55:1. It matures in mid- to late August in Jinzhong of Shanxi Province (Chen et al., 2011). Wuhe Cuibao is a new early-ripening seedless grape cultivar that was bred by crossing Guibao and Centennial Seedless. Its fruit clusters are large and conical, with a mean weight of 345 g. The berries are ovoid shape, with a mean weight of 3.6 g and a yellowish skin colour. The flesh is crisp, with rose aroma and seedless or with one to two vestigial seeds. It has a Brix of 17.20 and a TA of 3.9 g/L. The sugar:acid ratio is 4.0:1. The vine is vigorous with strong resistance and adaptability (Tang et al., 2012) (Table 12.11).

Table 12.10 **Table grape cultivars released by Hebei Normal University of Science and Technology**

Cultivars	Parentage	Year of cross	Year of release	References
Jintian 0608	Autumn black × Niunai	2000	2007	Xiang et al. (2008c)
Jintian Meigui	Muscat Hamburg × Red Globe	2000	2007	Xiang et al. (2008b)
Jintianmi	96-12 × 94-08	1996	2007	Xiang et al. (2008a)
Jintian Feicui	Fenghuang No. 51 × Victoria	2001	2010	Wang et al. (2012a)
Jintian Meizhi	Niunai × Minicure Finger	2000	2010	Wang et al. (2012b)
Jintian HuangjiaWuhe	Niunai × Autumn Royal	2000	2007	Xiang et al. (2010)

Table 12.11 **Table grape cultivars released by the Pomology Institute, Shanxi Academy of Agricultural Sciences**

Cultivars	Parentage	Year of cross	Year of release	References
Guibao	Ispissar × Vera Rose	1973	1988	Ouyang et al. (1989)
Zaoheibao	Guibao × Zaomeigui	1993	2000	Chen et al. (2001)
Qiuhongbao	Guibao × Taifi Rose	1999	2007	Chen et al. (2007)
Zaokangbao	Guibao × Centennial Seedless	1998	2008	Chen et al. (2009)
Qiuheibao	Double (Guibao × Qiuhong)	1999	2010	Ma et al. (2010)
Lihongbao	Guibao × Centennial Seedless	1999	2010	Chen et al. (2011)
Wuhe Cuibao	Guibao × Centennial Seedless	1999	2011	Tang et al. (2012)

12.4.3 Table grape breeding in Northwest China

Northwest China includes Gansu Province, Qinghai Province, Shaanxi Province, Ningxia Autonomous Region and Xinjiang Autonomous Region. The northwestern part of China has very different climate conditions from the eastern part of China. The terrain is arid and dry. The historic Silk Road snaked from its eastern terminus at Xi'an across the mountains and deserts to Central Asia. There is very little rainfall here in summer months, and daytime temperatures can get above 100°F (37 °C). The night-time temperatures drop radically after sunset so that evenings are cool. Winters are very cold with snow at times (http://gochina.about.com/od/weather/qt/Northwest-China-Weather.htm).

The Xinjiang Centre of Grape and Melon selected Xinpu No. 1 from open-pollination seedlings of Rose de Italia from 1984 to 1990 and named and registered it in 1996. Xinpu No. 1 has moderate vigour, and it is fruitful with stable yield, large clusters, good quality, and late maturity (Luo et al., 1997). Xinyu is a hybrid cultivar derived from E42-6 (selected from Red Globe) × Rizamat, ripening in mid-September in the Shanshan City area. The berry is egg-like and purple-red in colour. The mean berry weight is 11.6 g. The fruit cluster is conical, weighting more than 800 g, with a Brix of 16–19 and a TA of 3.3–3.9 g/L. It has excellent characteristics, such as strong vigour, high yield and good quality (Luo et al., 2007) (Table 12.12).

Shihezi Grape Institute in Xijiang Region released Shuijing Seedless (Xinpu No. 2) and Kunxiang Seedless (Xinpu No. 3), which were selected from the hybrid population of Queen of the Vineyard × Kang Nairuo. The former is early-ripening and has a large berry size. It is high quality, fertile and adaptable. The latter is mid-season, with muscat flavour, strong resistance, wide adaptability, high yield, and good quality, and it is easily cultivated. Zixiang Wuhe (Xinpu No. 4; Muscat Hamburg × Black Monukka) was bred in 2004. It is an early- to mid-season cultivar with disease resistance that is good for storage (Chen, 2001; Rong et al., 2004).

Zuirenxiang is a mid- to late-ripening table grape cultivar that was selected by the Pomology Institute of Gansu Academy of Agricultural Sciences from the offspring of Kyoho × Чарас Мускатний. The cross was made in 1985. Its cluster is medium in size, weighing 700 g. The mean berry weight is 9–11 g. The Brix is 18, and it has very good and strong flavours of strawberry and muscat. This cultivar ripens in early September in Lanzhou. The vine is vigorous, productive and resistant to disease (Gao et al., 2001; Hao et al., 2011).

12.4.4 Grape breeding in South Central China

South Central China includes the provinces of Guangdong, Hainan, Henan, Hubei and Hunan as well as the Guangxi Zhuang Autonomous Region. The climate of Central China is affected by the monsoons, and as the season changes, the temperature quickly changes. In the summer, the monsoon from the sea takes rainfall to Central China, and in the winter, the monsoons from the continent bring the cold air to this area.

12.4.4.1 *Wine grape breeding with* V. quinquangularis *Rehd*

Lingfeng (NW196) was a superior individual selected by the Horticultural Institute of Guangxi Academy of Agricultural Sciences and Northwest A&F University from

Table 12.12 **Table grape cultivars released in Northwest China**

Cultivars	Parentage	Unit	Year of cross	Year of release	References
Zaomeigui	Muscat Hamburg × Pearl of Csaba	Northwest Agriculture & Forestry University	1963	1974	Kong (2004)
Zaojinxiang	Muscat Hamburg × Pearl of Csaba		1963	1975	He and He (2003)
Xinpu No. 1	Rose Ito seedling	Xinjiang Research Centre of Grape and Melon	1984	1996	Luo et al., 1997
Xinyu	E42-6 × Rizamat		1991	2005	Luo et al. (2007)
Kunxiang Seedless	Queen of the Vine-yard × Kang Nairuo	Shihezi Grape Institute in Xijiang Region	1977	2000	Chen et al. (2001)
Zixiang seedless	Muscat Hamburg × Black Monukka		1978	2004	Rong et al. (2004)
Zuirenxiang	Kyoho × Чарас Мускатний	Pomology Institute of Gansu Academy of Agricultural Sciences	1985	2009	Hao et al. (2011)

hybrids of an interspecies cross (cross combination No. 88–110) made in Guangxi using *V. quinquangularis* 83-4-96 as the female parent and *V. vinifera* Muscat Rose as the male parent. The cross was made in 1995–1996, and it was officially released in 2005. Lingfeng has great adaptability, strong disease resistance and vigour, high fruit set and hermaphrodite flowers, and it was suitable for domestic cultivation in the southern producing area. Experimental test plots have been established in Duan, Shanglin and Xingye Counties of Guangxi Province. Another superior individual 2-1-3 (NW213) was also selected from the same cross. This individual was named as Lingyou in 2005 after successful trials in Duan, Luocheng and Yulin Counties of Guangxi Province (Huang et al., 2006).

12.4.4.2 Table grape breeding

Hubei Special Animal and Plant Research Institute (Wuhan) made crosses in 1958 and released Zijixin (BaiJixin × Muscat Hamburg) in 1973 (Kong, 2004). The Zhengzhou Fruit Research Institute of the Chinese Academy of Agricultural Sciences started grape breeding in the early 1960s with the goals of developing new cultivars with early ripening, large berry size and better fruit quality. Zhengzhouzaoyu (trial #18-5-1) (Liu et al., 2003) and Zhengzhouzaohong (Muscat Hamburg × Pearl of Csaba) were released in the 1990s. In 2009, an early-maturing cultivar, Xiazhihong (Cardinal × Muscat Hamburg), was released (Liu et al., 2011). Its shape of cluster is conical, the mean weight is 750 g, the berry shape is round and the mean berry weight is 8.5 g. It has a fruit colour that is red to mauve, a Brix of 16.0–17.4 and a TA of 2.5–2.8 g/L. This grape cultivar has good yield, attractive appearance, high adaptability and good storage. It can be used in greenhouse cultivation as an early-season cultivar.

12.4.5 Grape breeding in East China

This region includes the provinces of Anhui, Fujian, Jiangsu, Jiangxi, Shandong and Zhejiang as well as the municipality of Shanghai. Because the Chinese government claims Taiwan and the few outlying islands of Fujian governed by the Republic of China (Taiwanese government) as its territory, China's pseudo-province 'Taiwan Province, People's Republic of China' is also classified in this region (Table 12.13).

12.4.5.1 Rootstock breeding from V. pseudoreticulata *in Shanghai*

Because phylloxera was not a concern in China, nurseries have mostly propagated cultivars from own-rooted cuttings. Rootstock breeding was largely ignored for a long time. However, in the last 10 years, Chinese viticulturists came to understand that resistant rootstocks not only address the problem of phylloxera, but also contribute to many aspects of viticulture by overcoming abiotic problems. Scientists turned their attention to Chinese wild species for rootstock breeding. In 1984, the Horticultural Research Institute of the Shanghai Academy of Agricultural Sciences crossed *Vitis pseudoreticulata* with Carignane, a European cultivar, from which a seedling was selected as rootstock and named as Huajia No. 8 in 1999. This was the first grape

Table 12.13 **Table grape cultivars released in East China**

Cultivars	Parentage	Unit	Year of cross	Year of release	References
Zaohong	Muscat Hamburg × Queen of the Vineyard	Shandong Vine and Winemaking Institute	1963	1978	Kong (2004)
Zaohuang	Muscat Hamburg × Queen of the Vineyard		1963	1978	Kong (2004)
Honglianzi	Muscat Hamburg × Queen of the Vineyard		1963	1978	Kong (2004)
Quanlongzhu	Muscat Hamburg × Queen of the Vineyard		1963	1978	Kong (2004)
Cuihong	Muscat Hamburg × Gold muscat		1964	1978	Kong (2004)
Hongxiangjiao	Muscat Hamburg × Gold muscat		1964	1978	Kong (2004)
Hongshuangwei	Queen of the Vineyard × Hongxiangjiao		1985	1994	Kong (2004)
Fengbao	Queen of the Vineyard × Hongxiangjiao		1985	1994	Kong (2004)
Heixiangjiao	Hongxiangjiao × Queen of the Vineyard		1985	1994	Kong (2004)
Hongyuni	Hongxiangjiao × Queen of the Vineyard		1985	1994	Kong (2004)
Guifeimeigui	Hongxiangjiao × Queen of the Vineyard		1985	1994	Kong (2004)
Feicuimeigui	Hongxiangjiao × Queen of the Vineyard		1985	1994	Kong (2004)
Shenxiu	Kyoho seedling	Shanghai Academy of Agricultural Science	1985	1996	Jin et al. (1996)
Shenbao	Kyoho seedling		1986	2008	Jiang et al. (2009)
Hupei No. 1	Himrod × Kyoho		1990	2006	Jiang et al. (2007)
Hupei No. 2	Youngeer × Zizhenxiang		1995	2007	Jiang et al. (2008)
Shenfeng	Jingya × Zizhenxiang		1995	2006	Jiang et al. (2007)
Shenhua	Jingya × 86-179		1995	2010	Jiang et al. (2011)
Shenyu	Fujiminoari × Honghou		1997	2011	Jiang et al. (2012)
Zexiang	Muscat Hamburg × Longyan	Hongshan Garden Pingdu city of Shandong Province	1956	1979	Kong (2004)
Zeyu	Muscat Hamburg × Longyan		1956	1979	Kong (2004)
Zaomeikang	Muscat Hamburg × Campbell Early	Jiangxi Agricultural University	1963		Fan and Zhang (1985)
Baimeikang	Muscat Hamburg × Campbell Early	Jiangxi Agricultural University	1963	1985	Fan and Zhang (1985)
Zimeikang	Muscat Hamburg × Campbell Early		1963	1985	Fan and Zhang (1985)
Meiyehei	Muscat Hamburg × *Vitis flexuosa* Thunb		1973	1985	Fan and Zhang (1985)

rootstock developed in China, and it has been used to a certain extent in southern China (Li and Jin, 1999). In recent years, grape rootstock breeding using Chinese native wild species as parents is being conducted at the Zhengzhou Institute of Pomology, the Northwest Agricultural University and the Beijing Botanical Garden.

12.4.5.2 Breeding for hot temperature and high humidity tolerance

In 1963, the Horticultural Department of Jiangxi Agricultural University selected Meiyehong and Meiyehei from a cross of Muscat Hamburg and *Vitis flexuosa*. These cultivars are adapted to hot and humid climate conditions. However, these selections are only preserved in research institutions (Table 12.13).

12.4.5.3 Table grape breeding

Shandong Grape and Wine Institute started grape breeding in 1963 and released several early-ripening grape cultivars in the 1970s (Table 12.13), including Zaohong, Zaohuang, Honglianzi and Quanlongzhu, which are all hybrids of Muscat Hamburg × Queen of the Vineyard, as well as Cuihong and Hongxiangjiao (both are selected from seedlings of Muscat Hamburg × Golden Muscat) (Kong, 2004). In 1990, the institute also released mid- to late-maturing grape cultivars Hongshuangwei and Fengbao (both Queen of the Vineyard × Hongxiangjiao) as well as Heixiangjiao, Hongyuni, Guifeimeigui and Feicuimeigui (all Hongxiangjiao × Queen of the Vineyard) (Kong, 2004).

Shanghai Academy of Agricultural Science started a grape-breeding programme in the 1980s and has released five new table grape cultivars thus far (Table 12.13). Shenxiu and Shenbao, developed from the Kyoho family, are early maturing with excellent quality and productive and stable yield (Jin et al., 1996; Jiang et al., 2009). Triploid cultivar Hupei No. 1 (Himrod × Kyoho) is mid- to early maturing, with strong aroma, disease resistance, and good storability (Jiang et al., 2007a). Another triploid cultivar, Hupei No. 2 (Youngeer × Zizhenxiang), is early maturing, with bright skin colour, and it is seedless (Jiang et al., 2008). Late-maturing Shenfeng (Jingya × Zizhenxiang) has high yields and strawberry flavour (Jiang et al., 2007b).

Hong Shan Horticulture Farm in Pingdu County, Shandong Province, made crosses in 1956 and released Zexiang and Zeyu (both from a cross of Muscat Hamburg × Longyan) (Kong, 2004, Table 12.13). Jiangxi Agricultural University started making crosses in 1963 and released Zaomeikang, Baimeikang and Zimeikang (all Muscat Hamburg × Campbell Early) as well as Meiyehei (Muscat Hamburg × *V. flexuosa*) (Fan et al., 1985, Table 12.13).

12.5 Conclusions and future trends

From the 1950s to the present, Chinese breeders have selected and released more than 200 grape cultivars and advanced lines (those have never been named as cultivars). More than 120 of these have been registered (protected with plant new cultivar rights), 82% of them are table grapes and 16% are wine grape cultivars (Tao et al., 2012)

(Figure 12.3, Figure 12.4). Overall, the objectives of table grape-breeding programmes focus on large berries, muscat flavour, firm texture, novel colours and shapes, early maturation and seedlessness. The objectives for wine grape breeding are cold hardiness and disease resistance by incorporating characteristics from the Chinese wild grapes.

Clonal selection, mutation breeding, open-pollination seedling selection, designed hybridization and embryo-rescue methods have all been used in various grape-breeding programmes. Among them, cross-pollination, the conventional approach of grape breeding, is the most widely used, and most Chinese cultivars are released by this approach. Hupei No. 1 and Hupei No. 2 were developed by using embryo-rescue technology (Jiang et al., 2007, 2008).

The most commonly used parents among the Chinese grape-breeding programmes in the last century are Muscat Hamburg, Queen of the Vineyard, Pearl of Csaba, Kyoho, Thompson Seedless and Black Monukka. In the meantime, Chinese wild grape species were also used in some programmes for improving the tolerance to biotic and abiotic stress. In general, the germplasm used in the Chinese grape-breeding programmes for decades is quite narrow, and not enough attention has been paid for using the Chinese wild grape species, especially for improving biotic and abiotic stress tolerances of current varieties. Future grape breeding in China should take advantage of these germplasm resources and expand the parentage base available around the world.

A conventional breeding approach that selects hybrids based mainly upon phenotypes is time-consuming, expensive, and low in efficiency. Using a marker-assisted selection strategy can accelerate the breeding cycle and improve selection efficiency. Chain Agricultural University and Northwest A&F University are now using the molecular breeding strategy to integrate the good fruit quality from *V. vinifera* grapes and the stress tolerance from the Chinese *Vitis* species.

Acknowledgements

This work was supported by the earmarked fund for Modern Agro-industry Technology Research System (CARS-30-yz-1 and CARS-30-yz-2).

References

NB. All but *Luo and Zhang (1990) and *He et al. (1990) were published in Chinese with English translation.

Chen, Hu, 2001. Excellent seedless raisin grape cultivar ‘Xinpu #3. Xin Jiang Agric. Sci. Technol. 3, 16.

Chen, Jun, Tang, Xiaoping, Li, Dengke, Ma, Xiaohe, Dong, Zhigang, 2001. ‘Zaoheibao’ an early-maturing, good quality and large berry grape variety. Acta Hortic. Sin. 28 (3), 277.

Chen, Jun, Tang, Xiaoping, Ma, Xiao-he, Zhao, Qifeng, Dong, Zhigang, 2009. Breeding report of a new early season seedless grape cultivar ‘Zaokangbao’. J. Fruit Sci. 26 (2), 258–259.

Chen, Jun, Tang, Xiaoping, Ma, Xiaohe, Zhao, Qifeng, Dong, Zhigang, 2011. An excellent mid-season seedless grape cultivar ‘Lihongbao’. Acta Hortic. Sin. 38 (3), 595–596.

Chen, Jun, Tang, Xiaoping, Ma, Xiaohe, Dong, Zhigang, Zhao, Qifeng, 2007. ‘Qiuhongbao’, a new mid-late ripening grape cultivar. J. Fruit Sci. 24 (6), 867–868.
Fan, Bangwen, Zhang, Putting, 1985. The characteristics and values of the three new grape strains selected by our university. Acta Agric. Univ. Jiangxiensis 25 (4), 27–32.
Fan, Pei ge, Li, S., Yang, M., Li, S., 2007a. Extremely late-ripening juice grape variety ‘Beixiang’. Acta Hortic. Sin. 34 (1), 259.
Fan, Peige, Li, S., Wang, L., Yang, M., Wu, B., Duan, H., Li, L.S., Zhong, Jingyi, Zhang, Y., Wen, L., Zhang, F., Luo, F., Li, S., 2010. Breeding of two new wine grape cultivars ‘Beihong’ and ‘Beimei’. China Fruits 4, 5–8.
Fan, Peige, Li, Shengchen, Yang, Meirong, Li, Shaohua, 2006. Late-ripening juice grape cultivar ‘Beizi’. Acta Hortic. Sin. 33 (6), 1404.
Fan, Peige, Li, Shengchen, Yang, Meirong, Li, Shaohua, 2007b. Late-ripening juice grape variety ‘Beifeng’. Acta Hortic. Sin. 34 (2), 527.
Fan, P., Wang, Lijun, Wu, Benhong, Duan, Wei, Yang, Meirong, Li, Shaohua, 2012. An early-ripening, red and muscat flavor table grape cultivar ‘Jingyan’. Acta Hortic. Sin. 39 (6), 1199–1200.
Fan, Peige, Yang, Meirong, Zhang, Yingzhu, Li, Shengchen, 2004a. A new early-ripening grape cultivar ‘Jingyou’. Acta Hortic. Sin. 31 (1), 130.
Fan, Peige, Yang, Meirong, Zhang, Yingzhu, Li, Shengchen, 2004b. Early-ripening seedless grape ‘Jingzaojing’. Acta Hortic. Sin. 31 (3), 415.
Fan, Peige, Yang, Meirong, Wang, Lijun, Li, Shengchen, Wu, Benhong, Li, Liansheng, Li, Shaohua, 2008a. A new early-ripening grape cultivar ‘Jingcui’. Acta Hortic. Sin. 35 (10), 1552.
Fan, Peige, Yang, meirong, Wang, Lijun, Li, Shengchen, Wu, Benhong, Li, Liansheng, Li, Shaohua, 2008b. An early-ripening table grape cultivar ‘Jingxiangyu’. Acta Hortic. Sin. 35 (12), 1850.
Fan, Peige, Yang, Meirong, Wang, Lijun, Li, Shengchen, Wu, Benhong, Li, Liansheng, Li, Shaohua, 2008c. A very early-ripening table grape cultivar ‘Jingmi’. Acta Hortic. Sin. 35 (11), 1710.
Fang, Yaolan, He, Ning, Liu, Surong, Jia, Zhifu, Wen, Jinghui, 1993. Breeding of a new wine grape cultivar ‘Gongzhubai’. J. Vitic. Enol. 3, 010.
Gao, Yanyi, Hou, Boping, Wang, Falin, Hao, Yan, 2001. Breeding of a grape variety ‘Zuirenxiang’. Gan Su Agric. Sci. Technol. 1, 015.
Hao, Rui, 1982. Wild fruit tree resources in Changbai Mountain. Acta Hortic. Sin. 9 (3), 9–16.
Hao, Yan, Li, Hongxu, Yang, Rui, Wang, Hong, Wang, Yuan, Gao, Yanyi, Wang, Falin, 2011. A new table grape cultivar ‘Zuirenxiang’. J. Fruit Sci. 28 (5), 938–939.
*He, Ning, Fang, Yaolan, Liu, Shurong, 1990. Grape breeding for cold resistance in North China for 30 years. Vitis, special issue of Grape Breeding in China. In: Proceedings of the International Symposium on Grape Breeding, pp. 329–332.
He, Ning, Fang, Yaolan, Liu, Surng, Chen, Hongmao, Wen, Jinghui, Jia, Zhikuan, 1989. A new grape variety ‘Tianfeng’. Vitic. Enol. 3, 5–7.
He, Ning, Zhao, Baozhang, Fang, Yufeng, Fang, Yaolan, Liu, Shurong, 1981. The inheritance of some characteristics in interspecific hybrid of grape, with special reference to cold resistance. Acta Hortic. Sin. 8 (1), 18.
He, Puchao, He, Chuncheng, 2003. A new grape cultivar ‘Zao Jinxiang’. Grape Res. Pap. 5 (1), 32.
Hu, Ruobing, Wang, Faming, 1986. The investigation and utilization of Shandong wild grape resources. Vitic. Enol. 1, 1–9.
Hu, Xianxiao, 1956. Learn how to use plant resources in China from Michurin. Chin. Sci. Bull. 8, 18–34.
Huang, Fengzhu, Peng, Hongxiang, Zhu, Huajian, Zhang, Ying, Xu, Ning, Li, Hongli, 2006. A new wine grape cultivar ‘Ling You’. Fruit Growers’ Friend 9, 12.

Huang, Honghui, Peng, Hongxiang, Zhu, Jianhua, 2003. Wine grape production status and development of wild grape in Du'an County. Guangxi Agric. Sci. 2, 4–5.

Huang, Puchun, Xiu, Jingchang, Zhang, Hui, 1994. The breeding of 'Shuangyou', a new perfect flower variety of *V. amurensis*. Vitic. Enol. 4, 51–53.

Huang, Puchun, Xiu, Jingchnag, Guo, Xiangui, Li, Chenghong, Guo, Zhengui, Qian, Youwei, Zhang, Hui, 1998. Hermaphrodite flower *V. amurensis* variety 'Shuangyou'. J. Jilin Agric. Univ. 10 (4), 31–33.

Jiang, Aili, Cheng, Jieshan, Li, Shicheng, Zhang, Chaoxuan, Jin, Peifang, Xi, Xiaojun, 2011. Breeding report of a new grape cultivar 'Shenhua'. J. Fruit Sci. 28 (5), 936–937.

Jiang, Aili, Cheng, Jieshan, Xi, Xiaojun, Li, Shicheng, Jin, Peifang, 2012. A new table grape cultivar 'Shenyu'. J. Fruit Sci. 29 (3), 516–517.

Jiang, Aili, Li, Shicheng, Jin, Peifang, Yang, Tianyi, Luo, Jun, 2007a. 'Hupei 1'— a new triploid seedless grape cultivar obtained by embryo culture. J. Fruit Sci. 24 (3), 402–403.

Jiang, Aili, Li, Shicheng, Yang, Tianyi, Jin, Peifang, Luo, Jun, 2007b. A new tetraploid grape cultivar 'Shenfeng'. Acta Hortic. Sin. 34 (4), 1063.

Jiang, Aili, Li, Shicheng, Yang, Tianyi, Luo, Jun, Zhang, Chaoxuan, Jin, Peifang, 2008. A new seedless grape cultivar—'Hupei No.2'. J. Fruit Sci. 25 (4), 618–619.

Jiang, Aili, Li, Shicheng, Yang, Tianyi, Jin, Peifang, Zhang, Chaoxuan, 2009. 'Shenbao' a new table grape cultivar. J. Fruit Sci. 26 (6), 922–923.

Jin, Guihua, Zhang, Liming, Zhao, Kuihua, Yang, Guang, Wang, Pengfei, 2007. A midseason grape variety 'Zhunagyuanhong'. China Fruits 5, 1–3.

Jin, Peifang, Li, Shicheng, Jiang, Aili, Luo, Jun, Shan, Chuanlun, 1996. The breeding of grape variety 'Shenxiu'. Grape Cultiv. Enol. 4, 12–15.

Kong, Qingshan, 1986. Chinese wild germplasm resources of Vitis. In: Sino-west Germany Workshop on Grape, Landau/pflaz, West Germany.

Kong, Qingshan (Chief Editor), 2004. Chinese Ampelography. China Agricultural Scientific and Technical Press, Beijing.

Li, Chaoluan, 1998. The Chinese Flora (Vol. 48(2), Vitaceae). Science Press, Beijing.

Li, Enbiao, Chen, Dian-Yuan, Wang, Shuxian, Li, Weiqing, Ning, Sheng, 2008. A new grape cultivar 'Bixiang Wuhe'. Acta Hortic. Sin. 35 (4), 619.

Li, Jianyi, Li, Xianjun, Yang, Guohua, 1985. An elite grape variety 'Zifeng'. Liaoning Fruits 1, 38–40.

Li, Shengchen, Wen, Lizhu, Zhang, Fengqin, Fangmei, Yang, Meirong, Zhang, Yingzhu, Huang, Depan, 1983. A new grape variety 'Beichun' for cold tolerance. Bot. Bull. 1 (2), 28–30.

Li, Shicheng, Jin, Peifang, 1999. A new grape rootstock variety 'Huajia No.8'. Vitic. Enol. 4, 1–5.

Li, Yiyuan, Tong, Shumei, Liu, Yapin, 1987. New table grape cultivars 'Zaomanao', 'Zizhenzhu', 'Cuiyu' and 'Yanhong'. Acta Agric. Boreali-Sin. 2 (3), 90–98.

Liao, Feixiong, 1988a. Utilization of *vitis* in jiangxi province. Treatise China Grape Meet. 112–115.

Liao, Zhengxiong, 1988b. Utilization of *vitis* resources in guangxi region. In: The Treatise of National Grape Meeting, Zhengzhou, Henan Province.

Lin, Peijun, 1998. Investigation on the Wild Fruit Resources of Tianshan Mountain in Xingjiang Region. Forestry Press, Beijing.

Lin, Xinggui, Sun, Kejuan, Shen, Yujie, 1991. A new *Amurensis*-type variety 'Zuoshan No.2'. Acta Hortic. Sin. 18 (3), 281–283.

Lin, Xinggui, Yi, Lizhai, Shen, Yujie, 1993. Characteristic inheritance of intraspecific cross in *V. amurensis*. Acta Hortic. Sin. 20 (3), 231–236.

Lin, Xinggui, 1982. The discovery and utilization of perfect flower resources of *V. amurensis*. Crops Genet. Resour. 2, 36–37.

Liu, Sanjun, Kuai, Chuanhua, Yu, Qiaoli, Liu, Chonghuai, Gu, Hong, Chen, Yongpeng, Xiazhi, Hong, 2011. A new early ripening grape cultivar. J. Fruit Sci. 28 (2), 367–368.

Liu, Sanjun, Zhang, Qiuye, Kuai, Chuanhua, 2003. An early season grape variety 'Zhengzhou Zaoyu'. Fruit Growers' Friend 6, 6.

Lu, Wenpeng, Wang, Jun, Song, Rungang, Zhang, Yafeng, Shen, Yujie, Guo, Zhengui, Liu, Zhonghe, Liu, Jingkuan, 2000. Breeding research for cold resistant grape variety of 'Zuohong No.1'. Sino-Overseas Grapevine Wine 1, 13–14.

*Luo, Fangmei, Zhang, F., 1990. Grape breeding in China. *Vitis*, special issue. In: Proceedings of the International Symposium on Grape Breeding, pp. 212–216.

Luo, Guogunag, 2011. Research and utilization of grape in Russia and the former Soviet Union. Sino-Overseas Grapevine Wine 5, 74–76.

Luo, Qiangwei, Li, Xuewen, Cai, Junshe, 1997. Xinpu No.1' a new large grain, high-quality, storage and transportation grape cultivar. Turpan Technol. 1, 14–15.

Luo, Qiangwei, Sun, Feng, Cai, Junshe, Geng, Xinli, Rebi, Guli, 2007. A new grape cultivar 'Xinyu'. Acta Hortic. Sin. 34 (3), 797.

Ma, Xiaohe, Tang, Xiaoping, Chen, Jun, Zhao, Qifeng, Dong, Zhigang, 2010. A new good quality and mid-maturing grape cultivar 'Qiuheibao'. Acta Hortic. Sin. 37 (11), 1875–1876.

Miao, Pingsheng, Chen, Yeguang, Li, Changfa, Chen, Xingchang, Wang, Dingrong, 1999. Investigation and utilization of wild grape resources in Hainan Province. Fujian Fruits 4, 25–27.

Ouyang, Shouru, Guo, Yaying, Chen, Jun, Li, Taibao, Wang, Kemin, Guan, Shuyu, 1989. Breeding of table grape cultivar 'Guibao'. Shanxi Fruits 1, 2–5.

Pu, Fushen, 1960. Breeding new fruit varieties in China under the guidance of Michurinism. Bull. Biol. 4, 168–171.

Qiu, Baolin, 1990. Three new species of *Vitis* in Zhejiang Province. Plant Res. 10 (3), 39–43.

Qiu, Baolin, 1992. Searches for table grape plant in Zhejiang Province. Comm. Hangzhou Bot. Garden 2, 1–3.

Rong, Xinmin, Sun, Guixiang, Zhang, Shangjia, 2004. A new seedless grape 'Zixiang Wuhe'. Sino-Overseas Grapevine Wine 4, 41–42.

Shan, Zhenfu, Zhao, Baili, Zhao, Pucang, Zhang, Liping, Xu, Lili, Liu, Zhihua, Ma, Danlin, Liu, Yan, Xing, Guojin, Lin, Ming, 2011. Breeding of a new *V. amurensis* grape cultivar 'Mushan No.1'. China Fruits 1, 003.

Shen, Xiansheng, 1989. A new species of *Vitis*. Acta Phytotaxon. Sin. 27 (4), 304–305.

Shi, Limin, 1995. Investigation on wild fruit genetic resources of Liupanshan Mountain. J. Pomol. 12 (3), 194–197.

Shi, Xuehui, Yang, Guoshun, Ni, Jianjun, Liu, Kunyu, Zhong, Xiaohong, Xiong, Xingyao, 2008. A new type of *Vitis davidii* Foëx. Grape– 'Shuijing Grape' and its biological characteristics. Sino-Overseas Grapevine Wine 5, 22–24.

Sun, Hua, 1979. Fruit germplasm resources in China. J. Northwest Agric. Coll. 2, 1–18.

Song, Rungang, Li, Wei, 1998. A new cultivar of *Vitis amurensis* Rupr—'Shuanghong'. China Fruits 4, 5–7.

Song, Rungang, Lu, Wenpeng, Guo, Taijun, Liu, Jingkuan, Shen, Yujie, Lin, Xinggui, Li, Xiaohong, Guo, Zhengui, 2005. A new dry-red wine grape variety 'Zuoyouhong'. Acta Hortic. Sin. 32 (4), 757.

Song, Rungang, Lu, Wenpeng, Shen, Yujie, Jin, Renhao, Li, Xiaohong, Guo, Zhengui, Liu, Jingkuan, Lin, Xinggui, 2008. New ice-red wine grape cultivar 'Beibinghong'. Acta Hortic. Sin. 35 (7), 085.

Song, Rungang, Lu, Wenpeng, Wang, Jun, Shen, Yujie, Lin, Xinggui, Ge, Yuxiang, Li, Xiaohong, Sun, Kejuan, 1999. Review and prospect of *V. amurensis* varieties breeding. North. Hortic. 36–38.

Song, Rungang, Lu, Wenpeng, Zhang, Qingtian, Li, Xiaohong, Yang, Yiming, Fan, Shutian, Ai, Jun, Shen, Yujie, Lin, Xinggui, 2012. Breeding of a new wine grape cultivar of *V. amurensis* Rupr 'Xuelanhong'. China Fruits 5, 1–5.

Tang, Shumei, Li, Yiyuan, Xu, Haiying, 1992. New grape variety 'Aishenmeigui' and 'Zaomeiguixiang'. China Fruits 1, 5–6.

Tang, Xiaoping, Chen, Jun, Ma, Xiaohe, Zhao, Qifeng, Dong, Zhigang, LI, Xiaomei, 2012. A new early-ripening seedless grape cultivar 'Wuhe Cuibao'. Acta Hortic. Sin. 39 (11), 2307–2308.

Tao, Ran, Wang, Chen, Fang, Jinggui, Shang, Guanlingfei, Leng, Xiangpeng, Zhang, Yanping, 2012. General situation of grape breeding research in China. Acta Agric. Jiangxi 24 (6), 24–30.

Wang, Desheng, 1999. A grape variety 'Zuijinxiang'. Chinese Native Produce 4, 28.

Wang, Desheng, 2000. A grape variety 'Xiyanghong'. China Seeds 1, 37.

Wang, Haibo, Xiu, Deren, Wang, Bao-liang, Wang, Xiao-di, Wei, Chang-cun, He, Jin-xing, Zheng, Xiaocui, Liu, Wanchun, Liu, Fengzhi, 2012a. A new wine and rootstock grape cultivar 'Huapu No.1'. Acta Hortic. Sin. 39 (11), 2309–2311.

Wang, Jun, Zong, Rungang, Yin, Lirong, Sun, Kejuan, Lin, Xinggui, Feng', Shuang, 1996. A new hermaphrodite cultivar of *V. amurensiss* Rupr. Acta Hortic. Sin. 23 (2), 207.

Wang, Na, Qin, Ziyu, LI, Shaoxing, Luo, Shuxiang, Liu, Jun, Xiang, Dianfang, 2012b. A late-ripening grape cultivar 'Jintian Feicui'. Acta Hortic. Sin. 39 (3), 593–594.

Wang, Na, Xiang, Dianfang, Qin, Ziyu, Li, Shaoxing, Luo, Shuxiang, Liu, Jun, 2012c. A late-ripening grape cultivar 'Jintian Meizhi'. Acta Hortic. Sin. 39 (4), 801–802.

Wang, Suiyi, 1978. Studies on wild fruit resources in Henan Province. Henan Acad. Agric. For. Sci. 1, 15–22.

Wang, Wencai, 1980. The progress in taxonomic studies of *Vitis*. Acta Phytotaxon. Sin. 18, 3.

Wang, Wencai, 1988. Notulae de Vitaceis guangxi Ensibus. Plant Guangxi 8 (2), 109–119.

Wang, Yuejin, 1993. Fruit quality and utilization of *V. quiquangularis*. Spec. Wild Econ. Anim. Plant Res. 2, 15–17.

Wang, Yuhuan, Jiang, Pinxue, Wang, Guihua, Zong, Lirong, 2003. A new grape variety - 'Jumeigui'. China Fruits 1, 3–6.

Wei, Wenna, Wang, Qirong, Li, Runtang, 1991. Investigation on wild grape resources of Hunan Province. Bull. Hunan Agric. Univ. 17 (3), 447–450.

Wen, Shanglin, Hou, Boping, Wu, Gang, 1989. Investigation on wild grape resources in Gansu Province. J. Pomol. Tree 6 (3), 11–14.

Wu, Jinjing, Zhou, Shengxue, Qi, Shiying, 1989. Breeding report of an early ripening and large berry variety 'Fenghuang No.51'. Shanxi Fruits 2, 2–3.

Xiang, Dianfang, Li, Shaoxing, Zhang, Menghong, Liu, Jun, Wang, Na, Wang, Xuedong, Luo, Shuxiang, Qi, Huixia, Geng, Xuegang, 2008a. A new grape cultivar 'Jintianmi'. Acta Hortic. Sin. 35 (7), 1086.

Xiang, Dianfang, Li, Shaoxing, Zhang, Menghong, Liu, Jun, Wang, Na, Wang, Xuedong, Luo, Shuxiang, Qi, Huixia1, Geng, Xuegang, 2008b. A new grape cultivar 'Jintian Meigui'. Acta Hortic. Sin. 35 (6), 926.

Xiang, Dian-fang, Li, Shao-xing, Zhang, Meng-hong, Liu, Jun, Wang, Na, Wang, Xue-dong, Luo, Shu-xiang, Qi, Huixia, Geng, Xuegang, 2008c. A late-ripening grape cultivar 'Jingtian 0608'. Acta Hortic. Sin. 35 (7), 1242.

Xiang, Dianfang, Li, Zhaoxing, Wang, Na, Liu, Jun, 2010. Breeding of a new late ripening seedless grape cultivar 'Jintian Huangjia Wuhe'. China Fruits 1, 4–5.

Xiong, Xingyao, Wang, Rencai, Sun, Wuji, Li, Zhiqing, Ouyang, Jianwen, Li, Guiyong, Liu, Dongbo, 2006. A new cultivar of *V. davidii* 'Ziqiu'. Acta Hortic. Sin. 33 (5), 1165.

Xu, Guizhen, Chen, Jinglong, Zhang, Liming, 2003. A new grape cultivar 'Xiangyue'. China Fruits 6, 24–25.

Xu, Guizhen, Chen, Jinglong, Zhang, Liming, Fu, Bo, 1992. An early ripening and high quality new variety 'Zizhenxiang'. China Fruits 3, 4–5.

Xu, Guizhen, Chen, Jinglong, 1994a. A new large berry, long shelf life and late –ripening grape cultivar—'Xiyanghong'. China Fruits 1, 4–5.

Xu, Guizhen, Chen, Jinglong, 1994b. A new *vinifera-labrusca* hybrid variety 'Guixiangyi'. Sino-Overseas Grapevine Wine 4, 43–44.

Xu, Haiying, Liu, Jun, Liu, Huazhi, Yie, Jinwei, Zhang, Guojun, 2000. 'Fenghou'- a grape variety of good quality and large berry. Acta Hortic. Sin. 27 (2), 153.

Xu, Haiying, Liu, Jun, 1994. The very early and early varieties 'Aishenmeigui' and 'Zaomeiguixiang'. Beijing Agric. Sci. 12 (5), 42.

Xu, Haiying, Zhang, Guojun, Yan, Ailing, Liu, Jun, 2001. 'Xiangfei'- a new early ripening grape variety. Acta Hortic. Sin. 28 (4), 375.

Xu, Haiying, Zhang, Guojun, Yan, Ailing, Sun, Lei, 2011. A new seedless grape cultivar 'Ruidu Wuheyi'. Acta Hortic. Sin. 38 (3), 593–594.

Xu, Haiying, Zhang, Guojun, Yan, Ailing, 2008. A new early-maturing grape cultivar 'Ruidu Cuixia'. Acta Hortic. Sin. 35 (11), 1709.

Xu, Haiying, Zhang, Guojun, Yan, Ailing, 2009. A new early muturity grape cultivar 'Ruidu Xiangyu'. Acta Hortic. Sin. 36 (6), 929.

Yang, Jinghui, Wu, Deling, 1959. Cold hardy grape breeding in China. China Fruits 3, 22–24.

Yang, Lizhu, Wang, Baiqiu, Wang, Nini, 2012. 'Zhuosexiang' grape variety. North. Fruits 2, 21–22.

Yang, Meirong, Fan, Peige, Zhang, Yingzhu, Li, Shengchen, 2003. Early-ripening grape 'Jingxiu'. Acta Hortic. Sin. 30 (1), 117.

Yang, Meirong, 1990. A new grape variety 'Jingya'. Plant J. 6, 9.

Yu, Dejun, 1959. Development of botanical garden industry in our country in ten years. Bull. Biol. 10, 449–455.

Yu, Zhengjin, 1994. The wild grape resources and its utilization in Hunan Province. Vitic. Enol. 2, 15–19.

Zhang, J.L., Ma, J.F., Cao, Z.Y., 2009. Screening of cold-resistant seedlings as rootstocks from a chinese wild grape (*Vitis piasezki*i Maxim var. *pagnucii*) native to loess plateau of eastern Gansu Province, China. Sci. Hortic. 122, 125–128.

Zhang, Liming, Jin, Guihua, Zhao, Kuihua, Liu, Changyuan, Miao, Zeyan, Liang, Chunhao, Chen, Xu, Xu, Guizhen, Chen, Jingrong, Wang, Pengfei, 2006. Breeding of a new tetraploid variety 'Xiangyue'. Liaoning Agric. Sci. 2, 88–89.

Zhang, Puting, Fan, Bangwen, 1985. 'Tangwei Grape', a bisexual variety of *V. davidii*. China Fruit 3, 32–34.

Zhang, Putting, Luo, Jiaxin, He, Kaiye, 1989. The discovery and study of the *V. davidii* 'Xuefeng'. Hunan Agric. Sci. 6, 27–28.

Zhang, Weichang, 1987. Breeding report on grape cultivar 'Xiongyuebai'. Sino-Overseas Grapevine Wine 4, 1.

Zhao, Shengjian, Guo, Zijuan, Zhao, Shuyun, Zhang, Xinzhong, Zhou, Licun, 2003. A new triploid table grape cultivar 'Hongbiao Seedless'. Acta Hortic. Sin. 30 (6), 758.

Zhao, Shengjian, Guo, Zijuan, Zhao, Shuyun, Zhou, Licun, 2000. A new triploid grape variety 'Wuhezaohon'. Acta Hortic. Sin. 27 (2), 155.

Zhou, Jinsong, Guo, Shuxian, 1995. Wild fruit trees resources in Qinghai Province. J. Pomol. 12 (s), 149–152.

Zhou, Zhide, Fang, Deqiu, 1986. Investigation on wild grape resources in Meiling Mountain of Jiangxi Province. Acta Agric. Univ. Jiangxiensis 8 (2), 37–42.

Zhu, Jianhua, Peng, Hong-xiang, Zhang, Ying, Huang, Fengzhu, Lin, Mingjuan, Li, Hongli, 2006. Existing problems and strategy of *Vitis quinquangularis* Rehd. Production in Guangxi. Agric. Sci. 37 (1), 78–80.

Zong, Lirong, Ma, Haifeng, Xu, Mingyi, 2009a. Preliminary study on breeding of 'Honey Red' grapes. Mod. Agric. Sci. 16 (1), 74–75.

Zong, Lirong, Ma, Haifeng, Xu, Mingyi, 2009b. The breeding and cultivation of 'Heiguixiang'. Sino-Overseas Grapevine Wine 5, 40–41.

Zuo, Daxun, Yuan, Yiwei, 1981. The geographical distribution and utilization of *Vitis* L. In: China. Bull. Nanjing Botanical Garden. Jiangsu Scientific and Technical Press, Nanjing, pp. 25–31.

Grapevine breeding in Canada

13

A.G. Reynolds[1], *K.H. Fisher*[2], *A. Jamieson*[3]
[1]Brock University, St Catharines, ON, Canada; [2]University of Guelph, Guelph, OM, Canada; [3]Agriculture and Agri-Food Canada Research Station, Kentville, NS, Canada

13.1 Grape breeding in Ontario

It is widely accepted that grape growing for winemaking purposes began in Ontario in the early nineteenth century. It is assumed that cultivars used for winemaking during this time were either native *Vitis riparia* or perhaps naturally occurring hybrids of *V. riparia*, *V. labrusca* and *V. vinifera*. Catawba was introduced in 1823, followed by Concord in 1852, and this was followed by Delaware (1856), Elvira (1874), Niagara (1882) and many hundreds of others (Hedrick, 1908). With the proliferation of much new material on the market and various unscrupulous nurseries selling old as new, the Ontario Department of Agriculture (ODA) Fruit Branch established a series of volunteer experimental plots across the province of Ontario in 1895 under the guidance of Professor Hutt of the University of Toronto Ontario Agriculture School located at Guelph. These plots were to test new cultivars of fruit for trueness-to-type and general performance. Mr Linus Wolverton, then secretary of the Ontario Fruit Growers' Association, became the unofficial scribe for this work, and ODA published *The Fruits of Ontario* in 1905 as a summary of the fruit cultivars recommended for the province (Ontario Department of Agriculture, 1914). The recommended grapes included a short list of 15 suitable for the southern and central regions of the province, and with one exception, all U.S. cultivars and all with some shortcomings (Table 13.1).

As a result of this unsatisfactory and incomplete guide for the local industry, fruit breeding programmes were introduced at the now consolidated fruit testing station developed in 1906 at Jordan Harbour, Ontario, adjacent to the present village of Vineland Station. Eventually this was re-named the Horticultural Research Institute of Ontario (HRIO). In particular, a grape-breeding programme was established by the ODA Fruit Branch in 1913 under the leadership of Jacobus van Haarlem (Palmer, 2006).

The goals at this early stage were to improve the shipping quality of the fresh market grapes since the growing western market (by train to Winnipeg and beyond in the new prairies) and the existing British market were proving quite lucrative with the development of artificial ice-making. These early breeding efforts were largely open-pollinated seedlings, sown outdoors in the fall after harvest, and the survivors transplanted to test fields adjacent to Lake Ontario. Although ample seedlings were tested in this manner, very little progress was made in the next 20 years beyond the existing mother vines of the parents selected. The genetic base for this work was not very broad because the mother vines were nearly all *V. labrusca* selections from the Great Lakes regions on both sides of the border. Although many of the Rogers' hybrids (*V. labrusca* × *V. vinifera*) were used as

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00013-2

Table 13.1 Cultivars recommended for planting in Ontario (Ontario Department of Agriculture, 2014)

Cultivar	Region	Origin	Colour	Use
Agawam	Southern ON	Roger's hybrid 15 E.S. Rogers, Salem, MA	Red	Dessert
Brighton	Central/Northern ON	Jacob Moore, Brighton, NY	Red	Dessert
Campbell	Southern ON	G.H. Campbell, 1896	Black	Dessert
Champion	Central/Northern ON	aka Talman's seedling, 1873	Black	Dessert
Concord	Southern ON	E.W. Bull, Concord, MA, 1853	Black	Dessert, juice
Delaware	Southern ON	Unknown, Frenchtown, NJ, 1855	Red	Dessert
Diamond	Southern ON	Jacob Moore, Brighton, NY, 1873	White	Dessert
Lindley	Southern ON	Rogers' hybrid 9 E.S. Rogers, Salem, MA	Red	Dessert
Moore	Southern ON	J.B. Moore, Concord, MA, 1872	Black	Dessert
Moyer	Central/Northern ON	W.N. Read, Pt. Dalhousie, ON	Red	Dessert
Niagara	Southern ON	C.L. Hoag, Lockport, NY	White	Dessert
Vergennes	Southern ON	Vergennes, VT, 1880	Red	Dessert, wine
Wilder	Southern ON	Rogers' 4 E.S. Rogers, Salem, MA	Black	Dessert
Winchell	Central/Northern ON	aka 'Green Mountain' A. Winchell, Green Mountain, VT	White	Dessert
Worden	Southern ON	S. Worden, Minnatoo, NY	Black	Dessert

seed parents, they were frequently female and subsequent populations were 50% female; therefore, they needed pollinators to be commercially useful. This was a recognized weakness of many of the good-quality Rogers' hybrids from the previous century. By the late 1920s, van Haarlem was emasculating the seed parents and using applied pollen for the crosses, but the genetic base was similar and still little progress was made.

In 1938, the breeding programme was invigorated by the appointment of Oliver A. Bradt (1913–2004), who oversaw the programme until his retirement in 1978. K. Helen Fisher oversaw the breeding programme from 1978 to 2012.

During much of this period, the wine industry in Ontario consisted primarily of Concord, Niagara, Delaware, Elvira, Agawam and other *V. labrusca*-based cultivars (de Chaunac, 1952). These cultivars were used for dessert wines in addition to non-varietal semi-dry table wines. By the late 1940s, French–American hybrids were planted in small quantities, but it was 20 years before these cultivars were widely available as varietal wines. Small acreages of *V. vinifera* were also established. The HRIO programme's breeding objectives evolved toward producing hardy, productive non-labrusca-flavoured selections that could be used for dessert wines, non-varietal table wines, and varietal wines. Over time, specific objectives included selection for muscat flavour, increasing anthocyanin content and identifying winter-hardy selections that might allow industry expansion into non-traditional zones.

Bradt first broadened the scope of the breeding material by accessing the French–American hybrids from Europe. The first examples of these, Seibel 1000 (Rosette) and several others, were imported by the New York State Agriculture Experiment Station in Geneva, NY in the early years of the twentieth century. These hybrids were productive and relatively tolerant of disease and pest, considering that most had a substantial percentage of *V. vinifera* in their bloodlines. They were collectively the result of the French nursery industry's response to the devastating epidemics of North American pests and diseases that almost wiped out the commercial wine industry in Western Europe in the late nineteenth century. Bradt had observed some of these hybrids in Geneva and received permission from the Canadian government to deal with France in 1947 and purchase a large collection of these hybrids from many of the prominent breeders (Bertille-Seyve, Galibert, Galibert-Coulondre, Joannes Seyve, Seibel and Seyve-Villard). Although Adhemar de Chaunac, winemaker at T.G. Bright and Company, subsequently Bright's Wines of Niagara Falls, Ontario, also imported a collection at the same time, their purpose was for direct field testing for their growers and company vineyards and not breeding new cultivars.

This importation of almost 100 selections with a very mixed lineage dramatically changed the direction of the breeding programme at Vineland. From largely *V. labruscana* parentage, with small injections of *V. vinifera* (Rogers' hybrids) and *V. riparia* (Clinton and Elvira), the breeding material now included hybrids of many North American species, with *V. labruscana* being noticeably absent. The French breeders had consciously selected against the flavour traits of *V. labrusca* because of its unsuitability for table wines, their main product. They used *V. riparia*, *V. rupestris*, *V. lincecumii*, *V. berlandieri*, *V. champinii*, *V. aestivalis*, *V. cinerea* and possibly other natural hybrids on the basis of their purported phylloxera and fungal disease resistance. In Ontario, before the importation of this material, *V. labruscana* was really the only species of influence in the industry and the main products – fresh-market grapes, juice and wine – were all labrusca-flavoured. With the increase in European immigration after the end of World War II, and the return of many armed forces personnel from the European theatre, tastes had changed and labrusca flavours were no longer unconditionally accepted in the wine trade.

With this new material from France and the knowledge that pure *V. vinifera* cultivars struggled with Ontario winters and pests, these mixed hybrids were a logical source of the wine traits desired by this new wave of population. Bradt was still conservative in his thinking and initially crossed *V. labruscana* cultivars with these French hybrids to retain good winter hardiness and better disease resistance. Direct field tests for these hybrids conducted by ODA/HRIO/Vineland and the six local wineries showed considerable winter injury when these hybrids were grown in the manner of the *V. labruscana* cultivars that preceded them. Although this disappointed Bradt and the local wineries, tests with new management techniques (mainly flower cluster thinning and more rigorous spraying regimes) convinced the wineries and the growers that these new selections had a future in the industry and would satisfy the demand for non-*V. labruscana* dry table wines. For the new ODA/HRIO hybrids to surpass the value of the now-established French hybrids, Bradt selected new material for superior disease resistance and better balance with respect to yield and vine vigour to reduce management input costs.

The first successful selections from this programme were Vincent, bred in 1949; Ventura, bred in 1951; and Veeblanc, bred in 1953. Of these three, Vincent had superior stable colour compared with the traditional *V. labruscana* cultivars and a better flavour profile, Ventura had superior winter hardiness but was reminiscent of *V. riparia* flavours and Veeblanc had a neutral flavour and better cropping balance than most of the large clustered French hybrids.

With the increase in interest from the wineries in this new material, Bradt's crossing strategy changed to more complex intercrosses between successful selections within his own programme, much as the French breeders, particularly Seibel, had done as their programmes progressed. Flavour profiles became the main selection criteria, after successful overwintering and minimal disease evidence. The building of the Horticultural Products Laboratory and the hiring of Dr A. Adams, Mr R. Crowther in 1953 and later Dr T. Fuleki (1968) and Dr R.V. Chudyk, created a very cohesive team that investigated appropriate yeast technology, annual winemaking, detailed flavour/colour profile analysis and commercial winery application of these new selections, respectively. This concentration of oenology support for the wine-breeding programme allowed Bradt to make very rapid progress with the confidence of the local wine industry.

To further this concentrated approach to wine grape breeding, annual wine tastings were held with industry (wineries), government (ODA, Liquor Control Board of Ontario) and other researchers, namely the oenology and viticulture group from the New York Agricultural Experiment Station at Geneva as well as other representatives of the northeastern U.S. wine industry. This international exchange was very productive, with active exchange of plant material between Ontario and New York, Arkansas, Illinois, North Carolina, Florida, Virginia and Maryland. Naming of advanced selections was rapidly followed by extensive plantings of the various cultivars in commercial vineyards because of the promotion by the individual local wineries to their own growers (Figure 13.1).

In the 1960s and 1970s, Bradt made more effort to concentrate on specific traits requested by the wineries, being good stable colour for red wines, clean, non-labrusca flavours for all wines, but with some interest in Muscats. At this time, Dr Fuleki developed the Vineland Grape Flavour Index that was based on concentrations of methyl anthranilate and volatile esters in the fruit for identifying threshold levels of labrusca flavours to act as a screening tool for the breeding materials at the winemaking stage. This test was used not only on the selections being made for wine but also on the parents

Figure 13.1 An example of cultivars and selections released from the Horticultural Research Institute of Ontario grape breeding programme: (a–j) wine grapes and (k–p) table grapes. Photo credits: A. Reynolds.

as probable source. Dr Chudyk performed an analysis of all of the breeding parents and families and recommended the elimination of parents with high probability of transmitting labrusca flavour profiles to their offspring. A project was also initiated aimed at elucidating the inheritance of methyl anthranilate (Reynolds et al., 1982). This advanced the Bradt breeding lines another step toward acceptability within the wine industry.

At this time, another member of the research team, Dr J. Wiebe, recommended large-scale trials, with the growers, of several advanced selections. These would be planted as a block at each of many sites and observed collectively by research and winery field staff. This would further advance the acceptance, through well-designed field tests, of the newest selections from the breeding programme. Ten white selections (neutral whites were the need at this time) were propagated up and sent out to various growers who volunteered. These tests accelerated the naming of Ventura in 1974 and Veeblanc in 1977. Vivant, also part of this large trial, was later named in 1983.

With the retirement of Mr Bradt in 1978, Dr Helen Fisher became the grape breeder at the HRIO/Vineland Station. The industry was changing very rapidly at this point and new priorities were being developed for cultivars suitable for wine.

By 1980, there were 238 selections in the HRIO inventory, not including 1980 seedlings. Grape breeding continued at HRIO throughout the 1980s until Dr Fisher's retirement in 2012. The 1980s saw significant vineyard expansion in Ontario, and most new cultivars planted were *V. vinifera* or high-quality hybrids. The creation of the Vintner's Quality Alliance (VQA) in 1988 excluded all *V. labruscana* cultivars for production of VQA wines, as well as any cultivar with *V. labrusca* ancestry, regardless of flavour profile. Consequently, all *V. labruscana* cultivars except Concord and Niagara (which continued to be used for juice and low volumes of port and sherry-style wines) were removed, and the area devoted to grapes decreased from 10,800 to 6700 ha. Only six hybrids were allowed for the VQA wines of Baco noir, Chambourcin, Maréchal Foch, Seyval blanc and Vidal blanc. New vineyards were in most cases *V. vinifera*. This set of circumstances minimized the potential for many HRIO selections thereafter. The breeding programme continued, but it primarily focused on table grapes, teinturier cultivars and hybrids with promise for emerging wine regions in Ontario with winters too severe for *V. vinifera* (Table 13.2).

Although Bradt had not completely ignored the table grape portion of the industry, it was mainly focused on existing *V. labruscana* cultivars such as Fredonia, Concord and the newly introduced Sovereign Coronation. One particularly fine *V. labruscana* seedling was selected and named Vinered for its success in Virginia and North Carolina, but it was considered too late for the Niagara industry and not of the Concord-like flavour favoured by the small fresh-fruit industry.

The assumption at this time was that very firm textured *V. vinifera* types, particularly seedless *V. vinifera* table grapes of the commercial table grape trade, were an impossibility in this climate. However, some firm textured seedlings from the wine programme were observed and many of these were part *V. vinifera*. Several were selected and subsequently named for the local fruit markets. Festivee was named in 1976 and Vanessa Seedless in 1983.

Fisher concentrated on improving the existing complex wine hybrids created by Bradt, backcrossing to vinifera and using the cleanest flavoured recent HRIO hybrids. Riesling, Chardonnay and Gamay noir were used extensively as pollen parents because of their flavour popularity and reliable field performance. Seed parents were Vivant and many other advanced selections with good hardiness, good disease tolerance and minimal thinning or crop control requirements. However, with this decrease in support for the wine-breeding programme, less emphasis was placed on

Table 13.2 Summary of crosses made at Vineland, Ontario, 1980 to 2006

Year	Number of crosses	Number of selections	Nature of crosses
1980	25	15	Vineland superior selections backcrossed to vinifera – Chardonnay, Riesling
1982	27	<10	French hybrid/Vineland hybrid crosses
1984	7	5	Vinifera – French hybrid crosses
1985	28	Many table grapes	Vineland hybrids × early German vinifera or traditional red wine vinifera
1987	14	Many table grapes	Vineland hybrids × traditional red vinifera
1989	21	<10	Several table grapes, beginning of teinturier crosses
1990	31	<10	Several table grapes, traditional red vinifera with French hybrids
1997	35	<10	Several table grapes, also superior Vineland selections × traditional red vinifera and some pure vinifera crosses
1998	30	No data	Table grapes using California pollen
1999	29	No data	Table grapes and teinturier crosses
2001	17	No data	All teinturier crosses
2003	15	No data	Teinturier and table grape crosses
2005	36	No data	Table grape intercrosses using all Vineland superior material
2006	64	No data	Large riparia population, superior Swiss material and superior Vineland table grape crosses

subsequent winemaking and it became more difficult to continue the annual wine tastings.

With dwindling interest in new hybrids, the focus became traditional *V. vinifera* cultivars for the commercial wineries. Fisher continued to make small populations of hardier, more disease-tolerant hybrids for the table market and non-traditional wine-growing districts. However, with no winemaking capability, progress was hard to measure. There was limited propagation of some advanced seedlings for the fresh fruit market and some cold wine-growing regions, but with her retirement in 2011, the programme was terminated and the vines removed.

13.1.1 Descriptions of selections from HRIO

The descriptions that follow are those of Bradt (1975) and Fisher et al. (1979), with revisions made for consistency. It should be noted that many of these selections from the 1920s to 1940s might be considered of little relevance today, but they are good examples of the nature of the crosses being made at that time.

13.1.2 Wine grape selections

Veeport (V29143; Wilder × Winchell). Introduced in 1961, Veeport is a blue grape cultivar maturing a few days before Concord (c. 10 October). The vine is fairly vigorous and productive. It suffers from winter injury and is more susceptible to powdery mildew than Concord. Its chief value is for dessert wine purposes, and it was originally released as an alternative cultivar to Concord for 'port'-style wines.

Vinered (V29186; Brocton selfed). Introduced in 1964, Vinered is an attractive red colour when well matured. It ripens a few days before Catawba, requiring a long growing season to attain best quality. The clusters are large to very large with medium compactness. Vines are vigorous and productive. It had potential as a dessert grape, although its seeded character limited its popularity.

V292718 (Manito selfed). This is a black grape selection of Concord season. It is a regular bearer of medium-sized clusters. Vines are above average in vigour. Wines were favourable, and trials continued for many years.

V35122 (unknown *Vitis vinifera* × Seneca). This is an early white grape selection that is vigorous and very productive. Its very low acidity gave it value for blending.

V49063 (Buffalo × Chelois). This early blue selection is vigorous, productive and produces medium-sized clusters and berries. Wine ratings were good during the time of evaluation.

V49404 (V35011 × Chelois). Red Hamburg, Ontario and Chelois are in the breeding background of V49404. It is a white selection once rated as making excellent table wine. It ripens about Chelois season (mid-October) with medium to large clusters with medium compactness, no breakdown and attractive yellow berries. The vine vigour is good, but it is susceptible to winter injury. When under observation it was considered worthy of further trial, and it was planted in several grower test vineyards.

Vincent (V49431; V370628 (Lomanto × Seneca) × Chelois). Introduced in 1967, Vincent is a dark blue (teinturier) grape cultivar with large compact clusters and medium-sized berries. The juice is very dark. It received excellent wine ratings. Foliage is somewhat susceptible to powdery mildew late in the season, but vine vigour is good. There is some tendency for the upper parts of the vine to be subject to winter injury.

V50061 (Alden × Lomanto). V50061 is a blue grape selection with highly coloured juice and an excellent wine rating. It is a vigorous selection with a good crop record and medium to small cluster and berries. This and V50062 have good wine possibilities, and trials were extended.

V50062 (Alden × Lomanto). This is a blue wine grape selection of Concord season. Clusters and berries are medium size. Vines are very vigorous and productive.

V50154 (Seibel 5455 × Seibel 14664). V50154 is blue grape selection with wine possibilities. It is vigorous and very productive. Clusters are medium in size and very compact. It may not be sufficiently hardy above the Niagara Escarpment.

Ventura (V51061; Chelois × Elvira). Introduced in 1974, this white grape cultivar of Concord season showed distinct promise for wine. It has medium-sized clusters and a small berry that does not split or crack like Elvira. Ventura is very productive and hardy. Because of its superior hardiness, it was considered useful for expanding to less favoured sites above the Niagara Escarpment. Ventura has high soluble solids content, but it is also quite acidic. Wineries showed interest in the 1970s and plantings expanded at that time.

Veeblanc (V53263; Cascade × Seyve-Villard 14-287). Introduced in 1977, Veeblanc is a white grape maturing a week ahead of Concord. Both the cluster and berry are larger than Concord, and the cluster is of medium compactness. Veeblanc produces relatively neutral white table wine. Vines on clay soil have low vine size and can be planted closer in the row than *V. labruscana* and hybrid cultivars. Veeblanc was intended to aid in supplying increasing demands for non-labruscana, white juice in the 1960s and 1970s.

L'Acadie blanc (V53621; Cascade × Seyve-Villard 14-287). This cultivar was actually named in Nova Scotia by the Grand Pre Winery in the 1970s. HRIO did not consider that it had potential for Ontario because of its low acidity and low cropping potential compared with its sibling, Veeblanc. However, under maritime conditions, the acidity was retained. Flavours include citrus and grassy notes.

V54077 (de Chaunac × Concord). V54077 is a blue grape selection showing excellent vine characteristics. Clusters are medium to large in size and of medium compactness. Wine ratings were good. It does not require cluster thinning. It had been considered worthy of an extended trial during the period that it was under investigation.

V58032 (V35122 × Muscat de Moulin). V58032 has Seneca, *V. vinifera* and Muscat de Moulin in its breeding. It is an early white grape with a pleasant muscat flavour. Had additional muscat cultivars been required, this selection could have been tried with several other Vineland selections because they are better growers than the Muscats available at the time of evaluation. This selection had limited propagation.

Vivant (V63331; V50154 × NY25681). Vivant is a white grape of complex breeding with medium-sized clusters and medium to small berries. It propagates easily and grows well in the nursery. It was one of the more promising white selections during the time of evaluation. It had been planted in large-scale grower trials and was subsequently named in 1983. It has done well in the central United States, Missouri and Arkansas.

V64035 (Alden × J.S. 23-416). V64035 is a non-labruscana white selection that had been in large-scale grower trials. It suffered some winter injury on second-test vines, and it was considered worthy of further testing. It is very productive. Wine flavour has been described as 'grapefruit' and citrusy. It has had limited propagation.

V64111 (Canada Muscat × Joannes Seyve 23-416). V64111 is a white selection with medium-sized, rather loose clusters. It has moderate vigour. Second-test vines did particularly well until receiving some winter injury. It is a mild Muscat with good aromatics. It has had some limited propagation.

V64201 (V35122 × V58011). V64201 has Seneca, Canada Muscat and *V. vinifera* in its breeding. It was one of the most promising white Muscats at the time. Both the original vine and second-test vines did well. It had been considered worthy of extended trial at the time as a muscat type.

V64232 (Vincent × de Chaunac). At the time, V64232 was considered a promising blue selection for red table wine. Vines have been productive and hardy. It had been considered worthy of extended trial at the time.

V64235 (Vincent × de Chaunac). At the time, it was considered a promising blue selection for red table wine. It has large, compact clusters and above-average winter hardiness.

V64237 (Vincent × de Chaunac). This cross produced nine blue selections, and this one had been considered one of the best in terms of wine quality and superior to its parent De Chaunac. It survived well over severe winters above and below the Niagara Escarpment. It has had some limited propagation.

V65232 (Joannes Seyve 23-416 × Chardonnay). V65232 is a white grape selection with Chardonnay quality, but it is probably a better grower. At the time, it was tested on various soil types at the HRIO and in grower trials. It tolerated several very harsh winters with reasonable crops. It has had some limited propagation.

13.1.3 Table grape selections

V50081 (Alden × Romulus). V50081 is a white seedless selection that was considered useful as a table grape. It has medium to large compact clusters with berries of good size. It is attractive and keeps well. It ripens in Concord season or slightly later.

V50082 (Alden × Romulus). V50082 is a blue seedless selection with large berries and good quality. Clusters are looser than 50,081 and not as attractive.

Festivee (V53033; Alden × Verdelet). Festivee is a high-quality table grape cultivar with large clusters and very large, oval blue berries. It ripens in Concord season and keeps and ships well. Festivee did not attain popularity, probably because it is a seeded cultivar.

V64023 (Alden × Himrod). V64023 is a white seedless selection with larger, firmer berries than Himrod. It matures later in the season than Himrod (early September), but it was considered worthy of trial. It is a mild seedless Muscat and has had some limited propagation for the fresh fruit trade.

V65163 (Seneca × NY 45910). V65163 is a very early, red, seedless selection ripening in the middle of August. Berries are small and soft, but it was once considered a useful table grape selection for the roadside market.

Vanessa Seedless (V65164; Seneca × NY 45910). Vanessa Seedless is a red, seedless cultivar, ripening about Fredonia season (early September). It has firm flesh of good dessert quality. It has done well as a commercial table grape in New York, Ohio and Michigan. There has been limited propagation for the roadside stand market in Ontario.

V68042 (Festivee × V52084). V68042 is a very large berried, firm, black seeded table grape selection. It has better quality than Festivee. It has very large clusters up to 1 kg. It has crisp, neutral flesh, but it is somewhat winter tender. It has seen limited propagation for the roadside stand market.

13.1.4 Molecular breeding

A molecular breeding programme at the University of Guelph has been ongoing for over 15 years, spearheaded by Dr Annette Nassuth. The programme is based on the hypothesis that freeze tolerance genes present in *V. riparia* are lacking or not adequately expressed in *V. vinifera*. These genes (ICE genes) result in formation of ICE proteins – four master stress response regulators that serve as transcription factors for C-repeat binding factors (CBF) promoters. The expression of CBF genes in turn switch on a whole series of cold regulated (COR) genes that produce proteins that help the plant withstand freezing conditions (Siddiqua and Nassuth, 2011; Siddiqua et al., 2009; Xiao et al., 2008; Xiao and Nassuth, 2006). If this cascade is blocked, then a plant becomes less freeze-tolerant. Over-expression increases freeze tolerance (shown in *Arabidopsis*, surviving −9 °C). Nassuth's team has isolated four CBF genes in grape and hypothesizes that they induce freezing tolerance in different tissues (perennial stems and buds or annual leaves). One portion of this project involves crosses between *V. riparia* selections (males) and Riesling cl. 239 Gm plus backcrosses to Riesling. Seedlings have been grown and subsequently tested for cold hardiness by electrolyte leakage, and the populations have been tested for the presence of COR and CBF genes. In addition, differences in stomatal density have been measured between *V. riparia* and *V. vinifera*, suggesting the high stomatal density in *V. riparia* under drought situations may lead to up-regulation of dehydration response element binding (DREB) genes, which also act as stress response regulators. In total, 22 genes have been isolated from this system.

13.2 Grape breeding in British Columbia: the grape breeding programme in Summerland, British Columbia

13.2.1 Initial crosses, 1966–1967

The wine industry in British Columbia in the 1960s consisted mainly of *V. labruscana* types (Bath, Diamond), French–American hybrids (de Chaunac, Marechal Foch) and an obscure hybrid of unknown ancestry, Okanagan Riesling. Very few *V. vinifera* plantings existed. In 1966–1967, a grape-breeding programme was initiated at the Agriculture Canada Research Station, Summerland, British Columbia under the direction of Donald V. Fisher (1914–2007) and visiting scientist Catherine Bailey (Rutgers University). The general objectives were to produce interspecific hybrids for wine production and table use. Specific objectives included winter hardiness, early fruit maturity, seedlessness (for table grape crosses) and generic objectives such as productivity and fruit/wine quality. For table grape crosses, Himrod was exclusively used as a source of seedlessness whereas cultivars such as Alden, Golden Muscat, Schuyler, V34034 and V34022 were used for large berry and cluster size. Wine grape crosses involved Aurore, Bath, Cascade, de Chaunac and Marechal Foch, among others, which were intended as sources of winter hardiness, productivity and wine quality.

Fifty crosses were made in 1967. After Fisher's retirement, the programme was assumed by Lyall G. Denby (1920–2005). In 1971, the original number of more than 3900 seedlings was reduced to 394 selections (Table 13.3). This was reduced further in 1972 to 131, which involved 38 of the original 50 crosses (Table 13.4). Crosses involving Beta, Erie, Pearl of Csaba and Schuyler yielded very sparse progenies with

Table 13.3 **Crosses made at Summerland, British Columbia during 1967 and 1968**

Selection	Cross
1–3	Patricia × de Chaunac
4–5	Aurore × Portland
6–9	Cascade × Beta
10	Campbell Early × Pearl of Csaba
11–12	V37023 × Pearl of Csaba
13–18	Schuyler × Aurore
19–21	Cascade × de Chaunac
22	Campbell Early × Pearl of Csaba
23–27	Patricia × Himrod
28	NY 12128 × Schuyler
29–33	de Chaunac × Marechal Foch
34–40	NY 12128 × Schuyler
41–42	Aurore × Seneca
43	de Chaunac × Marechal Foch
44–45	Patricia × Seneca
46–49	Marechal Foch × Campbell Early
50–52	Cascade × Portland
53	'Vinifera seedling'
54–56	Schuyler × Marechal Foch
57	V37023 × Campbell Early
58–61	Aurore × de Chaunac
62–64	Cascade × Campbell Early
65–67	Schuyler × Himrod
68–70	Schuyler × Bath
71–75	V37023 × Himrod
76–77	Bath × Portland
78–84	Bath × Pearl of Csaba
85	Bath × Marechal Foch
86–88	Erie × NY 33873
89	S.V. 12-375 × Calmeria
90–118	Marechal Foch × Schuyler
119–169	Golden Muscat × Marechal Foch
170–173	Marechal Foch × Schuyler
174–175	Golden Muscat × Marechal Foch
176–181	Marechal Foch × Schuyler
182–184	Marechal Foch × Alden
185–190	Marechal Foch × Schuyler
191–214	Marechal Foch × Alden
215–248	Kendaia × Marechal Foch
249–285	Marechal Foch × Golden Muscat
286–305	Marechal Foch × Himrod
306–309	Watkins × Marechal Foch
310–322	V37022 × Marechal Foch
323–329	Watkins × Marechal Foch

Continued

Table 13.3 Continued

Selection	Cross
330–332	V37022 × Marechal Foch
334–341	V37034 × Marechal Foch
342–391	Patricia × Himrod
392	Canada Muscat × Himrod
393	Portland × Pearl of Csaba
394	‘Porritt seedling’

Selections were those retained as of September 1971.

Table 13.4 Selections (131) retained at Summerland by September 1972

Selection	Cross
3	Patricia × de Chaunac
5	Aurore × Portland
7	Cascade × Beta
10	Campbell Early × Pearl of Csaba
13, **16**	Schuyler × Aurore
22	Campbell Early × Pearl of Csaba
23, 25, 27	Patricia × Himrod
28	NY 12128 × Schuyler
30	de Chaunac × Marechal Foch
34–35, **37–39**	NY 12128 × Schuyler
41–42	Aurore × Seneca
44–45	Patricia × Seneca
48–**49**	Marechal Foch × Campbell Early
52	Cascade × Portland
55	Schuyler × Marechal Foch
58–**59**	Aurore × de Chaunac
63–64	Cascade × Campbell Early
65, 66, **67**	Schuyler × Himrod
71, 73–**75**	V37023 × Himrod
76–77	Bath × Portland
78, **80–83**	Bath × Pearl of Csaba
88	Erie × NY 33873
90, 91, 102, **105**, 106, **107–108**, 111, 112, 115, **117**	Marechal Foch × Schuyler
123, 126, 128, 129, **131**, **134, 136**, 141, 142, **145, 147**, **149**, **151**, **153**, 156, 159, **166**, **167**	Golden Muscat × Marechal Foch
170, 171, **180**, **181**, 187, 188	Marechal Foch × Schuyler
194, **207, 209**, 212	Marechal Foch × Alden
223, 227, **239, 240**, **245**	Kendaia × Marechal Foch
259, 272, 281, 282, 285	Marechal Foch × Golden Muscat

Continued

Table 13.4 Continued

Selection	Cross
293, 294, **299, 305**	Marechal Foch × Himrod
308	Watkins × Marechal Foch
312, **315**, 317	V37022 × Marechal Foch
323, 324, **326**, **327**	Watkins × Marechal Foch
332	V37022 × Marechal Foch
334, 338	V37034 × Marechal Foch
342, 343, 346, **347, 348**, 349, 351, **352**, 356, 358, **360–364**, **370, 371**, **372**, **375**, **378**, 387, **390**, 391	Patricia × Himrod

Selections, those retained after 1973 are boldfaced.

few if any selections. On the other hand, Marechal Foch and Golden Muscat yielded large progenies if they were parents. Many of their progeny were highly vigorous, late maturing, low yielding and winter tender. The 131 selections that were retained matured their fruit as follows: before 15 September (59), 16–30 September (33), 1–15 October (34) and after 15 October (5).

By 1977, a considerable number of selections (≈60) still remained (Tables 13.5 and 13.6; Figure 13.2). Several were given provisional names, all of which contained the prefix 'Sovereign'. The first to be officially named was the pink-skinned muscat wine grape cultivar Sovereign Rose (Denby and Wood, 1977) as well as the seedless table grape Sovereign Coronation (Denby, 1977). Sovereign Rose saw limited local commercial planting, but it did not achieve any modicum of popularity, and commercial varietal wines were never produced. Sovereign Coronation has become a very popular table grape in Ontario. Later releases included the table grape Simone, a sister seedling of Sovereign Coronation that was originally tested under the provisional name Sovereign Charter (Reynolds et al., 1989a). This cultivar received little commercial attention. Wine grape releases were Sovereign Tiara (Reynolds et al., 1989b) and Sovereign Opal (Reynolds et al., 1988). Although Sovereign Tiara was not popular among wineries because of a candy-like aroma, the mild Muscat Sovereign Opal achieved some popularity and was used for varietal wine production for many years.

13.2.2 Detailed descriptions of cultivars and selections

These descriptions have been taken from notes distributed by L.G. Denby in 1975–1976. They have been edited for consistency and conciseness. Many of the details of the descriptions are somewhat qualitative in nature. It is worth noting that most selections are described as having mean yields more than 15 kg/vine, with many greater than 20 kg/vine, on the basis of 2.4 × 3.0 m vine × row spacing (5.4 t/acre; 13 t/ha). These may seem excessive, but these selections were evaluated on divided canopy training and under irrigated conditions. These early selections were made by L.G. Denby and D.F. Wood. The bulk of the selections remained under test until Mr Denby's retirement in 1985.

Table 13.5 **Selections retained in the Summerland breeding programme by 1977**

Selection	Cross
3	Patricia × de Chaunac
5	Aurore × Portland
16	Schuyler × Aurore
22	Campbell Early × Pearl of Csaba
25	Patricia × Himrod (Sovereign Etoile)
27	Patricia × Himrod
30	de Chaunac × Marechal Foch
34	NY 12128 × Schuyler
37	NY 12128 × Schuyler
38	NY 12128 × Schuyler
39	NY 12128 × Schuyler
49	Marechal Foch × Campbell Early
55	Schuyler × Marechal Foch
59	Aurore × de Chaunac
63	Cascade × Campbell Early
64	Cascade × Campbell Early
65	Schuyler × Himrod (Sovereign gold)
67	Schuyler × Himrod
71	V37023 × Himrod
78	Bath × Pearl of Csaba (Sovereign Garnet)
80	Bath × Pearl of Csaba (Sovereign Rose)
81	Bath × Pearl of Csaba (Sovereign Rouge)
82	Bath × Pearl of Csaba (Sovereign Ruby)
83	Bath × Pearl of Csaba
88	Erie × NY 33873
105	Marechal Foch × Schuyler (Sovereign du Nord)
107	Marechal Foch × Schuyler
117	Marechal Foch × Schuyler (Sovereign Princess)
123	Golden Muscat × Marechal Foch (Sovereign Tiara)
134	Golden Muscat × Marechal Foch (Sovereign Sceptre)
136	Golden Muscat × Marechal Foch
145	Golden Muscat × Marechal Foch
149	Golden Muscat × Marechal Foch
166	Golden Muscat × Marechal Foch (Sovereign Opal)
167	Golden Muscat × Marechal Foch
180	Marechal Foch × Schuyler (Sovereign noir)
223	Kendaia × Marechal Foch (Sovereign Royale)
239	Kendaia × Marechal Foch
240	Kendaia × Marechal Foch (Sovereign Emerald)
245	Kendaia × Marechal Foch (Sovereign Prince)
305	Marechal Foch × Himrod (Sovereign bleu)
315	V37022 × Marechal Foch
326	Watkins × Marechal Foch

Continued

Table 13.5 **Continued**

Selection	Cross
327	Watkins × Marechal Foch
334	V37034 × Marechal Foch
347	Patricia × Himrod (Sovereign Jewel)
348	Patricia × Himrod
352	Patricia × Himrod
360	Patricia × Himrod
361	Patricia × Himrod (<u>Sovereign Coronation</u>)
362	Patricia × Himrod (Sovereign Divinity)
364	Patricia × Himrod (Sovereign Jade)
370	Patricia × Himrod (Sovereign Concordia)
371	Patricia × Himrod
372	Patricia × Himrod (Sovereign Splendor)
375	Patricia × Himrod (Sovereign Charter; re-named <u>Simone</u>)
378	Patricia × Himrod (Sovereign Jubilee)
390	Patricia × Himrod (Sovereign Sunglo)

Provisional names for the most promising selections are in parentheses. Those ultimately officially named are underlined.

Table 13.6 **Summerland selections retained post-1977 and their basic descriptions**

Selection	Cross	Basic description
3	Patricia × de Chaunac	Concord type
5	Aurore × Portland	Large-clustered white
16	Schuyler × Aurore	Green vinifera type
22	Campbell Early × Pearl of Csaba	Red labruscana
25	Patricia × Himrod (Sovereign Etoile)	Green seedless
27	Patricia × Himrod	Blue seedless labruscana
30	de Chaunac × Marechal Foch	Blue Marechal Foch type
34	NY 12128 × Schuyler	Blue de Chaunac type
37	NY 12128 × Schuyler	Red NY Muscat type
38	NY 12128 × Schuyler	Green Seneca type
39	NY 12128 × Schuyler	Red vinifera type
49	Marechal Foch × Campbell Early	Blue vinifera type
55	Schuyler × Marechal Foch	Green vinifera type
59	Aurore × de Chaunac	Green vinifera type
63	Cascade × Campbell Early	Mild blue labruscana
64	Cascade × Campbell Early	Concord type
65	Schuyler × Himrod (Sovereign Gold)	Mild White Muscat
67	Schuyler × Himrod	Green seedless
71	V37023 × Himrod	Green seedless
78	Bath × Pearl of Csaba (Sovereign Garnet)	Red Muscat
80	Bath × Pearl of Csaba (<u>Sovereign Rose</u>)	Red Muscat

Continued

Table 13.6 Continued

Selection	Cross	Basic description
81	Bath × Pearl of Csaba (Sovereign Rouge)	Red Muscat
82	Bath × Pearl of Csaba (Sovereign Ruby)	Red Muscat
83	Bath × Pearl of Csaba	Red vinifera type
88	Erie × NY 33873	Red vinifera type
105	Marechal Foch × Schuyler (Sovereign du Nord)	Mild blue labruscana
107	Marechal Foch × Schuyler	Blue vinifera type
117	Marechal Foch × Schuyler (Sovereign Princess)	Blue vinifera type
123	Golden Muscat × Marechal Foch (Sovereign Tiara)	Green vinifera type
134	Golden Muscat × Marechal Foch (Sovereign Sceptre)	Green vinifera type
136	Golden Muscat × Marechal Foch	Green vinifera type
145	Golden Muscat × Marechal Foch	Mild green labruscana
149	Golden Muscat × Marechal Foch	Concord type
166	Golden Muscat × Marechal Foch (Sovereign Opal)	Amber vinifera type
167	Golden Muscat × Marechal Foch	Mild green labruscana
180	Marechal Foch × Schuyler (Sovereign Noir)	Blue vinifera type
223	Kendaia × Marechal Foch (Sovereign Royale)	Blue vinifera type
239	Kendaia × Marechal Foch	Blue vinifera type
240	Kendaia × Marechal Foch (Sovereign Emerald)	Mild green labruscana
245	Kendaia × Marechal Foch (Sovereign Prince)	Blue vinifera type
305	Marechal Foch × Himrod (Sovereign Bleu)	Blue vinifera type
315	V37022 × Marechal Foch	Blue vinifera type
326	Watkins × Marechal Foch	White Muscat
327	Watkins × Marechal Foch	Red Muscat
334	V37034 × Marechal Foch	Large-clustered green
347	Patricia × Himrod (Sovereign Jewel)	Seedless green labruscana
348	Patricia × Himrod	Seedless blue
352	Patricia × Himrod	Early red
360	Patricia × Himrod	Green seedless
361	Patricia × Himrod (Sovereign Coronation)	Early seedless Concord type
362	Patricia × Himrod (Sovereign Divinity)	Seedless red vinifera type
364	Patricia × Himrod (Sovereign Jade)	Seedless green labruscana
370	Patricia × Himrod (Sovereign Concordia)	Concord type
371	Patricia × Himrod	Red seedless vinifera type
372	Patricia × Himrod (Sovereign Splendor)	Concord type
375	Patricia × Himrod (Sovereign Charter; re-named Simone)	Seedless Concord type
378	Patricia × Himrod (Sovereign Jubilee)	Seedless green labruscana
390	Patricia × Himrod (Sovereign Sunglo)	Seedless green labruscana

Named cultivars are underlined.

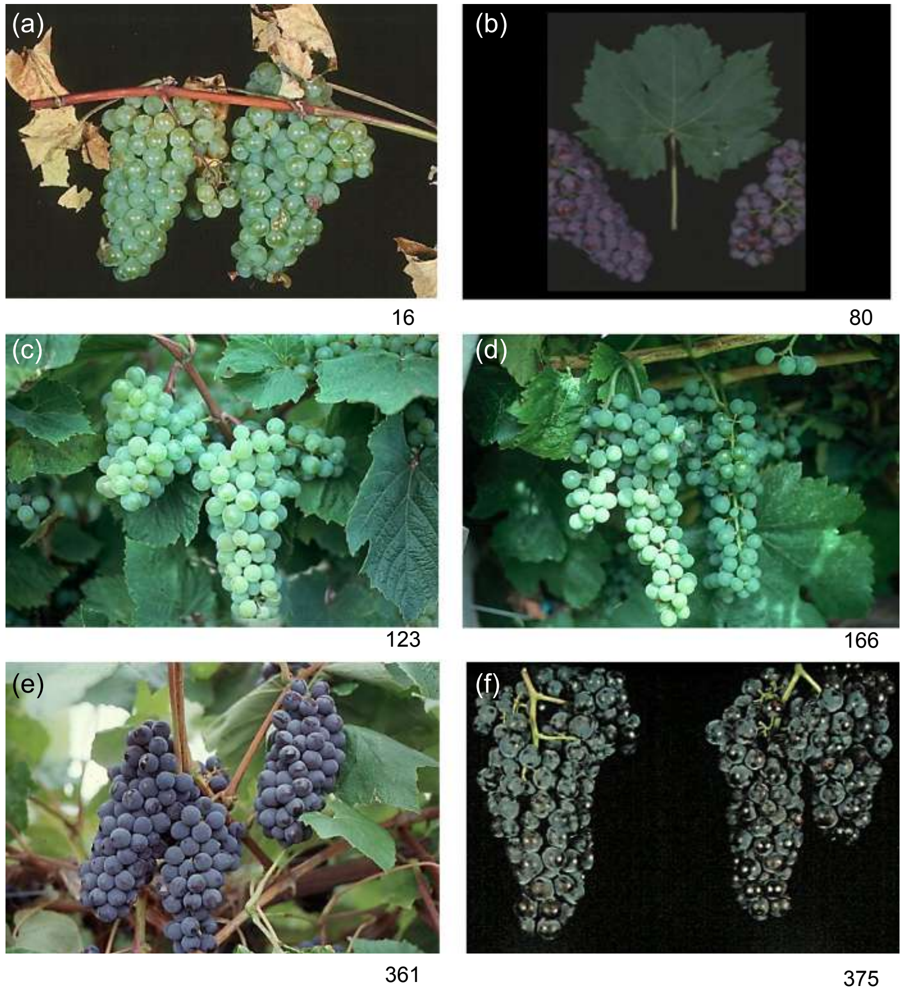


Figure 13.2 Cultivars and selections from the 1966–1967 crosses: (a) Selection 16 (Schuyler × Aurore), (b) Sovereign Rose (Selection 80; Bath × Pearl of Csaba), (c) Sovereign Tiara (Selection 123; Golden Muscat × Marechal Foch), (d) Sovereign Opal (Selection 166; Golden Muscat × Marechal Foch), (e) Sovereign Coronation (Selection 361; Patricia × Himrod) and (f) Simone (Selection 375; Patricia × Himrod). Photo credits: A. Reynolds.

13.2.3 Wine grape selections

Selection 63 (Cascade × Campbell Early). Selection 63 is a blue wine grape selection, with a hardiness of 8/10 and medium-sized berries in small to medium-sized loose cylindrical clusters averaging 75 g. The berries are crisp, vinifera-like (*sic*) and sweet with sharp overtones. The vine is fairly productive (≈14 kg/vine). Harvest date is 21 September in 1974, and Brix is 20.8. Wine has good colour, is slightly acidic and has a mild labruscana nose and flavour.

Selection 80 (Sovereign Rose; Bath × Pearl Csaba). Sovereign Rose (released officially in 1977) is a mid-season pink aromatic hybrid with a delicate muscat flavour that matures in late September to early October, 7–10 days before NY Muscat. Clusters are medium sized (133 g), shouldered, cylindrical, fairly tight and attractive. Berries are medium small, pinkish red with heavy bloom, tough skinned and resistant to shattering. Brix at maturity averages 19.0, with a titratable acidity (TA) of 9.0 g/L and low malic acid (≈20% of total). Vigour is medium strong, adapted to standard (2.4 × 3.0 m) hybrid spacing. Hardiness is comparable to Okanagan Riesling (i.e. quite winter-hardy). Sovereign Rose has good fresh-market potential in addition to making an excellent muscat wine. Field performance in 1976 was as follows: yield = 18.6 kg/vine, Brix = 21.3 and harvest date is c. 12 October, 1–2 weeks later than usual. Storage tests indicated that Sovereign Rose could be quite satisfactorily stored until late December.

Selection 88 (Erie × NY 33873). Selection 88 is a blue wine grape selection with a hardiness of 9/10. The berries are medium to small, with clusters shouldered to cylindrical and averaging 87 g. The berries are of Concord character, slipskin and sweet. Vines are productive, averaging 20.1 kg/vine in 1974. Harvest date is 14 September, with a mean Brix of 21.2. Wines are very robust, with good colour, good body and excellent balance. It has a slight labruscana or fruity nose.

Selection 107 (Maréchal Foch × Schuyler). Selection 107 is a blue wine grape selection of vinifera (*sic*) quality. The clusters are medium sized (78 g), shouldered and tight. The berries are medium small, sweet and seedy. Plant hardiness is 9/10, and vigour is medium strong. It is moderately productive, with a harvest date of 26 September (midseason). The Brix is 24.0, and TA is low. It was said to have potential for a Bordeaux-style wine.

Selection 117 (Sovereign Princess; Maréchal Foch × Schuyler). Selection 117 is an early (6 September) blue wine grape selection of vinifera (*sic*) character. The Brix is 21–22. Vigour is medium weak, with a hardiness of 9/10 and good productivity. Clusters are medium small (60 g), shouldered and tight. Berries are medium sized and dark blue. Wine is rich, full bodied, low acid and purplish in colour, with the potential for ageing.

Selection 123 (Sovereign Tiara; Golden Muscat × Maréchal Foch). Sovereign Tiara (officially released in 1989) is a green hybrid, vinifera (*sic*) in fruit character, with excellent potential for white wine and for fresh market. Sovereign Tiara matures early in October, with or slightly later than Okanagan Riesling. Clusters are medium size (98 g), shouldered, triangular and somewhat loose. Berries are medium small and light green to golden, with little tendency to shatter. Flesh is sweet, skin is tender and seeds are small. Brix at maturity is approximately 21, and TA is 12 g/L, of which less than half is malic. Vigour is medium strong, adapted to 2.4 × 3.0 m spacing. Hardiness is comparable to Okanagan Riesling. Sovereign Tiara makes an excellent clean white wine with delicate bouquet and flavour. It also has distinct fresh-market possibilities. This cultivar attains satisfactory Brix by early October, but it is not fully mature until the malic acid drops below 50% of the total. Therefore, it was suggested that this cultivar be restricted to warm sites in the southern end of the Okanagan Valley.

Selection 134 (Sovereign Sceptre; Golden Muscat × Maréchal Foch). This selection had been scheduled for introduction in 1977, but it was never officially named. At the time it was considered a promising grape for white wine. The selection is of medium-strong vigour, only moderately productive (≈18.2 kg/vine) and apparently very hardy. Maturity is late, about mid-October at Summerland, particularly if it is allowed to carry a crop more than 22 kg/vine. For this reason, this selection, similar to Sovereign Tiara, was recommended for early, warm sites. Clusters are medium to small size, averaging 70 g, loose, cylindrical and sometimes shouldered. Berries are medium small and bright green, of crisp vinifera (*sic*) character with few seeds and thick skin. Brix values are typically low, usually approximately 18.0, with a TA of approximately 13 g/L maximum at maturity. When the crop is controlled, and late and small clusters are removed, this selection produces a very aromatic full-bodied, well-balanced white wine of slightly hybrid flavour. The wine was said to be more consistent than that produced from Okanagan Riesling, the main white cultivar grown in the region at the time, indicating that off-flavours are not a problem with full maturity. At the time, Sovereign Sceptre was propagated for industry trials under the stewardship of a local large winery.

Selection 149 (Golden Muscat × Maréchal Foch). Selection 148 is a mid-season (1 October) vinifera (*sic*) type blue wine grape selection. It has a hardiness of 9/10, and it is vigorous. Berries are blue with a heavy bloom and of medium size. Clusters are medium (95 g), rather loose and shouldered. The flavour is clean, rather sharp, and vinifera-like (*sic*). Vines are very vigorous and productive (28 kg/vine in 1974). The Brix was 19.5 by 1 October. It was distributed to grower plantings beginning in 1975.

Selection 166 (Sovereign Opal; Golden Muscat × Maréchal Foch). Selection 166 is an attractive green wine grape cultivar with translucent amber or pinkish overcast that was eventually named officially in 1988. The vine is rated as of moderate vigour at best when grown on light soil. Its hardiness is rated as only fair, and it appears to be closely related to crop load. Yield when under test had been as high as 39 kg/vine, but 27 kg/vine was the likely mean yield. Clusters are medium-large, averaging 194 g, and it is cylindrical or has pronounced shoulders, ranging from tight in some years to moderately loose in others. Berries are of medium-small to medium size, with a thick astringent skin. Flavour is mild Muscat with no trace of labruscana aroma. The harvest date is late September or early October at Summerland. The Brix at maturity ranges from 20 to 23, and TA can reach 12.9 g/L if the malic acid is less than 40% of the total. Sovereign Opal consistently produces an excellent well-balanced white wine of delicate bouquet and flavour. It had been scheduled for industry trial under the stewardship of a large local winery, and it became the only Summerland hybrid to be commercially produced into a varietal wine.

Selection 180 (Sovereign Noir; Maréchal Foch and Schuyler). Sovereign Noir is a blue wine grape selection with possible fresh-market possibilities. It matures in late September or early October, 2 weeks before de Chaunac. Clusters are medium-large (140–150 g), shouldered, full and rather tight. Berries are medium sized, tough skinned, sweet, and low in acid when mature, with a pleasant vinifera (*sic*) flavour. The Brix average is 22.5, with a TA of 12 g/L, of which malic is less than 50%. Vigour is strong, with a hardiness equal to or better than de Chaunac. Sovereign Noir produces a full-bodied, balanced, rich red wine of excellent colour and bouquet. As an example of its productivity, in 1976, Sovereign Noir matured at least a week later than usual (harvested 12 October) with a Brix of 18.9 and a yield of 45 kg/vine, 34 kg/vine less than the year before. At the time of introduction, this selection had been scheduled for intensive propagation and industry trial under the stewardship of a large local winery.

Selection 223 (Sovereign Royale; Kendaia × Maréchal Foch). Sovereign Royale was regarded as one of this programme's most promising blue wine grape selections. It was scheduled for release in 1977, but it was never officially named. This selection is vigorous, highly productive and predominantly vinifera (*sic*) in character. Its hardiness is rated as good. It matures in late September to early October at Summerland, 2 weeks ahead of de Chaunac. Clusters are medium-large, (≈123 g), cylindrical and shouldered. Berries are medium sized, dark blue and crisp in texture. The TA is characteristically low for a blue grape, less than 12.5 g/L, and the Brix is an average of 22.0. There is a slight tendency to shatter, which ruled out fresh-market potential, which otherwise is good for this selection. Sovereign Royale consistently has produced an excellent full-bodied, well-balanced red wine of good colour, pleasant nose and fruity flavour. At the time it had been scheduled for intensive propagation and industry trial planting under the stewardship of a large local winery.

Selection 239 (Kendaia **× Maréchal Foch)**. Selection 239 is a blue wine grape with a hardiness of 10/10. The berries are medium-small of vinifera (*sic*) character, sweet, of low acid and fruity. Clusters are cylindrical to shouldered, with a mean weight of 104 g. Plant fairly vigorous, very productive with a mean yield of 46.8 kg/vine. The harvest date is 6 September with a Brix of 21.3. Wine is very deep red and fruity with a hint of Muscat, which adds to its distinctive fruity character.

Selection 240 (Sovereign Emerald; Kendaia × Maréchal Foch). Selection 240 is a mid-season (28 September) white wine grape selection with possibilities for both fresh market as well as wine production. Its hardiness is 10/10, and its vigour is medium strong. It is extremely prolific (46 kg/vine in 1974), with a Brix of 22.5. Berries are medium sized and slipskin with a slight labruscana flavour. Clusters are medium-small to medium, approximately 138 g and cylindrical. Wine is fruity, with a Riesling-like nose, and acidic, but with a clean refreshing flavour. It was considered very promising at the time of evaluation.

Selection 245 (Sovereign Prince; Kendaia × Maréchal Foch). Selection 245 is an early blue wine grape selection, with a hardiness of 8/10. Its berries are medium-small and seedy. Its juice is highly coloured. The clusters are small, tight and cylindrical, with a mean of 47 g. Vines are weak, and the yield is moderate at 9.1 kg/vine. Harvest date is 6 September, with a Brix 23.7. Wines are very heavy and full bodied.

Selection 305 (Sovereign Bleu; Maréchal Foch × Himrod). Selection 305 is an early blue wine grape selection resembling Marechal Foch but with larger sweeter berries and better flavour and character. Clusters are shouldered and approximately 141 g. Hardiness is 9/10 and vigour is strong. Productivity is relatively fair (24 kg/vine). The Brix was 24.6 by 6 September in 1974. Wine contains a good rich colour, fair bouquet, low acid and high tannin. It has the potential to age well.

13.2.4 Table grape selections

Selection 361 (Sovereign Coronation; Patricia × Himrod). Sovereign Coronation (officially named 1977) is an early mid-season black hybrid with mild Concord flavour, maturing in mid-September, at least 2 weeks before Patricia. Clusters are medium sized (105 g), larger if cluster thinned, cylindrical and fairly tight. Berries are of medium size, slipskin, seedless, black with a light bloom, tough skinned and resistant to shattering. Brix averages 20.0. Vigour is medium weak, adapted to 1.8-m vine spacing. Its hardiness appears to be superior to Patricia. Sovereign Coronation is suitable for fresh market, jam, juice and jelly. The field performance of Sovereign Coronation was very satisfactory in 1976, although as a result of the poor season it did not attain its full flavour characteristics. The yield was 14.3 kg/vine, Brix was 18.7 and it was harvested 4 October, a full week later than usual. Despite the season, Sovereign Coronation stored very well until late December. Sovereign Coronation is the most widely planted Summerland table grape in Canada. In Ontario, where most is produced, harvest dates are typically in mid-August.

Selection 375 (Simone; originally tested as Sovereign Charter; Patricia × Himrod). Simone is a late seedless blue grape with crisp flesh and delicate flavour. It matures in early to mid-October with Patricia. Clusters are large (265 g), shouldered, triangular and loose but full and attractive. Berries are medium in size, with a slight tendency to shatter. Brix averages 18.0, with a TA of approximately 9.0 g/L. Vigour is strong, necessitating vine spacing at 2.4–3.5 m. Hardiness appears to be superior to that of Patricia. Simone is suitable for table use, but it is too delicate in flavour to be recommended for juice or preserving. Despite cluster thinning, Simone produced 36 kg/vine in 1976. The harvest date was 12 October, with a Brix of 15.8, 2° lower than usual. Although it does not appear to store as well as Sovereign Coronation, it has been satisfactory until late December.

13.2.5 Second set of crosses, 1977–1980

A second set of crosses was performed under the direction of L.G. Denby in 1977–1980. At this point, the British Columbia wine industry had changed considerably from the period during which the original crosses were made. Most *V. labruscana* vineyards had been removed, as had many French–American hybrids, although other hybrids such as Chancellor, Chelois, Rougeon and Verdelet took the place of inferior cultivars such as de Chaunac. Okanagan Riesling remained ubiquitous and was the most widely planted cultivar. Of crucial importance was the recent popularity of *V. vinifera*, and many new vineyards of German *V. vinifera* intraspecific hybrids (Bacchus, Optima, Schönburger, Siegerrebe) as well as Riesling, Pinot blanc, Gewurztraminer and many others had been established. Concurrent with the new efforts in the breeding programme was a large cultivar evaluation trial referred to as the 'Becker Project' in honour of Helmut Becker, the grape breeder from Geisenheim who advised the industry as to which cultivars to plant and evaluate. It was with this background of industry change that many new crosses were made (Table 13.7).

General objectives of the 1977–1980 crosses were twofold: Production of early-season, seedless table grapes of high quality with texture similar to that of *V. vinifera* table grapes and production of winter-hardy, high-quality, early-season wine grapes. For table grapes, cultivars used to achieve quality and textural components included Ribier and Dattier, with seedlessness provided by Sovereign Coronation, Simone, Himrod and Romulus. Hardiness, large berry size, and large cluster size were

Table 13.7 **Summary of 1977–1980 crosses made at Summerland**

Selection	Cross
401	Early Violetta seedling
402	Severnyi × Selection 375
403–405	Selection 81 selfed
406	Selection 80 selfed
407	NY Muscat × Selection 361
408–409	Selection 5 × Selection 372
410	V37034 × Selection 362
411	V37022 × Selection 372
412	Selection 16 × Selection 123
413	Early Violetta seedling
414	Selection 108 selfed
415	Madeleine Angevine off-type; likely Perlette
416	Selection 81 selfed
417	Selection 81 seedling
418	Selection 108 seedling
419	Okanagan Riesling seedling
420–422	Saperavi Severnyi × Selection 375
423–424	NY Muscat × Selection 372
425	NY Muscat × Romulus
426	Vidal tissue culture
427–430	Selection 5 × Selection 364
431	Selection 5 × Himrod
432	NY Muscat × Himrod
433	NY Muscat × Selection 347
434	NY Muscat × Selection 362
435	Selection 5 × Selection 362
436–438	V37034 × Himrod
439–440	V37034 × Romulus
441	V37034 × Selection 25
442–443	V37034 × Selection 88
444	Pannonia Gold × Selection 347
445	V37034 × Selection 88
446–448	V37034 × Selection 364
449	V37034 × Selection 372
450–451	V37034 × Selection 375
452	V37022 × Selection 123
453	V37022 × Selection 347
454–455	V37022 × Selection 362
456	Pearl of Csaba × Selection 364
457	Morio-Muskat off-type
458	Pearl of Csaba × Selection 364
459	Inkameep Riesling × Kerner
460–461	Inkameep Riesling × Selection 378
462–463	Inkameep Riesling × Selection 364
464–465	Inkameep Riesling × Kerner

Continued

Table 13.7 Continued

Selection	Cross
466–467	Inkameep Riesling × Dattier
468	Selection 16 × Selection 378
469–470	Selection 83 × Selection 347
471	Selection 83 × Selection 347
472	Selection 83 × Selection 362
473	Selection 166 × Selection 378
474–475	Michurinetz × Selection 88
476	NY 12128 seedling
477–479	Selection 81 seedling
480–481	Madeleine Angevine × Selection 25
482	Pearl of Csaba × Selection 364
483–484	Selection 5 × Selection 364
485–486	Selection 5 × Selection 375
487	Selection 5 × Selection 347
488–491	V37034 × Himrod
492, 493, **494, 495**, 496, **497**, 498–499	V37034 × Romulus
500	V37034 × Selection 25
501	V37034 × Selection 88
502–506	V37034 × Selection 361
507–513	V37034 × Selection 347
514	V37034 × Selection 123
515–516	V37034 × Selection 88
517–521	V37034 × Selection 362
522–527	V37034 × Selection 372
528–529	V37034 × Selection 375
530–532	V37034 × Selection 378
533	V37022 × Himrod
534, **535**, 536, **537**	V37022 × Romulus
538	V37022 × Selection 361
539–540	V37022 × Selection 347
541	V37022 × Selection 123
542	V37022 × Selection 362
543–544	V37022 × Selection 364
545	V37022 × Selection 372
546–548	Selection 5 × Selection 25
549–550	Selection 5 × Selection 123
551–553	Selection 5 × Selection 347
554–557	Madeleine Angevine × Romulus
558	Madeleine Angevine × Selection 123
559	Madeleine Angevine × Selection 347
560	Madeleine Angevine × Selection 25
561	Pannonia Gold × Himrod
562	Saperavi Severnyi × Selection 375
563–565	Illinois 172-3 × NY 35814

Continued

Table 13.7 Continued

Selection	Cross
566–567	Pearl of Csaba × Selection 364
568–570	Selection 83 × Selection 378
571	Pearl of Csaba × Selection 364
572	Pearl of Csaba × Selection 372
573–576	Inkameep Riesling × Ribier
577	Inkameep Riesling × Kerner
578	Pearl of Csaba × Selection 390
579	Inkameep Riesling × Kerner
580–581	Inkameep Riesling × Selection 364
582–591	Inkameep Riesling × Dattier
592	Selection 16 × Selection 378
593–594	Optima × Selection 378
595–596	Selection 82 × Selection 362
597	Selection 82 × Selection 364
598–600	Selection 82 × Selection 390
601	Dattier × Selection 83
602	Selection 83 × Ribier
603	Selection 83 × Selection 347
604–605	Selection 83 × Selection 390
606	Aris × Kerner
607–609	Chasselas × Ribier
610–612	Chasselas × Selection 25
613–614	Chasselas × Selection 347
615	Chasselas × Selection 362
616–618	Chasselas × Selection 375
619	Michurinetz × Kerner
620	Pannonia Gold × Selection 362
621	Michurinetz × Kerner
622–626	Michurinetz × Ribier
627	Pannonia Gold × Selection 25
628	Pannonia Gold × Selection 378
629	Michurinetz × Ribier
630	Pannonia Gold × Selection 362
631	Selection 166 × Selection 378
632	Madeleine Sylvaner × Selection 378
633	NY Muscat × Selection 372
634–635	V37034 × Romulus
636	Madeleine Angevine × Romulus
637	Michurinetz × Selection 88
638	Illinois 172-3 × NY 35814
639	Chasselas × Selection 375
640	Michurinetz × Selection 375
641	Illinois 172-3 × NY 35814
642	Pearl of Csaba × Selection 390

Continued

Table 13.7 **Continued**

Selection	Cross
643	Inkameep Riesling × Dattier
644	Michurinetz × Kerner
645	Pannonia Gold × Selection 362
646–647	Michurinetz × Kerner
648	Madeleine Angevine × Romulus
649	Inkameep Riesling × Kerner
650	Inkameep Riesling × Dattier
651	Selection 83 × Dattier
652	Selection 82 × Selection 390
653	Inkameep Riesling × Kerner
654	Pearl of Csaba × Selection 390
655	Inkameep Riesling × Selection 378
656	Aris × Kerner
657	Inkameep Riesling × Kerner
658	Pearl of Csaba × Selection 364
659–665	Records unobtainable
666	Pearl of Csaba × Selection 364

Boldfaced selections were those retained for second test status and/or named.

provided by parents such as V37034 and V37022, Pearl of Csaba, and Pannonia Gold. Wine grape crosses used Madeleine Angevine, Madeleine Sylvaner and Chasselas for earliness, and Okanagan Riesling (syn. Inkameep Riesling), Saperavi Severnyi and Michurinetz (the latter two are *V. amurensis* hybrids) for winter hardiness. Many of the best selections from the 1966–1967 crosses were involved in many of the new crosses.

Evaluation of these selections occurred throughout the 1980s and much of the 1990s. However, several circumstances led to the programme's eventual demise. L.G. Denby retired in 1985 and his position was not refilled, and responsibilities for the programme were not officially designated to another scientist; Denby's former technician continued to collect data and delete inferior selections. That same year, many French–American hybrids were removed at the behest of one major winery, which cited a lack of consumer interest in hybrids in general. In 1988, VQA was created in Ontario and British Columbia, and this led to removal of all remaining hybrids. The approximately 1450 ha of grapes were reduced to approximately 330 ha, and nearly all of those remaining were *V. vinifera*. The industry slowly replanted, but all new vineyards were exclusively *V. vinifera* and few were interested in hybrid wine grapes or new table grape selections. The breeding programme ended in 1997.

Several table grape selections remained in the programme at the time of its termination (Figure 13.3). Five of these were white seedless types (Selections 433, 495 (Skookum Seedless), 497, 535 (Sooke Seedless), 537), one seedless pink (Selection 434), two seeded whites (Selections 494 and 645) and one seeded pink (Selection 651). Two high-quality seedless table grape cultivars were introduced at the termination of the

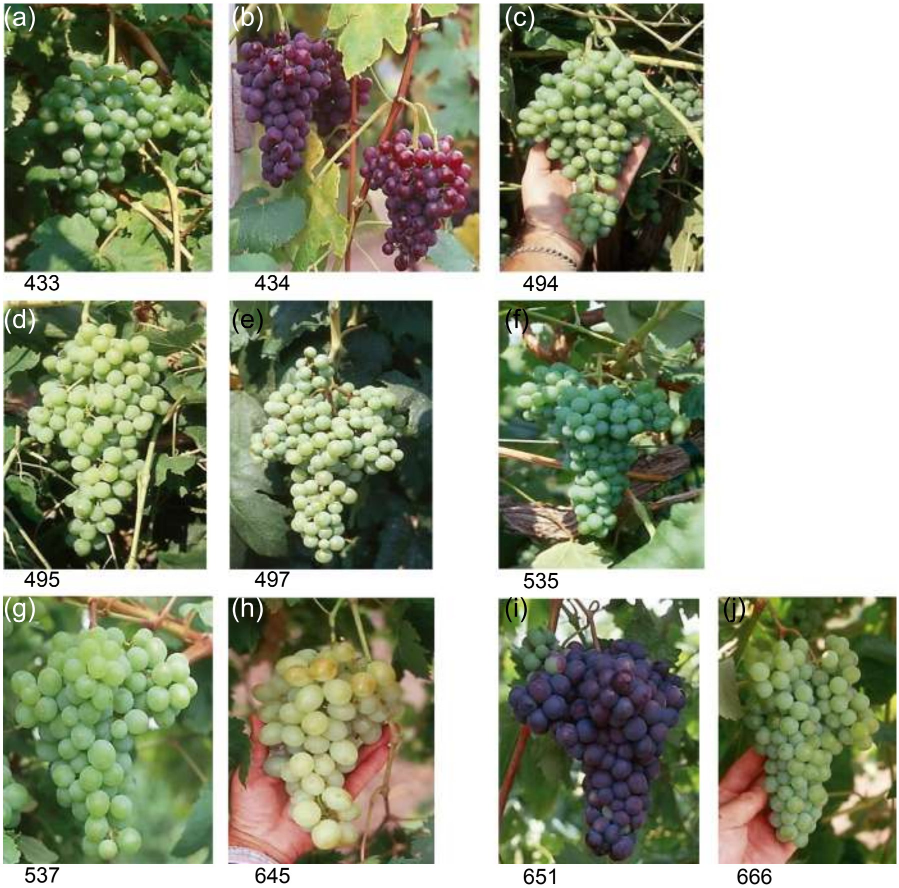


Figure 13.3 Cultivars and selections from the 1977–1980 crosses: (a) Selection 433 (NY Muscat × Selection 347), (b) Selection 434 (NY Muscat × Selection 362), (c) Selection 494 (V37034 × Romulus), (d) Selection 495 (Skookum Seedless; V37034 × Romulus), (e) Selection 497 (V37034 × Romulus), (f) Selection 535 (Sooke Seedless; V37022 × Romulus), (g) Selection 537 (V37022 × Romulus), (h) Selection 645 (Pannonia Gold × Selection 362), (i) Selection 651 (Selection 83 × Dattier) and (j) Selection 666 (Pearl of Csaba × Selection 364). Photo credits: A. Reynolds.

programme: Skookum Seedless (Reynolds et al., 1997a) and Sooke Seedless (Reynolds et al., 1997b). Both have seen limited commercial popularity at best, although Skookum Seedless has been planted commercially in Ontario. These cultivars were shown to respond favourably to both gibberellic acid and phenylurea compounds in terms of larger berries and clusters (Reynolds et al., 1992). The other selections remained in the programme but were not named, including Selections 433, 434, 494, 497, 537, 645, 651 and 666. These were compared in a large trial for several years against industry standards, and in many cases, these selections proved equal or superior to standard cultivars to which they were compared (Himrod, Interlaken, Lakemont and Romulus (white seedless), Einset Seedless (pink seedless), Seneca (seeded white), and Festivee (pink seeded)) (Reynolds et al., 2005). Sensory studies confirmed their superiority (Cliff et al., 1996; Reynolds et al., 2005).

13.2.6 Description of cultivars and selections

The best of the prospective table grape selections from the 1977–1980 series are the following. They were originally tested as single-vine and/or five-vine plots (1984–1989) and later (trial planted 1990; data collected 1993–1996) in a replicated trial including several comparison cultivars. These data are based on vines spaced 1.8×3.0m and trained to either a modified lyre (Y-shaped) trellis or to a 1.8-m high bilateral cordon.

Selection 433 (New York Muscat×Selection 347). Selection 433 is a seedless white selection crossed in 1977 and selected in 1984. Growth is moderately vigorous (1.1kg/vine) and procumbent. Yields exceeded those of cultivars such as Himrod, Lakemont and Romulus in a replicated trial. Moderately large clusters (mean 200g) are conical and moderately loose, and they are equal to or larger than Himrod, Interlaken, Lakemont and Romulus. Berries are moderately large (mean 2.3g), round, green skinned, of mild labruscana flavour and seedless. Berries are considerably larger than those of Himrod, Interlaken, Lakemont and Romulus.

Selection 434 (New York Muscat×Selection 362). Selection 434 is a pink-skinned, seedless selection crossed in 1977 and selected in 1984. The vine has moderate vigour, procumbent growth habit and is very winter hardy (0–8% primary bud damage in 1988–1989). Despite some inconsistency in initial observations, yields exceeded comparison cultivar Einset Seedless in a replicated trial conducted in 1993–1996. Clusters are medium sized (111g), cylindrical, loose and approximately equal in mass to Einset Seedless. Berries are round, medium sized (2.3g), pink skinned, moderately crisp, of fruity flavour and seedless. In some years, the 'hen-and-chicken' syndrome will appear in which some berries do not size; flower cluster thinning appears to overcome this problem.

Selection 494 (Vineland 37034×Romulus). Selection 494 is a seeded white selection crossed in 1977 and selected in 1984. Growth is vigorous and procumbent. Its very high yields and massive clusters initially attracted sufficient attention to elevate this selection to second-test status. Yield consistently exceeded Seneca in a replicated trial. Selection 494 produces very large clusters (300–1000g; mean 389g) that are triangular, shouldered, moderately tight and considerably larger than Seneca. Berries are ovoid, large (3.5g), green skinned, crisp, of light fruity flavour and seeded. This selection was rated highest in terms of visual liking, but the skins can be astringent (Cliff et al., 1996). Winter hardiness is moderate (18% primary bud injury in 1988–1989).

Skookum Seedless (Selection 495; V37034×Romulus). Skookum Seedless is a seedless white selection crossed in 1977 and selected in 1984. Growth is moderately vigorous and procumbent. Initial data suggested that this selection was capable of sustaining high yields along with high soluble solids and moderate TA. Yields are equal to those of cultivars such as Himrod, Interlaken, Lakemont and Romulus. Large clusters (300–600g; mean 242g) are triangular and moderately loose and equal to or larger than Himrod, Interlaken, Lakemont and Romulus. Berries are large (2.5–3.1g; mean 3.0g), ovoid, green skinned, of mild labruscana flavour and seedless. Berries are considerably larger than those of Himrod, Interlaken, Lakemont and Romulus.

Skookum Seedless was rated very high in terms of visual attractiveness (Cliff et al., 1996). This cultivar was released in 1997 (Reynolds et al., 1997a). It is widely planted commercially in British Columbia and Ontario.

Selection 497 (V37034×Romulus). Selection 497 is a seedless white selection crossed in 1977 and selected in 1984. Growth is moderately vigorous and procumbent. Yields were moderate throughout its initial testing period and were less than established commercial cultivars such as Himrod, Interlaken, Lakemont and Romulus in a replicated trial. Clusters are medium to small (109 g), triangular and moderately tight; they are smaller than Himrod, Interlaken, Lakemont and Romulus. Berries are round, medium sized (1.6 g), green skinned, crisp (i.e. similar in texture to traditional *V. vinifera* cultivars such as Thompson Seedless) neutral to light fruity flavoured and seedless. This selection may suffer from poor berry set in some seasons; flower cluster thinning appears to overcome this problem. It is relatively winter hardy and suffered only 14% primary bud damage in the very severe 1988–1989 winter.

Sooke Seedless (Selection 535; V37022×Romulus). Selection 535 is a seedless white cultivar crossed in 1977 and selected in 1984. Growth is moderate in vigour and procumbent. Initial data suggested that this cultivar could sustain high yields along with very high soluble solids (23.5–30.7 Brix). Yields consistently exceeded those of Himrod, Interlaken, Lakemont and Romulus in a replicated trial. Clusters are medium sized (100–200 g; mean 194 g), triangular and tight, and they are about equal in mass to Himrod, Interlaken, Lakemont and Romulus. Berries are round, medium sized (1.6–2.4 g; mean 1.83 g), green skinned, crisp, light fruity in flavour and seedless. Sooke Seedless was rated highest in flavour and texture liking among a collection of 12 selections and commercial table grape cultivars (Cliff et al., 1996). This cultivar was released in 1997 (Reynolds et al., 1997b). It is widely planted commercially in British Columbia.

Selection 537 (Vineland 37022×Romulus). Selection 537 is a seedless white selection crossed in 1977 and selected in 1984. Vigour is moderate, and growth habit is procumbent. As with its sister seedling, Sooke Seedless, Selection 537 gave an early indication of sustaining high yields along with high Brix values. However, yield has been less than Himrod, Interlaken, Lakemont and Romulus. Clusters are medium to medium-large (100–300 g; mean 126 g), cylindrical, shouldered, moderately loose and somewhat smaller than Himrod, Interlaken, Lakemont and Romulus. Berries are slightly ovoid, large (2.9 g), green skinned, moderately crisp, of light fruity flavour and seedless.

Selection 651 (Dattier×Selection 83). Selection 651 is a pink skinned, seeded selection crossed in 1980 and selected in 1985. Growth is moderately vigorous and somewhat erect. Yields initially did not exceed 10 t/ha, but those in a replicated block collected in 1993–1996 were equal to comparison cultivar Festivee. Clusters are large (200–300 g; mean 272 g), triangular to blocky, moderately tight and heavier than Festivee. Berries are ovoid, large (3.7 g), red skinned, crisp, of slight grassy flavour and seeded. This selection was rated extremely high for visual and overall liking among 12 selections and commercial cultivars (Cliff et al., 1996). Unfortunately, Selection 651 is not without its shortcomings. Its berries have a tendency to crack in moist seasons because of over-expansion of the large berries. This selection is quite winter tender, and it suffered between 56% and 84% primary bud damage in the 1988–1989 winter. Selection 651 is quite susceptible to powdery mildew.

Selection 666 (Pearl of Csaba × Selection 364). Selection 666 is a seedless white selection crossed in 1977 and selected in 1988. Attention was initially paid to this selection because of its very early harvest date. Vigour is moderate, and growth habit is procumbent. Clusters are medium sized (130 g), shouldered, moderately tight and somewhat smaller than Himrod, Interlaken, Lakemont and Romulus. Berries are small to medium (1.40 g), ovoid, green skinned, moderately crisp and of a light fruity flavour. Selection 666 is essentially seedless but with some traces of vestigial seeds. It has attracted attention in local markets because of its very early harvest (31 August in Summerland).

13.3 Grape breeding in Nova Scotia

The wine industry in Nova Scotia is quite small and consists of fewer than 20 wineries. Nonetheless, there has been sustained interest in grape growing for several decades, and Agriculture and Agri-Food Canada placed efforts into grape breeding for many years.

The Kentville Experiment Station (now the Atlantic Food and Horticulture Research Centre of Agriculture and Agri-Food Canada) came into being in 1911 at the request of the Nova Scotia Fruit Growers Association (GGANS). Grapes were first planted in 1913, and during the following 9 decades, more than 200 cultivars were evaluated. The first attempts at grape breeding were made in 1953 with 12 selections chosen in 1958 from *V. labruscana* parents such as Erie, Fredonia and Kendaia. Dr Donald L. Craig was the breeder. This breeding programme was discontinued because of the arrival of several promising French–American hybrids, including Maréchal Foch and de Chaunac. Another important milestone was the testing of several cultivars of Russian origin (*V. amurensis* hybrids) during the 1970s. Michurinetz was the most successful of these, becoming widely planted in Nova Scotia in the 1980s. However, by the turn of the century, most of these vines had been removed because of disease susceptibilities and fruit with low sugar levels and very high acid levels.

Among the many unnamed selections tested was a white wine selection from HRIO Vineland labelled V53261. It was derived from a Cascade × S.V.14-287 cross made in 1953 – the same cross that yielded Veeblanc. Compared with Seyval, V53261 proved to be more winter hardy and resistant to diseases, and it produced a high-quality white table wine with good varietal character. With encouragement from GGANS, it was formally named L'Acadie and introduced at a symposium on breeding and genetics of grapevines held at Montpellier, France in July 1998 (Fisher and Jamieson, 2000). L'Acadie has become the signature white wine grape of Nova Scotia (Winery Association of Nova Scotia (http://winesofnovascotia.ca/)).

The challenge of finding grapes that will thrive in Nova Scotia is made difficult by the brevity of summer and the coldness of winter in relation to those centres in North America and Europe, where most cultivars were developed. Historically, growing degree day (GDD) accumulation, calculated on a base of 10 °C, averaged <1000 at Kentville. Encouragingly, only one year in the past decade fell below 1000, and the mean GDD accumulation during that period was closer to 1100. In concert with warmer summers comes a longer growing season – harvest can be delayed to late October in the better sites. However, a negative implication is the delay of appropriate conditions for the harvest of grapes for icewine. As for minimum winter temperatures, experiencing temperatures below −25 °C is rare, but it still happens a few times per decade.

Subsequent to the first attempt at grape breeding in the 1950s, breeding was resumed in 1983 to fill the perceived need for early-maturing winter-hardy wine cultivars. As with ongoing breeding programmes in Ontario and British Columbia, objectives included general productivity, wine quality and winter hardiness. This was the year of Dr Craig's retirement, and at least part of the impetus to breed grapes came from Gerald Bishop, Dr Craig's principal technician who was also a home winemaker. About half of the seedlings planted in 1984 from these crosses were for red wine and half for white wine. Parents included French–American hybrids (Maréchal Foch, Kuhlmann 482-2, Castel 19637, Précoce de Colmar), *V. amurensis* hybrids (Michurinetz, Suputinskij Bielyi) and HRIO hybrids (V53035, V53261). In 1986, 1987, and finally in 1989, 11 seedlings (from a total of 2311) were chosen by Dr A.R. Jamieson and given a selection number. Most of these were white types; therefore, subsequent breeding focused on the whites. Of particular note were KW87-1 and KW87-2, both crosses of a white with a red. Further breeding was accomplished by Dr Jamieson in 1988, 1990 and 1991, which yielded 42 more selections with the last ones chosen in 1997. Some of the more promising of these were from the crosses Seyval × KW87-1, St. Pepin × Ortega and St. Pepin × Siegerrebe.

These Kentville selections have been evaluated for horticultural characteristics in a small vineyard at Kentville (5–10 vines each) and in a larger planting managed by Walter Wuhrer at North Kingston (25 vines each). In addition, several other growers throughout eastern Canada have been testing a few selections. Over the last decade, information has been gained on the winter hardiness, disease resistance, yield, season of maturity and accumulated sugars and acids in the grapes. In addition, small-batch wines were made from many of the selections by winemaker Bruce Ewert (of L'Acadie Vineyards). On the basis of this information, several selections were favoured whereas many were discarded. However, the main criterion for deciding whether to keep or discard a selection is the quality of its wine. This information is perhaps the most difficult to acquire because of variation in the grapes from season to season and the complexities inherent in small-batch winemaking and wine tasting.

There are currently (2013) three selections being considered for naming (Table 13.8). These are all for white wine and combine sufficient winter hardiness with resistance to downy mildew and/or powdery mildew. They all mature and are ready for harvest before L'Acadie.

Grape breeding in Nova Scotia was reborn in 2011with the arrival of Dr Sean Myles, the Canada Chair in Agricultural Diversity (www.cultivatingdiversity.org). Dr Myles, employed by Dalhousie University, has established a laboratory at the Atlantic Food and Horticulture Research Centre. He also brings an interest in grape diversity and expertise in genotyping by sequencing. Myles and Jamieson first crossed New York Muscat × L'Acadie in 2011 with a view to developing a more productive muscat cultivar. This cross was requested and sponsored by a leading Nova Scotia winery. Additional crosses were done in 2012. Seedlings were planted out in 2013 in a commercial vineyard. This is an example of participatory plant breeding in which a grower/winemaker manages the planting and has influence in the selection process with a very specific outcome in mind.

Table 13.8 **Summary of grape hybrids from the Nova Scotia breeding programme**

Parentage	Selection number	Description
1980s crosses and selections		
Michurinetz × V53035		132 plants from three crosses
Marechal Foch × Michurinetz		119 plants from three crosses
Précoce de Colmar × Michurinetz		94 plants from three crosses
Michurinetz × Castel 19637		98 plants from three crosses
Suputinskij Bielyi × Kuhlmann 482-2		41 plants from two crosses
V53035 × Castel 19637		32 plants from two crosses; three selections
	KW86-4	White wine selection with labruscana flavour
	KW87-1	White wine selection with a slight muscat flavour
	KR87-3	Red wine selection with a flavour similar to Castel 19637
V53035 × Michurinetz		21 plants from one cross; three selections
	KW86-2	White wine selection
	KW86-3	White wine selection
	KW87-2	White wine selection
Michurinetz × Précoce de Colmar		18 plants from one cross
Kuhlmann 482-2 × Suputinskij Bielyi		16 plants from one cross
V53261 × Michurinetz		70 plants from three crosses
Michurinetz × V53261		20 plants from one cross
V53261 × Castel 19637	KR86-1	Red wine selection
1990s crosses and selections		
Seyval × KW87-1	KW94-1	White wine selection
Seyval × KW87-1	KW94-2	White wine selection
St. Pepin × Siegerrebe	KW96-2	White wine selection

13.4 Conclusions

The breeding programmes at Vineland and Summerland produced numerous wine grape and table grape cultivars. Unfortunately, few of the wine grape cultivars were widely planted because the wine industry had evolved by the late 1980s to an almost exclusively *V. vinifera*-based industry in British Columbia whereas VQA Ontario permitted only six hybrid cultivars for VQA-labelled wines. Consequently, most commercial plantings of cultivars such as Veeblanc, Vivant, Veeport, Vincent, etc. were removed.

With table grapes, Sovereign Coronation has become popular in Ontario and approximately 200 ha are in production. Smaller acreages of Skookum Seedless are present in Ontario and British Columbia. Some Vineland hybrids such as Veeblanc and Vivant are recommended by U.S. universities as potential cultivars for cool and cold climates.

References

Bradt, O.A., 1975. The Grape in Ontario. Ontario Ministry of Agric. and Food Public. 487.

Cliff, M.A., Dever, M.C., Reynolds, A.G., 1996. Descriptive profiling of new and commercial British Columbia table grape cultivars. Am. J. Enol. Vitic. 47, 301–308.

de Chaunac, A., 1952. Canada-a winemaking country. Am. J. Enol. Vitic. 3, 23–26.

Denby, L.G., 1977. 'Sovereign coronation' grape. HortScience 12, 512.

Denby, L.G., Wood, D.F., 1977. 'Sovereign Rose' grape. HortScience 12, 513.

Fisher, K.H., Bradt, O.A., Cline, R.A., 1979. The Grape in Ontario. Ontario Ministry of Agric. and Food Public. 487.

Fisher, K.H., Jamieson, A.R., 2000. L'Acadie, a cold hardy, white wine cultivar for low heat unit districts. Acta Hortic. 528, 563–567.

Hedrick, U.P., 1908. The Grapes of New York. State of New York Department of Agriculture 15th Annual Report, vol. 3. Part II. J.B. Lyon Co., Albany.

Ontario Department of Agriculture, 1914. Fruits of Ontario. Fruit Branch, Ont. Dept. of Agriculture. L.K. Cameron, Toronto.

Palmer, E.F., 2006. The first fifty years 1906–1956. Reprinted from the original (1956). In: Loughton, A., Chudyk, R.V., Wanner, J. (Eds.), Celebrating a Century of Success 1906–2006. Horticultural Experiment Station, Vineland and the University of Guelph.

Reynolds, A.G., Bouthillier, M.J., Wardle, D.A., Denby, L.G., 1997a. 'Skookum Seedless' grape. HortScience 32, 743–744.

Reynolds, A.G., Bouthillier, M.J., Wardle, D.A., Denby, L.G., 1997b. 'Sooke Seedless' grape. HortScience 32, 745–746.

Reynolds, A.G., Denby, L.G., Bouthillier, M.J., 1989a. 'Simone' grape. HortScience 24, 866–867.

Reynolds, A.G., Denby, L.G., Bouthillier, M., Strachan, G.E., 1989b. 'Sovereign Tiara' grape. HortScience 24, 397–398.

Reynolds, A.G., Denby, L.G., Strachan, G.E., Bouthillier, M., 1988. 'Sovereign Opal' grape. HortScience 23, 642–643.

Reynolds, A.G., Fuleki, T., Evans, W.D., 1982. Inheritance of methyl anthranilate and total volatile esters in *Vitis* spp. Am. J. Enol. Vitic. 33, 14–19.

Reynolds, A.G., Wardle, D.A., Bouthillier, M.J., 2005. A comparison of table grape selections bred at Summerland, British Columbia. J. Am. Pomol. Soc. 59 (3), 161–168.

Reynolds, A.G., Wardle, D.A., Zurowski, C., Looney, N.E., 1992. Phenylureas CPPU and thidiazuron affect yield components, fruit composition, and storage potential of four seedless grape selections. J. Am. Soc. Hort. Sci. 117, 85–89.

Siddiqua, M., Nassuth, A., 2011. *Vitis CBF1* and *Vitis CBF4* differ in their effect on *Arabidopsis* abiotic stress tolerance, development and gene expression. Plant Cell Environ. 34, 1345–1359.

Siddiqua, M., Xiao, H., Nassuth, A., 2009. Promoter analysis of grape CBF genes. Acta Hortic. 827, 323–328.

Xiao, H., Tattersall, E.A.R., Siddiqua, M.K., Cramer, G.R., Nassuth, A., 2008. CBF4 is a unique member of the CBF transcription factor family of *Vitis vinifera* and *Vitis riparia*. Plant Cell Environ. 31, 1–10.

Xiao, H., Nassuth, A., 2006. Stress- and development-induced expression of spliced and unspliced transcripts from two highly similar dehydrin 1 genes in *Vitis riparia* and *Vitis vinifera*. Plant Cell Rep. 25, 968–977.

Grapevine breeding in the Eastern United States

14

A.G. Reynolds[1], *B.I. Reisch*[2]
[1]Brock University, St Catharines, ON, Canada; [2]Cornell University, Geneva, NY, USA

14.1 Cultivar selection in the nineteenth century

Before the beginning of formal grape breeding programmes administered by universities and research stations, amateur horticulturists and nurserymen throughout the eastern United States and Canada engaged in the selection of promising seedlings and conducted some controlled crosses (Cattell and Stauffer Miller, 1980). Many of these introductions were likely pure *Vitis labrusca*, although few records exist to verify the breeding history. Most are thought to be hybrids between *V. labrusca* and any of *V. aestivalis* (e.g. Ives; Table 14.1), *V. bourquiniana* (e.g. Delaware, Dutchess, Table 14.1), *V. riparia* (e.g. Clinton, Elvira; Table 14.1) and *V. vinifera* (numerous cultivars – e.g. Catawba, Isabella, Concord, Table 14.1). The ancestry of a few cultivars is known (e.g. most of the E.S. Rogers' hybrids and those introduced by Rommel in Missouri). The most comprehensive description of these many *V. labruscana* cultivars introduced throughout the nineteenth century can be found in Hedrick et al. (1908). Depictions of some common *V. labruscana* cultivars are found in Figure 14.1.

14.2 Breeding programme at the New York State Agricultural Experiment Station (Cornell University)

The story of grape breeding in the eastern United States from the beginning of the twentieth century to present is essentially written by the history of the New York State Agricultural Experiment Station in Geneva, NY. The station was established in 1882 and shortly thereafter began work in tree fruit, small fruit and grape breeding. Numerous individuals have filled the position of grape breeder since the station's establishment, including E.S. Goff (1882–1891), Spencer Beach (1891–1905), U.P. Hedrick (1905–1928), Fred Gladwin (stationed at Fredonia, 1913–1940), Richard Wellington (1906–1913, 1920–1953), George Oberle (1937–1948), John Einset (1942–1973), Robert Pool (1973–1979) and Bruce Reisch (1980–present). Table 14.2 summarizes the introductions made by Dr Wellington and colleagues at the beginning of the twentieth century. Table 14.3 roughly approximates those introductions made by Dr Einset whereas Table 14.4 summarizes the introductions made by Dr Reisch's programme.

Initial objectives of the programme were not substantially different from those today. In general, for table grapes, breeders attempted to combine the winter hardiness,

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00014-4

Table 14.1 Examples of nineteenth century grape cultivars bred in eastern North America, listed chronologically (Hedrick et al., 1908)

Cultivar	Ancestry	Date of introduction	Origin/breeder
Alexander	*labrusca*	Pre-1804	John Alexander, Philadelphia, PA
Catawba	*labrusca/vinifera*	1823	John Adlum, DC
Isabella	*labrusca/vinifera*	1816	W. Prince, Flushing, NY
Clinton	*labrusca/riparia*	1835	J.W. Bissell, Waterford, NY
Ives	*labrusca/aestivalis*	1844	Henry Ives, Cincinnati, OH
Delaware	*labrusca/bourquiniana/vinifera*	1851	A. Thompson, Delaware, OH
Concord	*labrusca/vinifera*	1854	E.W. Bull, Concord, MA
Agawam	*labrusca/vinifera* (Carter × Black Hamburg)	1860	E.S. Rogers, Salem, MA
Othello	*vinifera/riparia/labrusca*	1867	Charles Arnold, Paris, ON
Elvira	*riparia/labrusca* (Taylor × Martha)	1874	J. Rommel, Morrison, MO
Niagara	*labrusca/vinifera* (Concord × Cassady)	1872	C.L. Hoag and B.W. Clark, Lockport, NY
Noah	*riparia/labrusca* (Taylor open pollinated)	1876	O. Wasserzieher, Nauvoo, IL
Dutchess	*vinifera/labrusca/bourquiniana/aestivalis*	1880	A.J. Caywood, Marlboro, NY
Worden	*labrusca* (Concord seedling open pollinated)	1881	Schuyler Worden, Minetto, NY
Diamond	*labrusca/vinifera*	1885	Jacob Moore, Brighton, NY

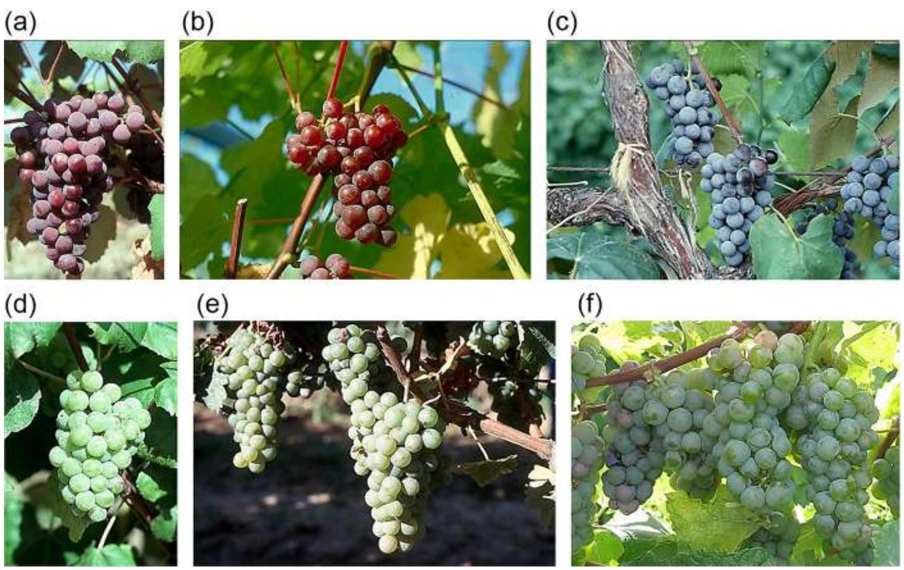


Figure 14.1 *Vitis labruscana* cultivars introduced during the nineteenth century: (a) Catawba, (b) Delaware, (c) Concord, (d) Diamond, (e) Niagara and (f) Elvira.
Photo credits: A.G. Reynolds.

Table 14.2 A list of grape cultivars released from the NY Agricultural Experiment Station, Geneva, NY, 1908–1938 (Slate et al., 1962)

Cultivar	Parentage and date released	Description
Goff	*labrusca/vinifera*, 1908	Large red-berried, cylindrical clustered table grape
Brocton	Brighton × NY 125 (Winchell × Diamond), 1923	White labruscana
Ontario	Winchell × Diamond, 1923	White, a labruscana-muscat juice grape
Sheridan	Herbert × Worden, 1923	Blue seeded juice or table grape
Urbana	Ross × Mills, 1923	Large-berried pink table grape
Fredonia	Champion × Lucile, 1928	Large-berried blue seeded table grape
Golden Muscat	Muscat Hamburg × Diamond, 1928	*Orientalis* type white seeded muscat table grape
Westfield	Herbert × Concord Seedless, 1930	Blue Concord type
Watkins	Mills × Ontario, 1930	Concord type
Seneca	Lignan blanc × Ontario, 1933	*Orientalis* type white seeded table grape
Van Buren	Fredonia × Worden, 1935	Concord type
Bronx Seedless	NY 8536 (Goff × Iona) × Sultanina, 1937	Red seedless
Yates	Mills × Ontario, 1937	Dark red-seeded table grape
Athens	Hubbard × Portland, 1938	Concord type
Buffalo	Herbert × Watkins, 1938	Blue seeded juice or table grape
Kendaia	Portland × Hubbard, 1939	Early-maturing Concord type

Table 14.3 A list of grape cultivars released from the New York Agricultural Experiment Station, Geneva, NY, 1947–1977 (Slate et al., 1962)

Cultivar	Parentage and date released	Description
Schuyler	Zinfandel × Ontario, 1947	Blue seeded table grape
Steuben	Wayne × Sheridan, 1947	Blue seeded table grape
Interlaken Seedless	Ontario × Sultanina, 1947	Seedless white table grape
Alden	Ontario × Gros Guillaume (Ribier), 1952	*Orientalis* type seeded blue muscat table grape
Bath	Fredonia × NY 10805 (Chasselas × Mills), 1952	Blue seeded juice or table grape
Himrod	Ontario × Sultanina, 1952	Seedless white table grape
Naples	Delaware × NY 8042 (Mills × Iona), 1952	Red berried seeded table grape
Romulus	Ontario × Sultanina, 1952	Seedless white table grape
Canada Muscat	Muscat Hamburg × Hubbard, 1961	Muscat juice or wine grape
New York Muscat	Muscat Hamburg × Ontario, 1961	Blue seeded muscat table grape; used for juice and wine
Cayuga White	Seyval blanc × Schuyler, 1972	Floral white wine grape
Lakemont	Ontario × Sultanina, 1972	Seedless white table grape
Suffolk Red	Fredonia × Black Kishmish, 1972	Pinkish seedless table grape
Canadice	Bath × Himrod, 1977	Small-berried, seedless pink table grape
Glenora	Ontario × Black Kishmish, 1977	Blue seedless table grape

Table 14.4 A list of grape cultivars released from the New York Agricultural Experiment Station, Geneva, NY, 1981 to present

Cultivar	Origin	Description
Remaily Seedless	Lady Patricia × NY 33979 (Ontario × Black Kishmish), 1981	*Orientalis* type white seedless table grape
Horizon (GW7)	Seyval blanc × Schuyler, 1982	Neutral white wine grape
Einset Seedless	Fredonia × Canner, 1985	Pink seedless table grape
Melody	Seyval blanc × GW5 (Pinot blanc × Ontario), 1985	Floral white wine grape
Chardonel (GW9)	Seyval blanc × Chardonnay, 1990	White wine grape similar to Chardonnay but hardier
Marquis	Athens × Emerald Seedless, 1996	Seedless white table grape
Traminette	J.S. 23-416 × Gewurztraminer, 1996	Traminer-like white wine grape
Geneva Red (GR7)	Buffalo × Baco noir, 2003	Red wine grape
Valvin Muscat	Muscat de Moulin × Muscat Ottonel, 2006	Muscat-flavoured white wine grape
Corot noir	S.V. 18-307 × Steuben, 2006	Red wine grape
Noiret	NY 65.0467.08 × Steuben, 2006	Red wine grape
Arandell	NY 84.0101.03 × NY 88.0514.01, 2013	Disease-resistant red wine grape
Aromella	Traminette × Ravat 34, 2013	Aromatic white wine grape

disease resistance and productivity characteristics in the *V. labruscana* cultivars with quality characteristics present in *V. vinifera*, including muscat flavour, crispness, storageability, large berry size and seedlessness. Therefore, traditional *V. labruscana* cultivars such as Concord, Delaware, Diamond and others were crossed with Black Hamburg, Chasselas, Gros Guillaume, Lignan blanc, Muscat Hamburg and Sultanina (Thompson Seedless) (Tables 14.2 and 14.3). Table grapes introduced during this early period included Fredonia (Champion × Lucile, 1928), Golden Muscat (Muscat Hamburg × Diamond, 1928), Seneca (Lignan blanc × Ontario, 1933) and Bronx Seedless (NY 8536 (Goff × Iona) × Sultanina, 1937). Some later introductions from these crosses included NY Muscat (Muscat Hamburg × Ontario, 1961) and Canada Muscat (Muscat Hamburg × Hubbard, 1961) (Table 14.3). In addition, numerous cultivars were introduced as juice grapes such as Westfield (Herbert × Concord Seedless, 1930), Watkins (Mills × Ontario, 1930), Van Buren (Fredonia × Worden, 1935) and many others (Table 14.2). Depictions of some cultivars introduced by the research station in Geneva between 1928 and 1961 are found in Figure 14.2.

Subsequent breeding efforts attempted to further increase quality and attractiveness in table grapes by introducing seedlessness as a primary objective. Concord Seedless was introduced after being brought to the attention of the research station in 1913. In 1919, a programme directed by Dr A.B. Stout of the New York Botanical Garden was initiated and several crosses were made involving Sultanina (Thompson Seedless). Stout Seedless (1929) and Bronx Seedless (1937) were the first two introductions

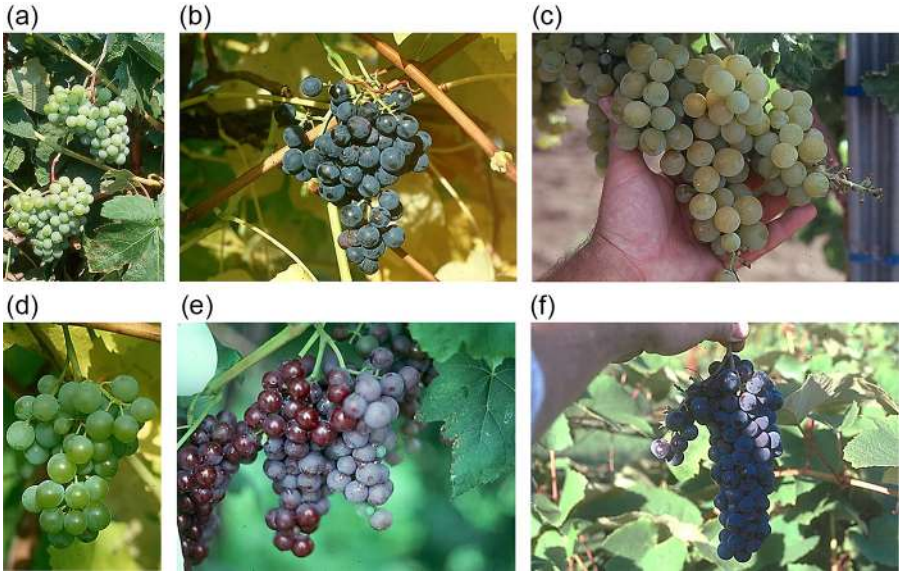


Figure 14.2 Examples of cultivars introduced by the New York State Agricultural Experiment Station, 1928–1961: (a) Seneca, (b) Buffalo, (c) Golden Muscat, (d) Canada Muscat, (e) New York Muscat and (f) Bath.
Photo credits: A.G. Reynolds.

(see http://www.hort.cornell.edu/reisch/grapegenetics/bronx.html). Subsequent seedless introductions included Interlaken Seedless (Ontario × Sultanina, 1947), Himrod (Ontario × Sultanina, 1952) and Romulus (Ontario × Sultanina, 1952) (Table 14.3). Lakemont was introduced from these crosses in 1972 (Table 14.3). Later crosses involved Geneva cultivars crossed with Black Kishmish and resulted in Suffolk Red (Fredonia × Black Kishmish, 1972) and Glenora (Ontario × Black Kishmish, 1977) (Table 14.3). Depictions of some mainly seedless cultivars introduced by the research station in Geneva between 1947 and 1972 are in Figure 14.3.

The first cultivar specifically designated as a wine grape was Cayuga White (Seyval blanc × Schuyler, 1972) (Table 14.3; Figure 14.3). After this introduction, several wine grapes followed, including Horizon (Seyval blanc × Schuyler, 1982), Melody [Seyval blanc × GW5 (Pinot blanc × Ontario), 1985], Chardonel (Seyval blanc × Chardonnay, 1990), Traminette (J.S. 23-416 × Gewürztraminer, 1996), Geneva Red (Buffalo × Baco noir, 2003), Valvin Muscat (Muscat de Moulin × Muscat Ottonel, 2006), Corot noir (S.V. 18-307 × Steuben, 2006) and Noiret (NY 65.0467.08 × Steuben, 2006) (Table 14.4). As is clear, the objective in the past 30 years has been to combine quality characteristics of *V. vinifera* with the disease resistance and winter hardiness of French–American hybrids such as Baco noir, Seyval blanc and J.S. 23-416, or those found in Geneva cultivars such as Steuben. Most recently, the floral/muscat cultivar Aromella (Traminette × Ravat 34, 2013; see Reisch et al., 2014a) and disease-resistant red wine grape Arandell (NY 84.0101.03 × 88.0514.01, 2013; see Reisch et al., 2014b) were introduced (Table 14.4). The latter cultivar represented a change in tactics by the

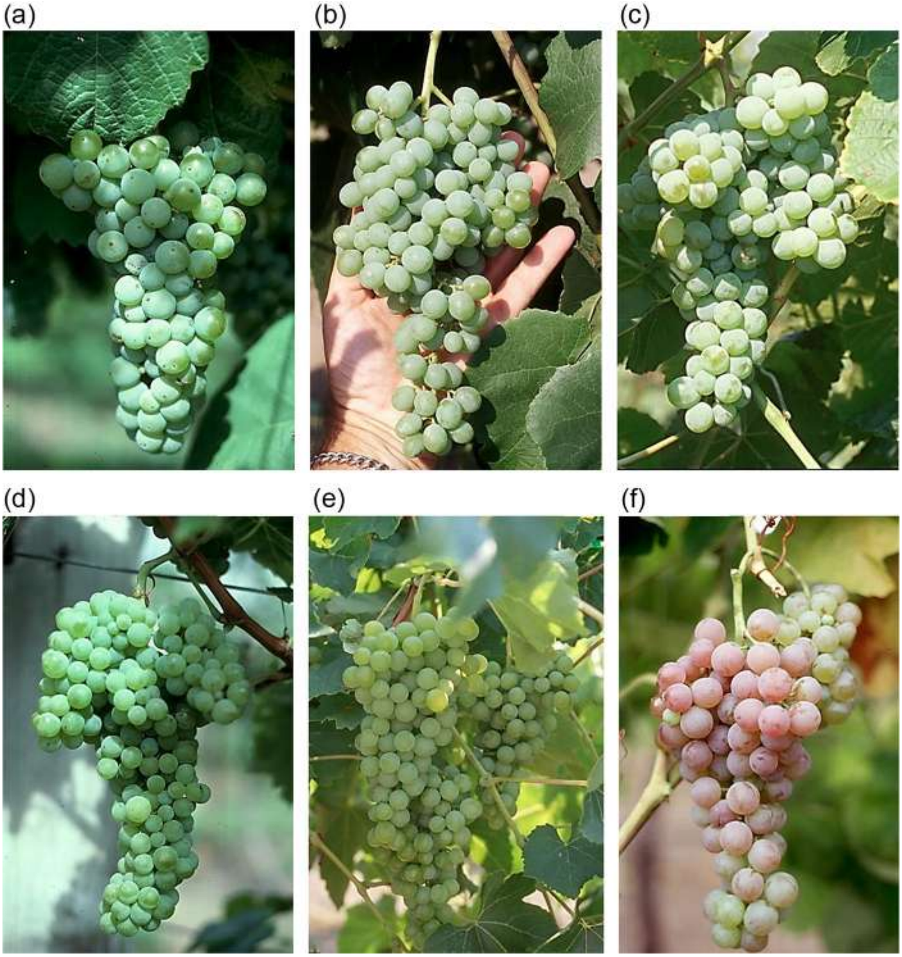


Figure 14.3 Examples of cultivars introduced by the New York State Agricultural Experiment Station, 1947–1972: (a) Cayuga White, (b) Himrod, (c) Interlaken, (d) Lakemont, (e) Romulus and (f) Suffolk red.
Photo credits: A.G. Reynolds.

programme. Rather than sourcing disease resistance from French–American hybrid vines, wild species such as *Vitis rupestris* and *Vitis cinerea* are now being used. The goal at present is to develop quality cultivars with the highest possible level of disease resistance, minimizing the need for fungicide use. Seedless grape breeding has also continued, and noteworthy introductions have included Remaily Seedless [Lady Patricia × NY 33979 (Ontario × Black Kishmish), 1981], Einset Seedless (Fredonia × Canner, 1985) and Marquis (Athens × Emerald Seedless, 1996) (Table 14.4). Depictions of some cultivars introduced by the research station in Geneva between 1981 and 2006 are found in Figure 14.4.

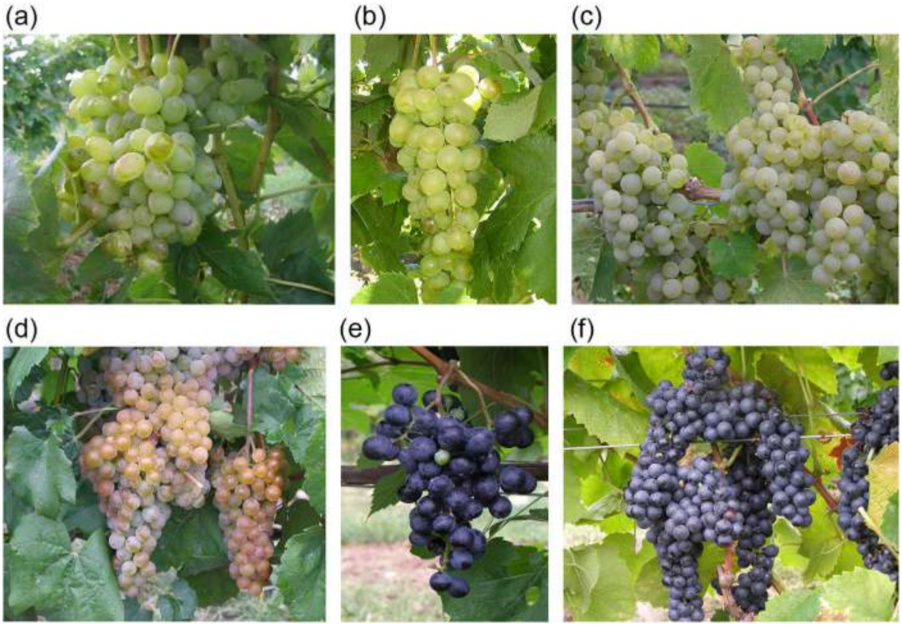


Figure 14.4 Examples of cultivars introduced by the New York State Agricultural Experiment Station, 1981–2006: (a) Remaily Seedless, (b) Marquis, (c) Valvin Muscat, (d) Traminette, (e) Corot noir and (f) Noiret.
Photo credits: (a), (c)–(f): A.G. Reynolds; (b): B.I. Reisch.

Brief descriptions of those cultivars released by the New York State Agricultural Experiment Station since 1947, in chronological order, are presented in the following sections. Detailed descriptions of the 1947–1961 releases can be found in Slate et al. (1962). Later releases are referenced accordingly.

14.3 Table grapes

Schuyler (Zinfandel × Ontario, 1947). Schuyler was released as a seeded table grape, but it was also used as a wine grape parent (e.g. giving rise to Cayuga White and Horizon). Vines are vigorous, productive and just moderately winter hardy. Clusters are large, conical with a small shoulder and with medium-large orbicular berries. Flavour is mild labrusca and berries have slipskin character.

Steuben (Wayne × Sheridan, 1947). Steuben has found some popularity in New York State vineyards, but more recently it has been known as the parent of two red wine grape cultivars, Corot noir and Noiret. Its main intended use at the time of release was as a table grape. Vines are vigorous, productive and winter hardy. Clusters are large and cylindrical with medium-large orbicular berries. Flavour is mild labrusca, and berries have a slipskin character.

Interlaken Seedless (Ontario × Sultanina, 1947). Interlaken Seedless was the first of four cultivars selected from Ontario × Sultanina crosses made in 1928 (the other three being Himrod, Romulus and Lakemont). Clusters are medium, conical and winged with medium-sized oval berries (Figure 14.3(c)). The texture is somewhat crisp, and it has a mild fruity/labrusca flavour. It matures in late August/early September.

Alden (Ontario × Gros Guillaume, 1952). Alden is a seeded table grape with large oval berries that have a firm texture and a mild muscat flavour. Clusters can be large but are relatively loose. The authors' experience with this cultivar is that it is somewhat winter tender.

Bath [Fredonia × NY 10805 (Chasselas × Mills), 1952]. Bath once was a major cultivar in British Columbia until the 1980s, but it did not achieve commercial success in eastern North America. Vines are vigorous, productive and winter hardy. Clusters are medium-sized, tight and cylindrical with large orbicular slipskin berries (Figure 14.2(f)). There is some labrusca flavour character.

Himrod (Ontario × Sultanina, 1952). Himrod was for many years one of the best hardy seedless table grapes. The vines are normally vigorous, productive and winter hardy. Clusters can be large and conical with prominent wings and orbicular berries that have thin friable skins, firm/juicy texture and a mild fruity honey-like flavour (Figure 14.3(b)). Fruit matures in early September. Himrod's main problem is that berries tend to drop from the rachis (shattering), particularly if harvest has been delayed. It has seen some commercial planting in New York State and Ontario, and it can be found growing commercially or being used as a table grape parent at many locations around the world.

Naples [Delaware × NY 8042 (Mills × Iona), 1952]. Slate et al. (1962) describe Naples as extremely vigorous and productive, with small conical clusters and small orbicular berries. It resembles its parent, Delaware. The authors are unaware of any significant commercial experience with this cultivar.

Romulus (Ontario × Sultanina, 1952). Romulus is a late-season (early October) seedless table grape. It is very vigorous, productive and moderately winter hardy. Romulus was used as a parent in the British Columbia program as a source of seedlessness. Clusters are large, conical and winged; berries are orbicular and medium-large, with firm flesh and thin, friable skin (Figure 14.3(e)). Flavour is neutral to slightly fruity.

Lakemont (Ontario × Sultanina, 1972). Lakemont is an early-season seedless table grape (Einset, 1972). As with its sister seedling, Interlaken Seedless, vines are at best moderately vigorous, productive and winter hardy. Clusters are large, conical and winged, with medium-sized oval berries that have friable skins and firm flesh (Figure 14.3(d)). Flavour is mild fruity. There is limited commercial experience with this cultivar.

Suffolk Red (Fredonia × Black Kishmish, 1972). Suffolk Red is one of several cultivars that resulted from Black Kishmish crosses made in 1935 (Einset, 1972). Vines are vigorous but only moderately winter hardy. Clusters are large, conical and winged (Figure 14.3(f)). However, the authors' experience has been that clusters can often be small, and the red colour is often irregular, with many green berries. The berries are medium-large, orbicular and red, with friable skin and firm or slightly meaty flesh. Flavour is neutral to mildly fruity.

Canadice (Bath × Himrod, 1977). Canadice is an attractive pink seedless cultivar (Pool et al., 1977). Vines are normally vigorous, productive and reasonably winter hardy. Clusters are medium-sized and conical, with a small wing and medium-small round berries. Berries have a thin, friable skin and flavour is not unlike Delaware – mildly fruity, very sweet and candy-like.

Glenora (Ontario × Black Kishmish, 1977). Glenora is a blue seedless table grape resulting from a cross made in 1947 (Pool et al., 1977). Vines are vigorous and productive, but they are somewhat sensitive to winter injury. Clusters are large and cylindrical with medium orbicular berries.

Remaily Seedless [Lady Patricia × NY 33979 (Ontario × Black Kishmish), 1981]. This cultivar was named in honour of George Remaily, an amateur grape breeder who worked briefly at the Geneva Research Station and made the cross resulting in this new cultivar (Pool et al., 1981). Vines are vigorous but only moderately productive and somewhat sensitive to winter injury. Clusters are very large and conical, with large, oval berries (Figure 14.4(a)). Berries have thin, friable skins and a firm texture, with mildly fruity flavour.

Einset Seedless (Fredonia × Canner, 1985). This cultivar was named in honour of Dr John Einset, who was the grape breeder at Geneva for many years (Reisch et al., 1985b, 1986b). Vines are vigorous, productive and reasonably winter hardy. Clusters are medium-sized and conical, with a small wing and slightly oval, pink seedless berries. Skin is friable and the flesh is crisp. The flavour is mildly fruity.

Marquis (Athens × Emerald Seedless, 1996). Marquis is a white seedless cultivar (Reisch et al., 1996a). Clusters are large, cylindrical and winged, with large round berries (Figure 14.4(b)). Berry skins are friable and thick, and the flesh is soft and juicy. Flavour is mildly fruity with a note of labrusca, increasingly so as it ripens further.

14.4 Wine grapes

Canada Muscat (Muscat Hamburg × Hubbard). Although not officially classified as a wine cultivar, Canada Muscat was once used as a blending component, particularly in Ontario, hence its name. Vines are vigorous, productive and winter hardy. Clusters are medium, conical, usually winged and with medium orbicular berries (Figure 14.2(d)). There is intense muscat flavour but also some less desirable flavour characteristics described by some as ‘cat urine.’

New York Muscat (Muscat Hamburg × Hubbard, 1961). Similar to Canada Muscat, New York Muscat was not officially designated as a wine grape cultivar upon its release; however, it has achieved some commercial success in eastern North America as a wine grape. The vines are vigorous, moderately productive and moderately winter hardy. Clusters are medium-large, conical and winged, with medium round berries (Figure 14.2(e)). Flavour is intense muscat with some other labrusca flavour elements unlike traditional European muscats.

Cayuga White (GW3; Seyval blanc × Schuyler, 1972). Cayuga White was the first wine grape cultivar introduced by Geneva that was officially designated as a wine grape (Einset and Robinson, 1972). The vines are very vigorous, productive and medium winter hardy. Clusters can be large and are conical and shouldered, with large, orbicular, slightly slipskin berries (Figure 14.3(a)). Wine flavour is normally pleasantly fruity if fruit is harvested at approximately 16–18 Brix, but if allowed to become overripe some labrusca flavour notes may develop. Cayuga White was widely planted in New York State and elsewhere and continues to maintain limited popularity in the wine industry.

Horizon (Seyval blanc × Schuyler, 1982). Horizon is a sister seedling of Cayuga White, tested for many years as GW7 (Reisch et al., 1982, 1983). It was introduced largely as a neutral white wine grape cultivar that could be used as a blending component. It never achieved the anticipated popularity in the wine industry. As with Cayuga White, vines are vigorous, productive and yet more winter hardy than Cayuga White. Clusters are medium-large, conical, with medium-large round berries. Wines are indeed neutral in flavour.

Melody [Seyval blanc × GW5 (Pinot blanc × Ontario), 1985]. Melody was introduced as an easy-to-grow wine grape that did not require cluster thinning like so many French–American hybrids (Reisch et al., 1985a, 1986a). It is productive, moderately resistant to disease and winter hardy. Wines can be fairly neutral to distinctively fruity with some apricot character. There has been some commercial success with Melody in New York, Maryland and elsewhere in the eastern United States.

Chardonel (GW9, Seyval blanc × Chardonnay, 1990). Chardonel is a late-maturing wine grape that has achieved significant commercial success in Missouri, Arkansas, Michigan and other locations in the eastern United States. The vines are vigorous, productive and moderately winter hardy (Reisch et al., 1990a,b). Clusters are large and tight with round berries. Wines are mildly fruity and can be considered reminiscent of Chardonnay. Chardonel has frequently been barrel-fermented or barrel-aged, which enhances its Chardonnay-like aspects.

Traminette (J.S. 23-416 × Gewürztraminer, 1996). Traminette is another Geneva cultivar that has achieved significant commercial success in the eastern United States, garnering many awards at national and international competitions. Wines are indeed reminiscent of Gewürztraminer and frequently are more intense (Reisch et al., 1996b, 1997). Vines are normally vigorous, productive and winter hardy enough to withstand cold winters in the U.S. Midwest. Clusters are medium-sized, conical and vary in compactness, with medium-sized round amber/pink berries.

Geneva Red (GR7, Buffalo × Baco noir, 2003). GR7 was originally named ‘Abundance.’ The name had to be abandoned because of a conflict with a pre-existing vineyard name in California. This cultivar is vigorous, productive and winter hardy (Reisch et al., 2003). Wines exhibit dark fruit notes but can be herbaceous or mildly labrusca in some seasons. Commercial success has been limited.

Valvin Muscat (Muscat de Moulin × Muscat Ottonel, 2006). This is a noteworthy contribution of the breeding programme. Vines are at best moderately vigorous and productive and should be grafted; winter hardiness is sufficiently high to permit cultivation in the U.S. Midwest (Reisch et al., 2006c). Wines have a pronounced floral/muscat flavour/aroma without the bitterness frequently found in muscat cultivars.

Corot noir (S.V. 18-307 × Steuben, 2006). Corot noir is one of two red wine cultivars released in 2006 (Reisch et al., 2006a). It is moderately winter hardy, relatively resistant to disease and matures in early or mid-October. Wines are intensely coloured and have elements of cherry and berry fruit aromas. It has been recommended as a potential varietal wine cultivar and for blending.

Noiret (NY 65.0467.08 × Steuben, 2006). As with Corot noir, Noiret is a red wine grape cultivar released from the Geneva program in 2006 (Reisch et al., 2006b). It is also moderately winter hardy and resistant to disease, ripening in late September/early October. Wines are dark-coloured, with intense aromas of dark fruits and black pepper. Noiret is also noted as one of the few eastern red wine cultivars with tannin.

Arandell (NY 84.0101.03 × 88.0514.01, 2013). Arandell and Aromella are the most recent introductions from this program. Arandell is noteworthy as a red wine grape cultivar with very high disease resistance, and it has potential for organic production (Reisch et al., 2013b, 2014a). Wines are dark red with clean berry aromas.

Aromella (Traminette × Ravat 34, 2013). Aromella was released to provide an aromatic white wine cultivar (Reisch et al., 2013a, 2014b) that is highly productive and very winter hardy. Wines are described as having elements of pineapple, honeysuckle, citrus peel and muscat. Vines are productive and resistant to disease.

A comprehensive list of all cultivars released by the New York State Agriculture Experiment Station can be found at http://www.hort.cornell.edu/reisch/grapegenetics/nyreleases.html. There are also several sites describing cultivar introductions and recommendations: http://www.hort.cornell.edu/reisch/grapegenetics/cultivars.html (recent variety introductions), http://www.hort.cornell.edu/reisch/grapegenetics/winehandout.html (the least risky varieties), http://www.hort.cornell.edu/reisch/grapegenetics/bulletin/wine/index.html (wine and juice varieties for cold climates; Reisch et al., 1993b) and http://www.hort.cornell.edu/reisch/grapegenetics/bulletin/table/index.html (table grape varieties for cool climates; Reisch et al., 1993a).

14.5 Molecular breeding

Since 1981, the grape breeding programme at Geneva has partially focused upon molecular breeding techniques in addition to its significant classical breeding. Initially, the gene transfer process was intended to be performed through standard *Agrobacterium*-mediated processes. However, invention of the gene gun by experiment station colleagues in the mid-1980s (Sanford et al., 1987) facilitated the gene transfer process. An example of this activity is the conferral of disease resistance to *V. vinifera* by transfer of a chitinase-producing gene. Chitinase attacks fungal cell walls and consequently inhibits their growth. Cell suspensions of Chancellor were initially 'bombarded' with marker genes that enable the researchers to track the transformation process. These markers were created by the insertion of genes producing β-glucuronidase (GUS) and neomycin phosphotransferase II enzymes into grape tissues. Transformed plants turned blue when supplied with metabolic precursors, but only if the GUS gene was successfully inserted into the DNA and produced the glucuronidase enzyme (Kikkert et al., 1996, 1997). Thereafter, researchers used the Chancellor-based system to transfer chitinase genes to cultivars such as Chardonnay and Merlot (Kikkert et al., 2009). As a result of this body of work, improvements in powdery mildew and *Botrytis* rot resistance were noted. However, the levels of resistance were not sufficiently elevated to pursue commercialization.

Another line of work aimed to improve disease resistance through the use of short proteins known as anti-microbial peptides (AMPs). Several such AMPs were transferred into Chardonnay, and their effects on disease resistance were studied (Vidal et al., 2006; Rosenfield et al., 2010). The level of resistance to crown gall disease was markedly improved, but again commercialization was not pursued.

A second significant area of research has been the characterization of molecular markers to identify specific genes responsible for traits such as powdery mildew and black rot resistance. A project involving a cross of Horizon (Seyval × Schuyler) × Illinois 547-1 (*V. rupestris* × *V. cinerea*) as well as Cayuga White × Aurore identified monogenic inheritance for flower type (Dalbó et al., 2001) but multi-genic inheritance for resistance to powdery mildew and black rot (Lodhi et al., 1995, 1997; Dalbó et al., 2001).

Further research on molecular marker-based genome mapping continues to date (see http://www.vitisgen.org). The inheritance of disease resistance and numerous other traits (e.g. cold tolerance, bud-break, fruit metabolites) is being studies in five related populations descending from *V. rupestris*, *V. cinerea*, Horizon and Chardonnay. Highly dense genetic maps are being created using single nucleotide polymorphism markers and are being used to scan the genome for regions controlling traits of interest for grapevine breeding. New loci controlling resistance and susceptibility to powdery mildew were recently identified (Barba et al., 2013).

Molecular marker-based maps are also being used to improve the efficiency of the grape breeding process. Markers linked to known genes for traits such as disease resistance and seedlessness are being used to pre-select seedlings during their first year of growth. This process (known as marker-assisted selection) is being used to incorporate at times multiple genes for resistance to powdery mildew into individual seedlings (Reisch et al., 2014c). Only these pre-selected elite seedlings are then planted to a permanent vineyard to undergo further testing for other important viticultural and enological traits.

Genetic 'fingerprinting' by random amplified polymorphic DNA polymorphisms has also been utilized to assess differences/similarities among cultivars with minor phenotypic differences. For example, the cultivars Pinot noir, Pinot Meunier, Pinot gris and Gamay Beaujolais (not Gamay noir) were identical, whereas Auxerrois and Melon were different (Guang-Ning et al., 1998). Clones of Chardonnay or Pinot noir could not be distinguished from each other.

Readers are referred to the following website for additional details on Cornell's grape genetics program: http://www.hort.cornell.edu/reisch/grapegenetics/grapegen.html.

14.6 Conclusions

The breeding program at Geneva has introduced at least 57 cultivars and has many more under test. It has had a significant effect on viticulture throughout North America. Recent introductions such as Cayuga White, Chardonel and Traminette have been planted not only in New York State but throughout the midwestern United States, including Michigan, Ohio, Indiana, Missouri and Arkansas. It is likely that the more recent introductions such as Corot noir, Noiret, Arandell and Aromella will likewise experience significant commercial success throughout the eastern United States.

References

Barba, P., Cadle-Davidson, L., Harriman, J., Glaubitz, J.C., Brooks, S., Hyma, K., Reisch, B.I., 2013. Grapevine powdery mildew resistance and susceptibility loci identified on a high-resolution SNP map. Theor. Appl. Genet. 127, 73–84.

Cattell, H., Stauffer Miller, L., 1980. The Wines of the East. Native American Grapes, vol. III. L & H Photojournalism, Lancaster, Pennsylvania.

Dalbó, M.A., Ye, G.N., Weeden, N.F., Wilcox, W.F., Reisch, B.I., 2001. Marker-assisted selection for powdery mildew resistance in grapes. J. Am. Soc. Hort. Sci. 126, 83–89.

Einset, J., August 1972. Lakemont and Suffolk Red seedless grapes named. N. Y. Food Life Sci. Bull. 21.

Einset, J., Robinson, W.B., August 1972. Cayuga White, the first of a Finger Lakes series of wine grapes for New York. N. Y. Food Life Sci. Bull. 22.

Guang-Ning, Y., Soylemezoglu, G., Weeden, N.F., Lamboy, W.F., Pool, R.M., Reisch, B.I., 1998. Analysis of the relationship between grapevine cultivars, sports and clones via DNA fingerprinting. Vitis 37, 33–38.

Hedrick, U.P., Booth, N.O., Taylor, O.M., Wellington, R., Dorsey, M.J., 1908. The Grapes of New York. State of New York, Dept. of Agriculture Fifteenth Annual Report, vol. 3. J.B. Lyon Co., Albany, NY. Part II.

Kikkert, J.R., Ali, G.S., Striem, M.J., Martens, M.-H., Wallace, P.G., Molino, L., Reisch, B.I., 1997. Genetic engineering of grapevine (*Vitis* sp.) for enhancement of disease resistance. In: Altman, A., Ziv, M. (Eds.), Proceedings of the Third International Symposium on In Vitro Culture and Horticultural Breeding. ISHS. June 16–21, 1996, vol. 447. Acta Horticulturae, Jerusalem, Israel, pp. 273–279.

Kikkert, J.R., Hébert-Soule, D., Wallace, P.G., Striem, M.J., Reisch, B.I., 1996. Transgenic plantlets of 'Chancellor' grapevine (*Vitis* sp.) from biolistic transformation of embryogenic cell suspensions. Plant Cell Rep. 15, 311–316.

Kikkert, J.R., Vidal, J.R., Wallace, P.G., Garcia-Zitter, S., Wilcox, W.F., Gadoury, D.M., Seem, R.C., Burr, T.J., Rosenfield, C.-L., Samuelian, S., Reisch, B.I., 2009. Disease resistance analyses of transgenic grapevines that contain endochitinase or antimicrobial peptide genes. In: Ninth International Conference on Grape Genetics and Breeding. July 2–7, 2006, vol. 827. Acta Horticulturae, Udine, Italy, pp. 379–384.

Lodhi, M.A., Daly, M.J., Ye, G.-N., Weeden, N.F., Reisch, B.I., 1995. A molecular marker based linkage map of *Vitis*. Genome 38, 786–794.

Lodhi, M.A., Weeden, N.F., Reisch, B.I., 1997. Characterization of RAPD markers in *Vitis*. Vitis 36, 133–140.

Pool, R.M., Remaily, G., Reisch, B.I., Watson, J.P., Kimball, K.H., 1981. Remaily Seedless grape. N. Y. Food Life Sci. Bull. 89.

Pool, R.M., Watson, J.P., Kimball, K.H., Einset, J., September 1977. Canadice and Glenora seedless grapes named. N. Y. Food Life Sci. Bull. 68.

Reisch, B.I., Luce, R.S., Bordelon, B., Henick-Kling, T., 2006a. 'Corot noir'™ grape. N. Y. Food Life Sci. Bull. 159.

Reisch, B.I., Luce, R.S., Bordelon, B., Henick-Kling, T., 2006b. 'Noiret'™ grape. N. Y. Food Life Sci. Bull. 160.

Reisch, B.I., Luce, R.S., Bordelon, B., Henick-Kling, T., 2006c. 'Valvin Muscat'™ grape. N. Y. Food Life Sci. Bull. 161.

Reisch, B.I., Luce, R.S., Henick-Kling, T., Pool, R.M., 2003. 'Geneva Red' grape. N. Y. Food Life Sci. Bull. 157.

Reisch, B.I., Luce, R.S., Mansfield, A.K., 2013a. 'Aromella'. An Aromatic White Wine Grape. On: http://www.hort.cornell.edu/reisch/grapegenetics/cultivars.html.

Reisch, B.I., Luce, R.S., Mansfield, A.K., 2014a. 'Arandell'—a disease-resistant red wine grape. HortScience 49, 503–505.
Reisch, B.I., Luce, R.S., Mansfield, A.K., 2014b. 'Aromella'—an aromatic white wine grape. HortScience 49, 676–678.
Reisch, B.I., Luce, R.S., Vanden Heuvel, J.E., Mansfield, A.K., 2013b. 'Arandell'. A Disease-Resistant Red Wine Grape. On: http://www.hort.cornell.edu/reisch/grapegenetics/cultivars.html.
Reisch, B.I., Mahanil, S., Consolie, N., Luce, R.S., Wallace, P.G., Cadle-Davidson, L., 2014c. Examination of marker-assisted selection for powdery and downy mildew resistance. In: Reisch, B.I., Londo, J. (Eds.), Proceedings of the 10th International Conference on Grapevine Breeding and Genetics. August 1–5, 2010, vol. 1046. Acta Horticulturae, Geneva, NY, USA, pp. 151–155.
Reisch, B.I., Peterson, D.V., Pool, R.M., Martens, M.H., 1993a. Table Grape Varieties for Cool Climates. Information Bulletin 234. Cornell Cooperative Extension. On: http://www.nysaes.cornell.edu/hort/faculty/reisch/bulletin/table/tableindex2.html.
Reisch, B.I., Pool, R.M., Martens, M.H., Luce, R.S., Remaily, G., Zabadal, T.J., 1996a. 'Marquis' grape. N. Y. Food Life Sci. Bull. 148.
Reisch, B.I., Pool, R.M., Peterson, D.V., Martens, M.-H., Henick-Kling, T., 1993b. Wine and Juice Grape Varieties for Cool Climates. Information Bulletin 233, Cornell Cooperative Extension. On: http://www.hort.cornell.edu/reisch/grapegenetics/bulletin/wine/index.html.
Reisch, B.I., Pool, R.M., Robinson, W.B., Henick-Kling, T., Gavitt, B.K., Watson, J.P., Martens, M.H., Luce, R.S., Barrett, H.C., 1996b. 'Traminette' grape. N. Y. Food Life Sci. Bull. 149.
Reisch, B.I., Pool, R.M., Robinson, W.B., Henick-Kling, T., Gavitt, B.K., Watson, J.P., Martens, M.H., Luce, R.S., Barrett, H.C., 1997. 'Traminette' grape. HortScience 32, 152–153.
Reisch, B.I., Pool, R.M., Robinson, W.B., Henick-Kling, T., Watson, J.P., Kimball, K.H., Martens, M.H., Howell, G.S., Miller, D.P., Edson, C.E., Morris, J.R., 1990a. 'Chardonel' grape. N. Y. Food Life Sci. Bull. 132.
Reisch, B.I., Pool, R.M., Robinson, W.B., Henick-Kling, T., Watson, J.P., Kimball, K.H., Martens, M.H., Howell, G.S., Miller, D.P., Edson, C.E., Morris, J.R., 1990b. 'Chardonel' grape. HortScience 25, 1666–1667.
Reisch, B.I., Pool, R.M., Watson, J.P., Robinson, W.B., Cottrell, T.H.E., 1985a. 'Melody' grape. N. Y. Food Life Sci. Bull. 112.
Reisch, B.I., Pool, R.M., Watson, J.P., Robinson, W.B., Cottrell, T.H.E., 1986a. 'Melody' grape. HortScience 21, 158–159.
Reisch, B.I., Remaily, G.W., Pool, R.M., Watson, J.P., 1985b. 'Einset Seedless' grape. N. Y. Food Life Sci. Bull. 113.
Reisch, B.I., Remaily, G.W., Pool, R.M., Watson, J.P., 1986b. 'Einset Seedless' grape. HortScience 21, 155–156.
Reisch, B.I., Robinson, W.B., Kimball, K.H., Pool, R.M., Watson, J.P., 1982. 'Horizon' grape. N. Y. Food Life Sci. Bull. 96.
Reisch, B., Robinson, W.B., Kimball, K., Pool, R., Watson, J., 1983. 'Horizon' grape. HortScience 18, 108–109.
Rosenfield, C.-L., Samuelian, S., Vidal, J.R., Reisch, B.I., 2010. Transgenic disease resistance in *Vitis vinifera*: potential use and screening of antimicrobial peptides. Am. J. Enol. Vitic. 61, 348–357.
Sanford, J.C., Klein, T.M., Wolf, E.D., Allen, N., 1987. Delivery of substances into cells and tissues using a particle bombardment process. Part. Sci. Technol. 5, 27–37.
Slate, G.L., Watson, J., Einset, J., 1962. Grape varieties introduced by the New York State Agricultural Experiment station 1928–1961. N. Y. State Agric. Expt. Stat. Bull. 794.
Vidal, J.R., Kikkert, J.R., Malnoy, M.A., Wallace, P.G., Barnard, J., Reisch, B.I., 2006. Evaluation of transgenic 'Chardonnay' (*Vitis vinifera*) containing magainin genes for resistance to crown gall and powdery mildew diseases. Transgenic Res. 15, 69–82.

Western United States grapevine breeding

15

K. Lund
University of California, Davis, CA, USA

15.1 Introduction

The western United States is home to one of the world's premiere grape-growing regions. California accounts for 90% of the wine produced (Wine Institute, 2014), 99% of the table grapes grown (California Table Grape Commission, 2014) and nearly all of the raisin grapes grown (Agricultural Marketing Resource Center, 2014) in the United States. Economically, this accounts for sales of $23,100,000,000 for California wine (Wine Institute, 2014), $1,500,000,000 for California table grapes (USDA National Agricultural Statistics Service, 2014) and $725,000,000 for California raisins (Agricultural Marketing Resource Center, 2014). On a global scale, California ranked sixth for total vineyard acreage, fourth for wine production and second for raisin grape production in 2013 (OIV, 2014). The hefty production base in California has made California a pivotal centre for grapevine breeding in new wine, table, raisin and rootstock cultivars. Public institutions, private companies and several dedicated individual breeders have all contributed pieces to the history of breeding in the western United States.

The strongest sector in grapevine breeding in California originated within two public institutions: the University of California–Davis (UC Davis) and the U.S. Department of Agriculture (USDA) facility located near Fresno, CA. UC Davis have released 4 white wine grapes, 7 red wine grapes, 1 raisin grape, 1 rootstock variety and 12 table grape cultivars that have all been used in California viticulture. The USDA facility has released 4 raisin and 17 table grape cultivars that have been used in California viticulture. These two institutions pioneered many of the technological advances that have brought California viticulture and grapevine breeding to its current acclaimed standing in the world.

For their vines to be accepted and prosper, California grapevine breeders have all had to deal with a similar group of issues above and below the ground. These challenges cover the typical range of environmental factors, disease pressures and consumer demands. The environment within the state of California is a key issue varying widely with mild temperatures along the coast and extreme heat in the interior valleys. These environmental pressures are compounded by the effect of coastal cooling, in which valleys and regions with access to coastal wind and fog cool down quickly at night. Conversely, regions farther inland may stay hot all summer long. Disease pressures include phylloxera, nematodes, powdery mildew, Pierce's disease (PD) and grapevine fanleaf virus. These disease pressures have all forced breeders to incorporate new sources of resistance to create new, more resilient cultivars.

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00015-6

15.1.1 Varietal labelling

The biggest effect on California wine grapevine breeding, as well as wine grapevine breeding worldwide, is derived from a California consumer marketing strategy that changed the way wine was sold around the world. Before the 1960s, wine was labelled with the region from which it was produced. Frank Schoonmaker, a U.S. wine writer, began pushing for wines to be labelled by the grape varietal. This approach was championed by legendary California winery owner Robert Mondavi, and soon varietal labelling became common practice across California and the world (Zraly, 2012).

The move to varietal labelling had an unforeseen side effect that can still be seen today. There is an immense lack of acceptance of newly bred wine cultivars into the California wine market. The last newly bred wine grape cultivar accepted by the California wine industry was Symphony, released by Dr Harold P. Olmo of UC Davis in 1981. For the subsequent 24 years, no newly bred wine grape cultivars were planted in California. This streak was not broken by a large public institution or private company. The extensive gap finally came to an end with the public release of the life's work of an individual breeder, Mr Fay Triplett. In contrast, during this same period, 31 new table and raisin grape cultivars were introduced and incorporated by the California grape industry. The problem arose from the consumer demand created by varietal labelling. Dr M. Andrew Walker, of UC Davis, and Dr Nick Dokoozlian, Vice President of Viticulture, Chemistry and Enology at E&J Gallo, agreed that creating new cultivars with equal or better quality was not the issue. The problem in keeping new cultivars of wine grapes from achieving release was generating consumer demand through marketing that fights the established cultivars that have become prominent from varietal labelling (Sommer, 2012).

15.1.2 Additional resources

The California Department of Food and Agriculture (CDFA) and the USDA's National Agricultural Statistical Service (NASS) put out two immensely valuable yearly reports to track trends in California viticulture. The California Grape Crush Report (available at http://www.nass.usda.gov/Statistics_by_State/California/Publications/Grape_Crush/) tracks the tonnage of grapes crushed, the average Brix and the price per ton for each cultivar organized into 17 growing regions within the state. The California Grape Acreage Report (available at http://www.nass.usda.gov/Statistics_by_State/California/Publications/Grape_Acreage/) tracks bearing and non-bearing acreage of each cultivar broken down into the same 17 growing regions. Archived copies of the California Grape Crush Report, dating back to 1976, and the California Grape Acreage Report, dating back to 1991, are available on the aforementioned websites. Information on individual cultivars can be found on three websites. The National Grape Registry (http://ngr.ucdavis.edu/index.cfm) compiles information on each grape cultivar from the USDA and Foundation Plant Services (FPS) at UC Davis. The Vitis International Variety Catalogue (VIVC) (http://www.vivc.de/index.php) has additional resources on a wider range of grapes. The VIVC Website also has information such as genetic profiles, resistance data and institutes within each country with known copies of each cultivar. The University of California Integrated Viticulture

Website (available at http://iv.ucdavis.edu/) has information on cultivars as well as general viticultural information. The FPS Website also maintains a publication and resource archive (available at http://fpms.ucdavis.edu/.Publications.html) that has a yearly grape newsletter as well as articles on specific topics and an expanded resource list. The FPS grape newsletter supplies information on newly released cultivars in California as well as profiles of important figures in California viticulture.

15.1.3 Future trends

The Western United States must deal with several developing issues over the next several decades. Global warming, continued droughts, pest evolution and an increased desire by the consumer to be more environmentally conscious are some of the main pressures that will increasingly affect how viticulture is practiced across the Western United States. The effects of global warming alone could reduce the premium wine-growing acreage in California by 30–50%, forcing more of California to grow grapes suited to hotter climates (Sommer, 2012). The drought of 2014 gripping California is one of the worst on record (Serna, 2014). Alarmingly, tree ring analysis shows that this drought may pale in comparison to those long past (Rogers, 2014). The current water situation could force California viticulturists to produce grapes with less water. Many grape pests have now adapted to the resistance found in current grape cultivars, forcing growers to rely on pesticides (Wade, 2011). This lack of pest resistance has made California wine grapes the largest consumer of pesticides in California, with table and raisin grapes the third highest users of pesticides (California Department of Pesticide Regulation, 2014). At the same time, many Californians want to see viticulture turn greener and more eco-friendly (Boone, 2014), which has caused the formation of organizations such as the California Sustainable Winegrowing Alliance.

The issues facing California can all be faced through diligent research and the breeding of new, more resistant and versatile grapes for the western United States (Sommer, 2012; Wade, 2011). UC Davis and many other institutions around the world are researching solutions to all of these issues. A discussion of some of the work being done by UC Davis to combat many of these issues will follow. The real issue is whether the solutions found by these research institutions will be incorporated into the different breeding programmes and new cultivars adopted by the grape industry. The table grape industry is adapted to facing these issues because there are several breeding programmes already in existence and new cultivars are readily accepted. A slight setback for the table grape industry occurred in 2012, when the USDA breeding programme in Fresno, CA decided not to hire a replacement for their legendary breeder, Dr David Ramming. This may indicate that the USDA has moved away from breeding new table grape cultivars. This would be a great loss to the table grape industry, but multiple private companies are ready to step in and fill the void. Several of these companies, profiled in the following, have been actively breeding new table grape cultivars since the 1980s. These companies have the experience and modern technology to incorporate genetic research from UC Davis and other viticultural research institutes into their breeding efforts.

The wine industry may have finally realized that new cultivars will be needed in the near future. E&J Gallo, the largest winery in the world, has a long reputation for conducting viticultural research (Caputi, 2000). In 2012, they hired Dr Peter Cousins, formerly of the USDA in Geneva, NY and an adjunct professor at Cornell University. His work at the USDA and Cornell focused on rootstock breeding for root-knot nematode resistance, studying the effects of PD in Texas and the release of a miniature constantly blooming research grape cultivar named Pixie. He also has ties to California viticultural research as a former graduate student of Dr Walker at UC Davis (Garris, 2010). Only rumours are currently available as to the ultimate focus of Dr Cousins' work at E&J Gallo; however, he is a great hire to jump start a new wine breeding programme in California.

15.2 Grapevine breeding at public institutions

15.2.1 University of California–Davis

The University of California system has maintained an important role in California viticulture since the state legislature established the University of California Department of Viticulture in 1880 (Walker, 2000). The work was initially located at the Berkley campus, but after the repeal of prohibition in the United States, the centre for research shifted to the Davis campus. Here, the professors would turn the department into one of the top viticultural research institutes in the world (Lukacs, 2000). Two larger-than-life professors have overseen much of the grapevine breeding and genetic research during this time. The first was Dr Harold P. Olmo, whose career spanned from 1931 until his retirement in 1979. The second is Dr M. Andrew Walker, whose career started in 1989 and is still going strong.

15.2.2 The Dr Olmo years

Dr Olmo's first grape crosses came in May of 1931 when he started crosses involving Austrian Seedless, Black Corinth, Muscat of Alexandria, Ribier and Sultana (Walker, 2000). This was the start of a career that would last more than 40 years and generate the release of more than 30 cultivars. His releases would cover rootstock, raisin, table, white wine and red wine grapes with many of his cultivars still seeing use in 2013, almost 34 years after his retirement. Dr Olmo had many different breeding objectives in his work. His resistance breeding work with *Muscadinia rotundifolia* tried to introduce this species' strong resistance to bacteria, fungi, nematode, phylloxera and viruses into commercially viable cultivars (Olmo, 1986). The cultivars that were best met in the commercial market were those that were suited for the hot environment of California's Central Valley with high productivity and good fruit quality (Pinney, 2005). Dr Olmo's work would help Chardonnay become the king of white wines in California through his clonal selection. His collection trips around the world would earn him the name 'the Indiana Jones of viticulture' and leave a legacy of plants from which his predecessors could breed.

Dr Olmo bred four white and seven red cultivars that saw use between 1976 and 2014. His most prominent cultivar during this period was Rubired (Alicante Ganzin × Tinto Cao). Rubired has seen an average production >100,000 tons per year (Table 15.1), which was more than 8% of the yearly red wine crush. Dr Olmo's second

Table 15.1 **Production statistics for white and red wine grape cultivars bred in California**

White cultivar	Breeder	Total tons harvested[a,b]	Average tons harvested[a,b]	Average price per ton[a,b]	Years in production[b,c]
Emerald riesling	Dr H.P. Olmo	370,668.9	9504.3	$211.38	1975–2013
Flora	Dr H.P. Olmo	26,359.4	675.9	$1021.99	1975–2013
Helena	Dr H.P. Olmo	1050.5	105.1	[d]	1976–1985
Symphony	Dr H.P. Olmo	221,422.8	7908.0	$329.24	1986–2013
Triplett blanc	Mr. Fay Triplett	150,295.6	16,699.5	$238.18	2005–2013
Total white[e]		45,819,359.9	1,174,855.4	$377.10	
Red cultivar	**Breeder**	**Total tons harvested[a,b]**	**Average tons harvested[a,b]**	**Average price per ton[a,b]**	**Years in production[b,c]**
Calzin	Dr H.P. Olmo	202.0	33.7	$264.76	1977–1979, 1982–1984
Carmine	Dr H.P. Olmo	6495.7	191.1	$376.60	1980–2013
Carnelian	Dr H.P. Olmo	406,721.3	10,428.8	$186.77	1975–2013
Centurian	Dr H.P. Olmo	143,759.2	3885.4	$206.71	1977–2013
Perelli 101	Mr Antonio Perelli-Minetti	8615.8	783.3	$883.53	1977–1981, 2002–2007
Pfeffer (cabernet)	Mr William Pfeffer	785.6	26.2	$1064.96	1981, 1984–2013
Royalty	Dr H.P. Olmo	253,937.8	6511.2	$206.01	1975–2013
Rubired	Dr H.P. Olmo	4,303,062.8	110,334.9	$212.43	1975–2013
Ruby cabernet	Dr H.P. Olmo	2,901,738.0	74,403.5	$218.17	1975–2013
Total red[f]		51,558,713.0	1,322,018.3	$454.91	

[a]Calculated from California Grape Crush Reports 1976–2014 (California Department of Food and Agriculture, 2014a).
[b]Calculated from data covering the growing seasons of 1975–2013.
[c]Maximum range 1975–2013.
[d]Data are withheld from source data to avoid disclosure of individual vineyard or winery operations.
[e]Total for all white wine cultivars grown in California.
[f]Total for all red wine cultivars grown in California.

most prominent cultivar during this period was Ruby Cabernet (Carignan × Cabernet Sauvignon). Ruby Cabernet had an average production of just less than 75,000 tons per year (Table 15.1), which was approximately 5.5% of the yearly red wine crush. Despite the heavy production of Rubired and Ruby Cabernet, neither brought a high price at market, with an average price of $212 per ton and $218 per ton, respectively (Table 15.1).

Several more of Dr Olmo's wine cultivars have been planted on a more limited basis. His red wine cultivars Carnelian [(Carignan × Cabernet Sauvignon) × Grenache], Royalty (Alicante Ganzin × Trousseau) and Centurian [(Carignan × Cabernet Sauvignon) × Grenache] have seen an average production of between 3000 and 11,000 tons a year (Table 15.1). These three cultivars accounted for approximately 1.6% of the total red wine harvest. All three cultivars were bred for high production in the hot interior valleys of California with good wine quality, but they have not lived up to the wine quality desires of the market. None of these cultivars have received a high price at market with average prices between $185 and $210 per ton (Table 15.1). His white wine cultivars Emerald Riesling (Riesling × Muscadelle du Bordelais Faux) and Symphony (Muscat of Alexandria × Grenache gris) have both seen average harvests between 7900 and 9500 tons per year (Table 15.1), and combined they account for approximately 1.3% of the total white wine crush. Both cultivars have fared on the lower end of the price range with an average price per ton of $211 for Emerald Riesling and $329 for Symphony. Symphony has seen a recent spike in activity because a varietal form of the wine has become more popular. Harvests for Symphony have spiked to more than 20,000 tons per year for 2010–2013, and the price broke $400 per ton in 2011 and 2012 (California Department of Food and Agriculture, 2014a).

Dr Olmo also released several table and raisin grapes. His table grape cultivars Red Globe (a complex cross of Hunisia, Emperor and Nocera), Ruby Seedless (Emperor × Sultanina) and Perlette (Koenigin der Weingaerten × Sultanina) have all seen major plantings, with yearly averages more than 1666 ha each, 4.5% of the total table grape acreage each (Table 15.2). Another nine cultivars have seen average production acreage between 20 and 375 ha per year each (0.05–1% of table grape acreage each) (Table 15.2). Dr Olmo's cultivars have accounted for up to 20% of total acreage in any one year; however, their popularity has been dropping in recent years. In 2013, Dr Olmo's table grape cultivars only accounted for 6% of the total California table grape acreage (California Deptartment of Food and Agriculture, 2014b). His only raisin grape cultivar Canner (Hunisia × Sultanina) has also seen limited success with no more than 25 ha planted in any one year (0.02% of total raisin grape acreage) (Table 15.3). In recent years it has been removed because newer cultivars have taken its place.

Dr Olmo also released one rootstock that has been successful at controlling fanleaf virus and the dagger nematode (*Xiphinema index*) that spread it. That rootstock is O39-16 (Almeria × *M. rotundifolia*), and it is able to counteract the effect of fanleaf virus when grafted to an infected scion. The mechanism of this induced resistance to fanleaf is still yet unknown. The rootstock also carries very strong resistance to *X. index* that prevents the nematode from successful reproduction. In locations where fanleaf virus and *X. index* are both present, O39-16 is the only available rootstock that will allow for continued use of the area for viticulture (Walker et al., 1991). It also has

Table 15.2 Production statistics for table grape cultivars bred in California

Cultivar	Origin	Average production area (ha)[a,b]	Years in production[a,b,c]	Average percentage of table grapes[a,d]
Arra	Giumarra vineyards	130	2008–2013	0.36%
Autumn king	USDA[e]	904	2008–2013	2.49%
Autumn royal	USDA	1251	1997–2013	3.51%
Autumn seedless	USDA	58	1991–2013	0.16%
Beauty seedless	UC Davis[f]	163	1991–2013	0.45%
Black emerald	USDA	37	1998–2008	0.07%
Blush seedless	UC Davis	57	2006	0.16%
Calmeria	USDA	536	1991–2013	1.51%
Cardinal	USDA	77	1991–2008	0.22%
Christmas rose	UC Davis	366	1991–2013	1.03%
Crimson seedless	USDA	4181	1991–2013	11.68%
Dawn seedless	UC Davis	22	1993–1998	0.06%
Early muscat	UC Davis	46	1991–2013	0.13%
Early sweet	Giumarra vineyards	33	2004–2013	0.09%
Emerald seedless (black seedless)	UC Davis	237	1991–2013	0.66%
Exotic	USDA	214	1991–2008	0.61%
Fantasy seedless	USDA	371	1991–2013	1.04%
Flame seedless	USDA	10,001	1991–2013	28.02%
Flaming red	Private breeder	75	1991–2013	0.21%
Holiday	Columbine vineyards	115	2000–2001	0.31%
Niabell	UC Davis	73	1991–2013	0.20%
Perlette	UC Davis	1650	1991–2013	4.64%
Princess	USDA	945	1999–2013	2.84%
Pristine (blanc seedless)	Private breeder	146	2004–2013	0.41%
Queen	UC Davis	63	1991–2008	0.18%
Red globe	UC Davis	5050	1991–2013	14.07%
Ruby seedless	UC Davis	2253	1991–2013	6.30%
Scarlet royal	USDA	1318	2009–2013	2.26%
Scarlet	UC Davis	219	2005–2013	0.24%
Sugraone (superior seedless)	Private breeder (Sun World)[g]	1506	1991–2013	4.21%
Sugranineteen (scarlotta seedless)	Sun World	160	2002–2012	0.45%

Continued

Table 15.2 **Continued**

Cultivar	Origin	Average production area (ha)[a,b]	Years in production[a,b,c]	Average percentage of table grapes[a,d]
Sugrasixteen (sable seedless)	Sun World	28	2003–2013	0.08%
Sugrathirteen (midnight beauty seedless)	Sun World	113	1999–2013	0.31%
Summer royal	USDA	227	2000–2013	0.64%
Sweet scarlet	USDA	104	2006–2013	0.29%
Sweet sunshine	International fruit genetics	39	2012–2013	0.11%
Thomcord	USDA	13	2012–2013	0.03%
Vintage red	USDA	255	2009–2013	0.69%
Total table grapes[h]		35,715		

[a]Calculated from California Grape Acreage Reports 1991–2013 (California Department of Food and Agriculture 2014b).
[b]Calculated from data covering the growing seasons of 1991–2013.
[c]Maximum range 1991–2013.
[d]Calculated only for years in production.
[e]USDA breeding programme in Fresno, CA.
[f]University of California breeding programme.
[g]Plant patent now owned by Sun World.
[h]Calculated for all table grapes grown in California.

Table 15.3 **Production statistics for raisin grape cultivars bred in California**

Cultivar	Origin	Ave. production area (ha)[a,b]	Years in production[a,b,c]	Average percent[a,d]
Canner	UC Daivs[e]	22	1991–1995	0.02%
DOVine	USDA[f]	213	1998–2013	0.24%
Fiesta	USDA	3269	1991–2013	3.56%
Selma Pete	USDA	937	2003–2013	1.12%
Total raisin[g]		99,767		

[a]Calculated from California Grape Acreage Reports 1991–2013 (California Department of Food and Agriculture 2014b).
[b]Calculated from data covering the growing seasons of 1991–2013.
[c]Maximum range 1991–2013.
[d]Calculated only for years in production.
[e]University of California breeding programme.
[f]USDA breeding programme in Fresno, CA.
[g]Calculated for all raisin grapes grown in California.

a reputation of inducing excessive vigour in scion cultivars; therefore, it is only used in conditions in which fanleaf is a problem.

One of the requirements to be a good breeder is the ability to select which plant or offspring will be successful. Dr Olmo put this skill to use in a different way by undertaking a series of clonal selection studies. He was hoping to find clones of each cultivar that had higher yields, were better adapted to the different environments of California and most importantly were free of disease. He worked with many of the popular cultivars of the day and some of the more obscure (at the time) cultivars (Walker, 2000). One of these obscure cultivars was Chardonnay, which in 1975 produced 10,000 tons of fruit, making it 2.5% of the total California white wine crush for that year (California Department of Food and Agriculture, 2014a). Chardonnay is currently one of the most productive and prominent grapes in California. From 2000 to 2013, Chardonnay averaged over 625,000 tons per year and had not been less than 40% of the total white grape crush over the same period (California Department of Food and Agriculture, 2014a). This successful turnaround is due to Dr Olmo finding clones of Chardonnay that had high production and fruit quality because of better adaptability to the California climate than clones used by the wine industry during the early 1970s (Walker, 2000).

One of Dr Olmo's most important achievements was his large collection of native and cultivated grape cultivars from around the world. His travels took him to Afghanistan, India, Iran, North Africa, Tunisia, Spain, Portugal, France, Greece, Brazil, northern Mexico and throughout the United States, making his nickname the Indiana Jones of viticulture well deserved. These collections now reside at the USDA National Clonal Germplasm Repository located just outside of Davis, CA, making it one of the most extensive in the world (Ferguson and Golino, 2006). This collection has laid the groundwork for Dr Walker to conduct resistance breeding work. Dr Walker's work with PD resistance and *X. index* resistance has come from plants collected by Dr Olmo.

15.2.3 The Dr Walker years

Dr Walker's career at UC Davis has involved classical breeding, identification of resistant source material and molecular genetic work. He has worked to identify sources of resistance and resistance genes to PD, multiple types of nematodes, powdery mildew and phylloxera. He has also started to work on drought and salt tolerance to prepare for future droughts and water issues in California. His work using marker-aided selection (MAS) has shortened the length between generations of his breeding programme, allowing for more rapid development of advanced cultivars. Dr Walker's breeding work includes table, wine and rootstock breeding. His only releases before 2013 have been five nematode-resistant rootstocks, although several PD-resistant wine cultivars are expected to be released in 2015.

Dr Walker's five rootstock releases are still relatively new (released in 2008); therefore, their ultimate effect on viticulture is still unknown. His rootstocks, named GRN1, GRN2, GRN3, GRN4 and GRN5, come from a complex set of hybridizations of multiple species including *Vitis rupestris*, *M. rotundifolia*, *Vitis rufotomentosa*, *Vitis champinii* and

Vitis riparia. During the initial testing of GRN1-5, their resistance was tested against multiple individual types of nematodes as well as mixtures of nematodes (Ferris et al., 2012). These rootstocks should prove to have durable long-term resistance in the future because nematode pressure continues to increase in California vineyards.

The bulk of the work done by Dr Walker's laboratory has been in identifying techniques, sources of resistance and genes for resistance to many grape pathogens. Their continued nematode work has identified a screening for root-knot nematodes (Cousins and Walker, 2001) and has seen the identification of a quantitative trait locus (QTL) and the cloning of a gene for dagger nematode resistance (Hwang et al., 2010; Xu et al., 2008). Their work on phylloxera has created a method to screen for phylloxera resistance (Forneck et al., 1996) and identified multiple sources of phylloxera resistance (Grzegorczyk and Walker, 1998). Dr Walker's laboratory's work with powdery mildew has identified sources of powdery mildew resistance (Riaz et al., 2013) and a QTL for powdery mildew resistance along with markers to conduct MAS (Riaz et al., 2011). His laboratory's work with PD has identified a resistance gene for PD along with markers for MAS (Krivanek et al., 2006).

Dr Walker's incorporation of molecular genetic work with PD into his breeding programme is perhaps the most important work done thus far. This is not just for the progress it has achieved combating PD but also for the speed at which the resistance alleles have been moved from a non-vinifera background into a vinifera background. The source for their PD resistance work is the gene *PdR1*, which was originally identified in a *Vitis arizonica* that was collected by Dr Olmo. Because of the markers created by Dr Walker's laboratory, more than half (61%) of the offspring from the F1, BC1 and BC2 generations were able to be discarded as susceptible, saving time and resources on screening the full populations. The BC1 generation (75% *Vitis vinifera*) was screened in 2006 (Riaz et al., 2009). In a time span of a mere 9 years, Dr Walker is set to release selections from the BC4 generation (97% *V. vinifera*) in 2015. These grapes have already been turned into wine that has been receiving favourable reviews from the wine industry (Tourney, 2013). This means that in those 9 years, Dr Walker and his laboratory have done three additional backcrosses, selected promising cultivars, created wine (with favourable review) and submitted the plants to FPS (in charge of new releases at UC Davis). FPS has certified the vines to be free of known viruses, and it has created a large enough stockpile of the vines to start supplying nurseries with these new selections. The use of MAS to increase the speed of and gains in a breeding programme is not revolutionary. Dr Walker had the foresight and understanding of the procedures to implement the technology within his genetic and breeding programmes that is now seeing great returns.

Dr Walker has also had foresight on a couple of issues that will be plaguing California viticulture for many years to come. The drought that has gripped California in 2014 is one of the worst on record (Serna, 2014) and has raised the issue of water use in viticulture. The issues of drought and water use have become a major focus of Dr Walker's laboratory in recent years. His laboratory has been working to develop a screen for assaying drought avoidance in grapes (Fort and Walker, 2012). In an effort to make grapes capable of using substandard water sources, Dr Walker has also been developing a screening method for identifying salt-tolerant grapevines (Fort and Walker, 2011). This new screen has been used to find different sources of salt tolerance (Heinitz and Walker, 2012). If Dr Walker's laboratory can have as much success with drought and salinity as has been accomplished with PD, then California viticulture will have a much better chance of surviving the uncertain future of water availability in the western United States.

15.2.4 The laboratory of Dr Carole Meredith

Dr Carole Meredith conducted genetic research on grapevines at UC Davis until her retirement in 2003. Although she released no cultivars, the work she accomplished set the stage for many of the current advancements in grapevine breeding. She was also the principal investigator for Dr Walker's and Dr Summaira Riaz's (Dr Walker's 'right-hand woman') PhD theses, giving them their training in grapevine research, grapevine breeding and molecular genetics. Dr Meredith's laboratory focused on understanding the genetic relationship between classic European wine grape cultivars. Using molecular markers, this work identified that many of the European wine grape cultivars in use today are closely related (Bowers and Meredith, 1997; Bowers et al., 1999). Her work with molecular markers also identified several cultivars that were actually synonyms for the same grapevine (Bowers et al., 1993). Another area of focus in Dr Meredith's laboratory was using molecular markers to create genetic maps and conduct QTL analyses (Doligez et al., 2002; Riaz et al., 2004). This initial mapping work done in Dr Meredith's laboratory paved the way for Dr Walker's laboratory to have the success it has enjoyed.

15.2.5 The USDA breeding programme

The USDA has been running a successful breeding programme near Fresno, CA since the 1930s. Fresno is located in the middle of the state's table and raisin production area, making table and raisin grapevine breeding the main focus of their efforts. The programme has been overseen by several prominent men, including Elmer Snyder, Frank Harmon, Dr John Weinberger and most recently Dr David Ramming, with the aid of his technician, Ron Tarailo. In total, they have produced 4 raisin and 17 table grape cultivars that have seen production acreage in California between 1991 and 2013. The table grape cultivars bred at the USDA have accounted for between 35% and 55% of yearly table grape acreage in California during this time period (California Department of Food and Agriculture, 2014b). The programme has also produced two rootstocks and pioneered new technologies that have fundamentally changed table and raisin grapevine breeding and production.

The most important work done by the USDA is the application of embryo rescue (culture) to seedless grapevine breeding done under the supervision of Dr Ramming. Seedlessness is a recessive trait in grapes, and breeding programmes would normally need to go through two breeding cycles and the loss of more than half of the progeny in the second generation because they would remain seeded. Through the use of embryo rescue, two seedless cultivars can now be directly crossed, creating populations with higher rates of seedless grapes in a single generation (Ramming, 1990).

The process was first attempted in 1981 (Emershad and Ramming, 1984), and since then it has become a standard procedure for many table grapevine breeding operations.

Dr Ramming has also maintained close ties with Dr Walker working together to combat PD and powdery mildew. Through a collaborative project, they have brought the *PdR1* gene into 98.5% *V. vinifera* table grapes (Walker et al., 2012). Dr Ramming has also been working on powdery mildew resistance efforts with eastern United States (Ramming et al., 2011) and western United States (Riaz et al., 2011) to find resistance genes for breeding/MAS. The ultimate desire of these projects was to make table grapes that were resistant to PD and powdery mildew (Walker et al., 2012) to eliminate two of the biggest diseases from table grapes.

The success of the USDA table grapevine breeding programme started with the duo of Snyder and Harmon. Between 1945 and 1960, they released four table grape cultivars: Blackrose, Calmeria, Cardinal and Exotic. Calmeria is still in use in 2013 and has averaged 545 ha in production between 1991 and 2013, accounting for approximately 1.5% of the table grape acreage in California. Cardinal and Exotic have also seen production over this time period with average production of 102 and 335 ha, respectively, during the 1990s. Both cultivars have fallen out of favour since 2000 and have recorded no production acreage since 2009 (Table 15.2).

The second successful breeding team at the USDA facility was Dr. Weinberger and Harmon. They teamed up for one raisin and three table grape releases. Flame Seedless is the pair's biggest success. Between 1991 and 2013 it averaged more than 10,000 ha in production or 28% of the total table grape acreage in the state (Table 15.2). Fiesta was the first attempt to replace Thompson Seedless as the king of raisin grapes. Fiesta has never gained the popularity of Thompson Seedless, but it has worked its way up to 1875 ha in production in 2013, or approximately 6.5% of the total raisin grape acreage in the state (California Department of Food and Agriculture, 2014b). Drs Weinberger and Harmon also released two rootstocks: Freedom and Harmony. These two rootstocks have good nematode resistance and are used frequently on sites with high nematode pressure.

The final duo of Dr. Ramming and Tarailo was the most productive, with 3 raisin and 13 table grapes released. Their first raisin grape released was DOVine, which stands for 'dry on the vine'. This cultivar matures up to 3 weeks earlier than Thompson Seedless (the standard raisin grape in California), allowing the canes to be cut and the fruit to dry on the vine. This has made it possible to mechanically harvest raisin grapes (Vasquez, 2013), saving growers the manual labour costs of hand harvesting. DOVine is special because it is the first release to come through the embryo rescue protocol pioneer by Dr Ramming (University of California Integrated Viticulture, 2014). The raisin grape industry has not found DOVine to be special, and it has never seen more than 297 ha in production (0.33% raisin grape production). The raisin grape industry has accepted their latest raisin grape cultivar, Selma Pete. This muscat-flavoured raisin grape has seen its acreage climb quickly to 1891 ha in production (2.34% raisin grape production) in 2013 (California Department of Food and Agriculture, 2014b).

The table grape cultivars released by Dr. Ramming and Tarailo have had a much bigger following by the table grape industry. In total, their 13 released cultivars have accounted for 25% of the total table grape acreage in California between 2004 and

2013 (California Department of Food and Agriculture, 2014b). The most popular cultivar is Crimson Seedless, which averaged over 4167 ha per year (11% of table grape acreage in California) between 1991 and 2013. Their cultivars Autumn King, Autumn Royal, Princess, Scarlet Royal and Vintage Red each had at least 417 ha in 2013, accounting for over 19% of the total table grape acreage (Table 15.2). Dr Ramming retired in 2012 and ended his run of successful releases.

As of September 2014, the USDA has not hired a replacement for Dr Ramming, which may spell the end of their table and raisin grapevine breeding programme. This will be a hard loss because between 2003 and 2013, at least 54% of all table grapes grown in California have come from the USDA (California Department of Food and Agriculture, 2014b). The table grape industry is ready to support itself. Several private companies have sprung up in the southern San Joaquin Valley since the 1980s. Many of these programmes have adopted the modern techniques pioneered by Dr Ramming and Dr Walker, making them capable of quickly adapting to new viticultural issues.

15.3 Grapevine breeding programmes within private companies

Starting in the 1980s, several privately held grapevine breeding companies started operating in the southern San Joaquin Valley of California. These companies have focused their efforts exclusively on breeding table grapes. This is because the table grape industry in California needs a wide cultivar of table grapes that come in multiple colours, mature at different times during the growing season, store and ship well, are easy to grow and meet the needs of the consumer. This leaves many opportunities for new cultivars to claim a piece of the market. Many of these companies have now taken themselves worldwide, with cultivar development and marketing around the world.

15.3.1 Sun World International, LLC

Sun World started as a packing and marketing company during the 1970s, supplying peppers, plums, apricots, citrus, grapes and other fruits and vegetables. By the 1980s they started their own breeding programme and have bred cultivars of plum, peach, apricot and grape. Their cultivar development is currently focusing on development of cultivars that are good for the consumers and good for the plant. They are looking for fruit that has a good blend of aroma, flavour and crispness as well as natural disease resistance (Sun World, 2014).

Sun World has had three cultivars that have seen use in the California table grape industry: Scarlotta Seedless (Sugranineteen), Midnight Beauty (Sugrathirteen) and Sable Seedless (Sugrasixteen). The three cultivars have a combined production acreage of over 500 ha, which accounts for 1.4% of the table grape production in California (Table 15.2). The breeder for these cultivars was Dr David Cain. He earned a PhD at Michigan State working on breeding techniques of stone fruit, strawberries and blueberries, and later he worked with Dr Ramming at the USDA doing embryo rescue work (Cain et al., 1983). Dr Cain brought this knowledge to Sun World, which now uses it in their grapevine breeding programme.

Dr Cain left Sun World in 2001 and was replaced by Dr Michael Striem. Originally from Israel, Dr Striem worked with Dr Reisch of Cornell University on transformations of embryogenic grape cell cultures and fungal resistance (Kikkert et al., 1996; Striem and Reisch, 1996). As of 2013, Sun World has only released one of Dr Striem's cultivars – Autumn Crisp – but the cultivar has yet to make an entrance into the California table grape market.

Sun World has now grown into an international corporation. They boast offices in Italy, Australia, Chile, Mexico and South Africa. The company maintains 4167 ha of production land and has over 950 growing partners worldwide (Sun World, 2014). Sun World truly has a bright future ahead of it.

15.3.2 Giumarra vineyard corporation

Giumarra vineyard corporation has its beginnings in Giumarra Brothers' Fruit Company, started in 1922 at the Los Angeles Wholesale Produce Market. The Giumarra Vineyard Corporation was founded upon the Giumarra family's purchase of their first vineyard in 1939, located near Bakersfield, CA (Giumarra Vineyard, 2014). From these first steps, the company has expanded to operations in Boca Raton, FL; Nogales/Rio Rico, AZ; and Reedley, CA, with trading partners in Argentina, Chile and New Zealand covering a wide range of fruits and vegetables. Growing out from a production company they now work on cultivar development in melons, berries and grapes. The grapevine breeding programme began in the late 1990s when Giumarra Vineyard Corporation partnered with Shachar Karniel of Grapa Cultivars, Ltd, an Israeli company. The two companies formed ARD, LLC as a subsidiary of Giumarra Vineyard Corporation. Mr Karniel, a fourth-generation grape grower, is in charge of breeding and cultivar evaluation (Giumarra Vineyard, 2014).

The ARD breeding programme is located just south of Bakersfield, CA. The breeding programme is focused on colour, texture, resiliency, ability to handle storage and travel, minimal labour input and most importantly crunchiness and sweet taste (Nunez and Bruins, 2012). In California, there have been two successful releases from the breeding programme: Arra and Early Sweet. Combined, the two cultivars have seen more than 167 ha in production per year (0.5% of the table grape market) for the 2009–2013 harvests (California Department of Food and Agriculture, 2014b).

ARD, LLC also has several more cultivars in testing and many more in their pipeline (information available at http://www.grapaes.com/index.php). The company is also successfully working with growers in the United Kingdom and Egypt to set up global production and distribution of their grapes (Whittaker, 2012). With such a strong international presence, Giumarra Vineyard Corporation and ARD, LLC should see strong growth of their table grapes worldwide.

15.3.3 International Fruit Genetics

International Fruit Genetics (IFG) was founded in 2001 when Jack Pandol, Jr, a third-generation grape grower and founder of Grapery, came together with the Stroller family, owners of Sunridge Nurseries. They hired Dr David Cain, formerly of Sun World, to run their breeding and research team. Under the leadership of Dr Cain, IFG has focused on breeding table grapes and cherries. Dr Cain brought with him his years of experience and desire to use the most modern techniques to produce new table grape cultivars. Their stated goals are to produce grapes that are available in all colours and at all points in the season; have good vinifera, muscat and exotic flavours; have large, firm and crisp berries; have weather and disease tolerance; have good storage and shipping; and have reduced cost to farmers (International Fruit Genetics, 2014).

The company has only had one release – Sweet Sunshine. The cultivar has only been planted for the last 2 years and has an average of 40 ha in production (Table 15.2). A list of IFG's hopeful grape releases is available at http://internationalfruitgenetics.com/grapes.php and should give you an insight to the company's true objective – sweetness. Of the 13 cultivars listed, 9 include the word 'sweet', 1 includes 'candy' and a final includes 'sugar'. IFG's new cultivar that is making the biggest splash is Cotton Candy, and yes, it is reported to taste like cotton candy (Price, 2013). With the large amount of experience on both the breeding and growing side, and with the large amount of press already focused on IFG, they should have a sweet future in store.

15.3.4 Columbine Vineyards

The Caratan family started growing grapes in the San Joaquin Valley in 1926. The land is now in the third and fourth generation of the Caratan family under the name Columbine Vineyards. Columbine Vineyards entered into the realm of breeding through the meeting of Luis Caratan, the current owner of Columbine Vineyards, and Dr Angelino Gargiulo, the director of the Argentine government's agricultural experimental station at Rama Caida in the Mendoza Province. The two met when Mr Caratan was visiting Chile and was impressed by one of Dr Angelion's cultivars. They struck up a partnership that is focused on cross-pollination and uses embryo rescue to produce new cultivars. Their goal is to create seedless cultivars with exceptional eating quality (Columbine Vineyard, 2014).

The programme has had three releases. The most successful has been Holiday, which saw more than 188 ha in production at its peak back in 2001 (California Department of Food and Agriculture, 2014b). The newest cultivar, Milano, has yet to make its mark on the market. The future of this programme is uncertain because Dr Gargiulo is now in his 80s. It is unknown if Columbine Vineyard will be able to replace him when he decides to retire.

15.3.5 Grapevine breeding programmes run by individuals

Private individuals have also tried their hand at breeding grapevines in the western United States. Although most of their contributions have been small, they are still an important piece of the breeding history in California. These individuals should not be referred to as amateurs because they all have ties to the grape-growing or nursery industries. Their interest in grape growing led them to take the next step and try to breed new cultivars to improve on those in their collections.

William Pfeffer grew and bred grapes in the Los Altos hills near present-day Mountain View, CA, during the late 1800s. He was considered a reputable winemaker in his day (Munson, 1909) and bred grapevines on his estate. His cultivar Cabernet Pfeffer, thought to be a cross of Cabernet Sauvignon and Trousseau, is the longest running cultivar bred in California. Most of his work was destroyed when phylloxera swept through his vineyard during the 1890s. Mr Pfeffer had given a few cuttings of Cabernet Pfeffer to a couple of wine grape growers in the Cienega Valley of San Benito County (Sullivan, 1998). A limited planting still remains in the Cienega Valley, with no more than 70 tons being crushed in any one growing season between 1976 and 2013 (California Dept. of Food and Agriculture, 2014a). Despite its limited harvest, this cultivar has fetched a good price with an average price over the same time period above $1000 per ton (Table 15.1).

John M. Garabedian of Fresno, CA, was a fruit breeder of reputation with patents for 45 cultivars of apricots, grapes, nectarines, peaches and plums (Corporation for Enterprise Development, 2014). His table grape cultivar Sugraone (also sold under the name Superior Seedless) is the most successful grape cultivar bred by a private individual in California. It is a cross of Cardinal and an unnamed seedless bud sport. The cultivar was initially patented in 1972 by Mr Garabedian, but it was sold along with his nursery to Superior Farming Company in 1986. Superior Farming Company was then merged into Sun World International in 1989 (University of California Cooperative Extension, 2014). The cultivar has been in constant production between 1991 and 2013 with an average of more than 1450 ha every year, which is approximately 4% of the total table grape acreage in California (Table 15.2). Aside from a strong grape cultivar, Mr Garabedian also left behind the Bertha and John Garabedian Charitable Foundation (Corporation for Enterprise Development, 2014), which has been helping students and programmes at Fresno Pacific University (Steffen, 2003) and Fresno State (California State University Fresno, 2014) since 1993.

Fay Triplett was a wine grape grower in Ceres, CA. His cultivar Triplett Blanc, a cross of Colombard and Vernaccia Sarda, was released in 2005. Since its release the harvest has grown to between 20,000 and 30,000 tons per year, although the cultivar only fetches $200–$300 per ton (Table 15.1). This cultivar is also very important because it is the first newly bred wine grapevine to see significant plantings in California since Symphony was released in 1981. Three additional releases from Mr Triplett's breeding work came in 2007 with the release of Maxine Rouge and Rougett and in 2010 with the release of Fay Rouge (Christensen and Fidelibus, 2010). These releases are the end of a breeding career that lasted more than 50 years. Mr Triplett may have been a wine grape grower by occupation, but he started breeding grapevines in the 1940s. He was known for keeping immaculate records of his crosses and on his new vines. He also kept in contact with Dr Harold Olmo of UC Davis, and he began to collect cultivars from Davis as well as from Europe (Christensen, 2002). Mr Triplett's breeding work also included cooperative interactions with the University of California Cooperative Extension in Stanislaus County, Allied Grape Growers and E&J Gallo Winery for input on his vines' performance and wine quality evaluations. By his death in 2000, 40 of his most promising cultivars had been transferred to the University of California Kearney Agricultural Research and Extension Center near

Fresno, CA for further evaluation and release. All of his cultivars have and will be released as public cultivars (Christensen, 2004).

Anton Caratan was the owner of Anton Caratan & Son, a table grape-growing operation in Delano, CA. He was also an active breeder with more than 20 years of breeding experience and 200,000 crosses (Highbeam Business, 2007). His most successful grape is Pristine (also sold under the name Blanc Seedless), which, since its introduction in 2003, has maintained between 125 and 166 ha (California Department of Food and Agriculture, 2014b). In 2011, Anton Caratan & Son was sold along with the rights to Pristine. The new owners are planning a large expansion of Pristine acreage (Hornick, 2011).

Marvin L. Nies is the owner of Proprietary Fruit Varieties, LLC in Lodi, CA. The company works with grapevines and fruit trees. Mr Nies currently has eight plant patents for new cultivars of grapevines and cherry trees. His only successful grape release is a table grape named Flaming Red. Between 1991 and 2013, Flaming Red has maintained between 40 and 125 ha in California (Table 15.2).

Antonio Perelli-Minetti was a historic figure in the California wine-making industry. A son of an Italian winemaker, he had been stomping grapes since the age of 5. In 1902 he immigrated to California and began working in the California wine industry for P.C. Rossi at the Asti winery (Fichera, 2011). He also owned his own wineries in Healdsburg and Mexico before creating his legacy in Delano, CA in the post-prohibition era (Teiser, 1975). He released one cultivar, Perelli 101, which has been planted in California on a limited basis twice between 1975 and 2010. The first planting was during the late 1970s and saw maximum harvest of just less than 2300 tons, but prices never climbed above $130 per ton. A second smaller harvest during the mid-2000s never exceeded 10 tons; however, prices were much higher at $1000–$2000 per ton (California Department of Food and Agriculture, 2014a).

References

Agricultural Marketing Resource Center, 2014. Website visited August 2014. http://www.agmrc.org/commodities__products/fruits/raisin-profile.

Boone, J., January 14, 2014. California Wine Gets Green Standards. San Francisco Chronicle.

Bowers, J.E., Bandman, E., Meredith, C., 1993. DNA fingerprint characterization of some wine grape cultivars. Am. J. Enol. Vitic. 44, 266–274.

Bowers, J.E., Boursiquot, J.-M., This, P., Chu, K., Johansson, H., Meredith, C., 1999. Historical genetics: the parentage of Chardonnay, Gamay, and other wine grapes of Northeastern France. Science 285, 1562–1565.

Bowers, J.E., Meredith, C.P., 1997. The parentage of a classic wine grape, Cabernet Sauvignon. Nat. Genet. 16, 84–87.

Cain, D., Emershad, R., Tarailo, R., 1983. In-ovulo embryo culture and seedling development of seeded and seedless grapes (*Vitis vinifera* L.). Vitis 22, 9–14.

California Department of Food and Agriculture, 2014a. California Grape Crush Report 1976–2013. Website visited June 2014. http://www.nass.usda.gov/Statistics_by_State/California/Publications/Grape_Crush/.

California Department of Food and Agriculture, 2014b. California Grape Acreage Report 1991–2013. Website visited June 2014. http://www.nass.usda.gov/Statistics_by_State/California/Publications/Grape_Acreage/.

California Department of Pesticide Regulation, February, 2014. Pesticide Use Report 2012.

California State University Fresno, 2014. Website visited August 2014. http://armenianstudies.csufresno.edu/hye_sharzhoom/vol21/may70/bertha.htm.

California Table Grape Commission, 2014. Website visited June 2014. http://www.tablegrape.com/overview.php.

Caputi Jr., A., 2000. Fifty years of research at the world's largest winery. Pract. Winery Vineyard 22 (3), 5–15.

Christensen, P., October, 2002. Fay Triplett Collection. FPMS Grape Program Newsletter.

Christensen, P., October, 2004. Triplett Blanc. FPS Grape Program Newsletter.

Christensen, P., Fidelibus, M., December, 2010. Release of 'Fay Rouge' – A Red Wine Variety Well Suited for the San Joaquin Valley. Vine Lines Fresno County.

Corporation for Enterprise Development, 2014. Website visited August 2014 http://cfed.org/assets/pdfs/Central_Valley_Funders.pdf.

Columbine Vineyard, 2014. Website visited July 2014 http://www.columbinevineyards.com/our-grapes/breeding-program/.

Cousins, P.M., Walker, M.A., 2001. A technique for screening grape germplasm for resistance to *Meloidogyne incognita*. Plant Dis. 85, 1052–1054.

Doligez, A., Bouquet, A., Danglot, Y., Lahogue, F., Riaz, S., Meredith, C., Edwards, K., This, P., 2002. Genetic mapping of grapevine (*Vitis vinifera* L.) applied to the detection of QTLs for seedlessness and berry weight. Theor. Appl. Genet. 105, 780–795.

Emershad, R.L., Ramming, D.W., 1984. In-ovulo embryo culture of *Vitis vinifera* L. C.V. 'Thompson Seedless'. Amer. J. Bot. 71, 873–877.

Ferguson, B., Golino, D., November, 2006. In Memory Harold P. Olmo. FPS Grape Program Newsletter.

Ferris, H., Zheng, L., Walker, M.A., 2012. Resistance of grape rootstocks to plant-parasitic nematodes. J. Nematol. 44, 377–386.

Fichera, S., 2011. Italy on the Pacific: San Francisco's Italian Americans. Palgrave MacMillian, Basingstoke, UK.

Forneck, A., Walker, M.A., Merkt, N., 1996. Aseptic dual culture of grape (*Vitis* spp.) and grape phylloxera (*Daktulosphaira vitifoliae* Fitch). Vitis 35, 95–98.

Fort, K., Walker, M.A., October, 2011. Breeding Salt Tolerant Rootstocks. FPS Grape Program Newsletter.

Fort, K., Walker, M.A., 2012. Developing a screen for assaying drought avoidance in *Vitis* rootstocks. Amer. J. Enol. Vitic. 63, 445A.

Garris, A., August 3, 2010. 5 Questions for Peter Cousins.. Appellation Cornell.

Giumarra Vineyards, 2014. Website visited July 2014. http://www.giumarravineyards.com/timeline.

Grzegorczyk, W., Walker, M.A., 1998. Evaluating resistance to grape phylloxera in *Vitis* species with an in vitro dual culture assay. Am. J. Enol. Vitic. 49, 17–22.

Heinitz, C., Walker, M.A., 2012. Continued screening for chloride exclusion in wild grapevines: new collections and genetic information. Am. J. Enol. Vitic. 63, 441A.

Highbeam Business, July, 2007. Pristine Condition, Anton Caratan Develops Seedless Table Grape. Progressive Grocer. Visited August 1, 2014. http://business.highbeam.com/4122/article-1G1-166591861/pristine-condition.

Hornick, M., February, 2011. Grape Growers Buy, Rename Anton Caratan & Son. The Packer.

Hwang, Xu, K., Hu, R., Zhou, R., Riaz, S., Walker, M.A., 2010. Cloning and characterization of *XiR1*, a locus responsible for dagger nematode resistance in grapes. Theor. Appl. Genet. 121, 789–799.

International Fruit Genetics, 2014. Website visited July 2014. http://internationalfruitgenetics.com.

Kikkert, J.R., Hebert-Soule, D., Wallace, P.G., Striem, M.J., Reisch, B.I., 1996. Transgenic plantlets of 'Chancellor' (Vitis sp.) from biolistic transformation of embryogenic cell suspensions. Plant Cell Rep. 15, 311–316.

Krivanek, A.F., Riaz, S., Walker, M.A., 2006. Identification and molecular mapping of *PdR1*, a primary resistance gene to Pierce's disease in *Vitis*. Theor. Appl. Genet. 112, 1125–1131.

Lukacs, P., 2000. American Vintage. The Rise of American Wine. Houghton Mifflin Co, Boston, New York.

Munson, T.V., 1909. Foundations of American Grape Culture. Orange Judd Company, New York, NY.

Nunez, C., Bruins, S., August 24, 2012. US: ARD Breeds Quality in California. Fresh Plaza.

Office International de la Vigne et du Vin (OIV), 2014. Website visited June 2014. http://www.oiv.int/oiv/cms/index.

Olmo, H.P., 1986. The potential role of (*vinifera x rotundifolia*) hybrids in grape variety improvement. Experientia 42, 921–926.

Pinney, T., 2005. A History of Wine in America: From Prohibition to the Present. University of California Press Berkeley, CA.

Price, K., May 9, 2013. Local Company Creates Cotton Candy Flavored Grapes. KGET Nexstar Broadcasting.

Ramming, D.W., 1990. The use of embryo culture in fruit breeding. HortScience 25, 393–398.

Ramming, D.W., Gabler, F., Smilanick, J., Cadle-Davidson, M., Barba, P., Mahanil, S., Cadle-Davidson, L., 2011. A single dominant locus, ren4, confers rapid non-race-specific resistance to grapevine powdery mildew. Phytopathology 101, 502–508.

Riaz, S., Boursiquot, J.-M., Dangl, G.S., Lacombe, T., Laucou, V., Tenscher, A.C., Walker, M.A., 2013. Identification of mildew resistance in wild and cultivated Central Asian grape germplasm. BMC Plant Biol. 13, 149.

Riaz, S., Dangl, G., Edwards, K., Meredith, C., 2004. A microsatellite marker based framework linkage map of *Vitis vinifera* L. Theor. Appl. Genet. 108, 864–872.

Riaz, S., Tenscher, A.C., Graziani, R., Krivanek, A.F., Ramming, D.W., Walker, M.A., 2009. Using marker-assisted selection to breed Pierce's disease-resistant grapes. Am. J. Enol. Vitic. 60, 199–207.

Riaz, S., Tenscher, A.C., Ramming, D.W., Walker, M.A., 2011. Using a limited mapping strategy to identify major QTLs for resistance to grapevine powdery milder (*Erysiphe necator*) and their use in marker-assisted breeding. Theor. Appl. Genet. 122, 1059–1073.

Rogers, P., January 25, 2014. California drought: past dry periods have lasted more than 200 years, scientists say. San Jose Mercury News.

Serna, J., July 31, 2014. California Breaks Drought Record as 58% of State Hits Driest Level. LA Times.

Sommer, L., September 4, 2012. The Heat Is on for California Wines. QUEST Northern California.

Steffen, W., April 2, 2003. Garabedian Grant Supports FPU Music Scholarships. Fresno Pacific University News.

Striem, M.J., Reisch, B.I., 1996. New grape cultivars resistant to fungus diseases. Alon-HaNotea 50, 540–542.

Sullivan, C.L., 1998. A Companion to California Wine: An Encyclopedia of Wine and Winemaking from the Mission Period to the Present. University of California Press, Berkeley, CA.

Sun World, 2014. Website visited July 2014. http://www.sun-world.com/variety-development.

Teiser, R., 1975. Antonio Perelli-minetti: A Life in Wine Making an Interview Conducted by Ruth Teiser in 1969. The Bancroft Library Regional Oral History Office, University of California, Berkeley.

Tourney, J., December 20, 2013. PD Resistant Vines Available in 2015? Pierce's Disease Research Symposium Highlights Progress and New Tools. Wines & Vines. Retrieved from http://www.winesandvines.com.

United States Department of Agriculture (USDA) National Agricultural Statistics Service, July, 2014. Noncitrus Fruits and Nuts 2013 Summary.

University of California Cooperative Extension, 2014. Website visited August 2014. http://cagardenweb.ucanr.edu/Growing_Grapes_in_the_California_Garden/?uid=232&ds=351.

University of California Integrated Viticulture, 2014. Website visited August 2014. http://iv.ucdavis.edu/Viticultural_Information/?uid=127&ds=351.

Vasquez, S., January 18, 2013. Grape Breeder, David Ramming Retires. San Joaquin Valley Viticulture.

Wade, N., January 24, 2011. Lack of Sex among Grapes Tangles a Family Vine. New York Times.

Walker, M.A., 2000. UC Davis' role in improving California's grape planting materials. In: Proc. Am. Soc. Enology Viticulture 50th Anniversary Meet. Seattle, Washington. Am. J. Enol. Vitic 51, 209–215.

Walker, M.A., Lider, L.A., Goheen, A.C., Olmo, H.P., 1991. VR O39-19 grape rootstock. HortScience 26, 1224–1225.

Walker, A., Ramming, D., Lin, H., March, 2012. California Department of Food and Agriculture PD/GWSS Progress Report 11-0184-SA.

Whittaker, J., June 7, 2012. UK: Grapevine Breeding Programme Bears Fruit for Mack and Belco. Fresh Plaza.

Wine Institute, 2014. Website visited August 2014. http://www.wineinstitute.org/resources/pressroom/04242014.

Xu, K., Riaz, S., Roncoroni, N.C., Jin, Y., Hu, R., Walker, M.A., 2008. Genetic and QTL analysis of resistance to *Xiphinema index* in a grapevine cross. Theor. Appl. Genet. 116, 305–311.

Zraly, K., 2012. Windows on the World Complete Wine Course. Sterling Publishing, New York, NY.

Grapevine breeding in the Southern United States

16

E.T. Stafne[1], *S.M. Sleezer*[2], *J.R. Clark*[2]
[1]Mississippi State University, Poplarville, MS, USA; [2]University of Arkansas, Fayetteville, AR, USA

16.1 Introduction

Southern grapes have played an important role in the history of grapevine breeding. As early as the 1700s or before, "Scuppernong" muscadine (subgenus *Muscadinia* Planch.; *Vitis rotundifolia* Michx. syn. *Muscadinia rotundifolia*) was selected and dispersed as a recognized cultivar (Hedrick et al., 1908). It was used as a parent for many modern muscadine cultivars and can still be found today in vineyards across the South. Even though muscadines are the predominant grape across many southern states, bunch grapes (subgenus *Euvitis* Planch.) continue to make inroads. Bunch grapes are difficult to grow in much of the Southern US. Growers have relied heavily on hybrids that contain grape species native to the region in order to resist Pierce's disease (PD) (*Xyllela fastidiosa* Wells et al.), grape phylloxera (*Daktulosphaira vitifoliae* Fitch), and mildew diseases (Lord, 1922). Organized breeding efforts in the South on both types began in the twentieth century and made great progress into the twenty-first century. This chapter will cover grapevine breeding in the Southern United States from early history to present day. The first section summarizes the industry in the past and present, the types of grape species that are native to the region and those most prevalent in breeding activities, and how grapes in this region are used by the consumer. The second section covers the breeding process, as well as needs and limitations for the region. Cultivar development is the focus of the third section with description of important parental materials, why they were used, and their resulting cultivars. The fourth section details grape breeding programs in the South, with primary emphasis placed on existing programs. The final section discusses the future needs of the southern grape industry and how breeding programs can address those needs.

16.2 Southern US grape industry perspective

16.2.1 Types of grapes grown in the Southern US

Muscadine grapes are native throughout much of the South. Many improved cultivars are widely grown. The cultivar choices available to growers are many, but improvements could still be made, particularly for fresh-market cultivars. Commercial production exists in several southern states, but finding markets for the fruit can be problematic. Often, it is used for wine production, but other products include jams, jellies, juice, and vinegar.

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00016-8

Both *Vitis vinifera* L. and hybrid bunch grapes can be grown in the Southern US. *V. vinifera* grapes can be grown with variable success in Arkansas, Georgia, Kentucky, North Carolina, Oklahoma, Tennessee, Texas, and Virginia. However, production of this species, and many bunch grape hybrids derived from *V. vinifera* and other non-resistant species, cannot be sustained due to PD, especially in the Gulf Coast region. A few hybrid bunch grape cultivars have been developed that resist or tolerate this disease. The source of resistance comes primarily from *V. rotundifolia* or other native grape species. The cultivar choices for growers are extremely narrow in this region, and only a handful of cultivars are even available in the commercial trade. Breeding of PD-tolerant hybrid grapes has been an off-and-on endeavor in the South and currently is underserved. With the booming local food movement and expanding wine industry throughout the United States, tremendous opportunity exists for cultivar improvement and development.

16.2.2 Primary usage of grapes in the South

The usage of grapes in the Southern United States runs the gamut of possible products. Small-scale growers often use muscadines for jams, jellies, and juice, whereas commercial producers lean toward wine production. Muscadines have high levels of nutraceutical compounds (Pastrana-Bonilla et al., 2003; Striegler et al., 2005) and thus are used to produce health-targeted products such as seed oil, pills, and other supplements for consumer markets. Fresh-market muscadine grape production ranges from local markets to shipping, and there is substantial potential to expand this area of marketing with improved cultivars, expanded production season, and increased promotion. Few bunch grapes are grown for anything other than wine, although there are some table grape cultivars that could be used to expand offerings in local markets. They can be consumed fresh or processed into other products. Some of the processed products include wine, brandy, jams and jellies, juice, syrup, grape seed extracts and oils, and vinegar, but the vast majority of processing grapes today are used for wine (USDA-NASS, 2013).

16.2.3 Past grape production in the South

The Southern US, especially the region near the Gulf Coast, is a challenging environment for bunch grapes. High humidity and temperatures contribute to elevated insect populations and disease pressure. The early 1800s was the time of the first extensive planting of muscadine grapes in the South. By the 1850s, some vineyards comprised several hundred hectares, and most of the fruit was processed into wine (Lane, 1977). This industry declined with the Civil War, as well as the rise of the California wine industry. It was not until muscadine breeding began in the early 1900s, with programs in Georgia and North Carolina, that improved fruit quality and disease resistance became important benchmarks to achieve.

European bunch grapes were first introduced into Florida by early European settlers, but they failed to flourish due to disease and poor tolerance to the climate (Lane, 1997). A second attempt using *V. labrusca* L. also met with failure. Other early efforts to grow European grapes, including several attempts by Thomas Jefferson, the third President of the United States, were unsuccessful in the South due to disease (Hedrick et al., 1908). Once it was found that native grapes and *V. vinifera* could be hybridized, bunch grapes became an important crop across many southern states in the 1800s and early 1900s. Much of this production was based on cultivars with *V. labrusca*, or hybrids of various native species (Hedrick et al., 1908).

In 1880, the South had roughly 4000 ha of grapes, both bunch and muscadine. That increased in a decade to over 6900 ha, with the production divided between table grapes (13,190 tons) and wine (4.5 million L) (Hedrick et al., 1908). Interspecific hybridization was attempted sporadically in the 1800s, but by the late 1800s and early 1900s, private and public breeders, following the lead of T.V. Munson, began the challenge of crossing existing cultivars with native species. Wine was a considerable part of the southern grape production until Prohibition (Lane, 1997). After Prohibition, bunch grape breeding progressed slowly in the South. Snyder (1937) suggested that the emphasis be placed on breeding for disease and insect resistance. He specifically mentioned downy mildew (*Plasmopara viticola* Berl. & de Toni), black rot (*Guignardia bidwellii* Viala & Ravaz), root rots, and phylloxera. Also referenced was the need for better berry size and quality, as well as soil and climatic adaptation.

16.2.4 Present state of grape production in the South

Grapevines are grown in every state, but tracking the amount of fruit produced is difficult. Some states have local production that largely goes unreported. The United States Department of Agriculture, National Agriculture Statistics Service (USDA-NASS) reports grape crop statistics for five southern states: Arkansas, Georgia, North Carolina, Texas, and Virginia. Of these, Virginia has the highest utilized production measured in US dollars with $10,248,000, while Arkansas has the least at $1,663,000, along with $8,711,000 for Texas, $3,961,000 for North Carolina, and $3,782,000 for Georgia. Utilized production in tons follows the same trend, with Virginia producing the most at 6100, Arkansas the least at 1640, and in the middle are Texas with 5590, North Carolina with 4700, and Georgia with 3300. However, when looking at bearing hectares, Texas has the most, followed by Virginia, North Carolina, Georgia, and Florida (USDA-NASS, 2013) (Table 16.1). Using the total hectares bearing nationally of 422,104 ha, compared to the total hectares bearing in the southern states, 6891, the southern states have 1.6% of the total hectares in the country (USDA-NASS, 2013). When looking at the national production measured in tons, 8,657,530, compared to the total southern production of 30,040 total tons, the South makes up 0.35% of total US production. However, the price received per ton nationally is $716, and when compared to the price received per ton in the southern states, they all received a higher dollar amount per ton than the national average in 2013. Reported average prices include North Carolina growers receiving (on average) $843, Arkansas $1010, Georgia $1150, Texas $1560, and Virginia $1680. Texas and Virginia vineyards produced primarily *V. vinifera* grapes and thus received higher prices than other southern states that produced mainly hybrids and muscadines. Yet, these prices indicate that there is a high demand for grapes from these southern states, and the risk of growing them in difficult environmental conditions may be worth it for the increased return potential.

Table 16.1 Number of wineries and bearing hectares of grapes in the Southern United States as of 2013

State	Number of bonded wineries[a]	Bearing hectares[b]
Alabama	15	172
Arkansas	14	291
Florida	46	484
Georgia	36	711
Kentucky	58	185
Louisiana	8	40
Mississippi	1	83
North Carolina	116	1087
Oklahoma	50	138
South Carolina	13	201
Tennessee	42	261
Texas	204	1640
Virginia	213	1511
West Virginia	23	87

[a]Data taken from Fisher (2014).
[b]Data from USDA-NASS (2013).

In 2014, there were 839 bonded wineries in the South (Fisher, 2014). Of all the southern states, Virginia had the most wineries with 213. Mississippi had the fewest of not only the southern states, but of all 50 states in the country, with only one bonded winery (Table 16.1). Only three states in the South have processing production reported in the USDA-NASS (2013) survey. The total processing and total processing wine production have the same reporting numbers, and therefore, it can be assumed almost all reported processing production is for wine in these states.

When reporting fresh-market production statistics, USDA-NASS (2013) indicated only two southern states with measurable amounts, North Carolina and Texas. North Carolina had a production value of $902,000, while Texas had a production value of $147,000. Production in other states exists, particularly in Georgia, where the largest production of muscadines occurs for the shipping market. Again, the lack of reporting of small, fresh-market production results in an undervaluing of overall production in the region.

16.3 Breeding grapevines for the Southern US

16.3.1 Breeding and selection techniques for the South

Breeding grapes in the Southern US utilizes the same approaches as other regions of the US or worldwide. A major issue is that muscadine and bunch grape breeding is done within subgenera. Muscadines have 40 chromosomes (2n = 40), whereas bunch grapes

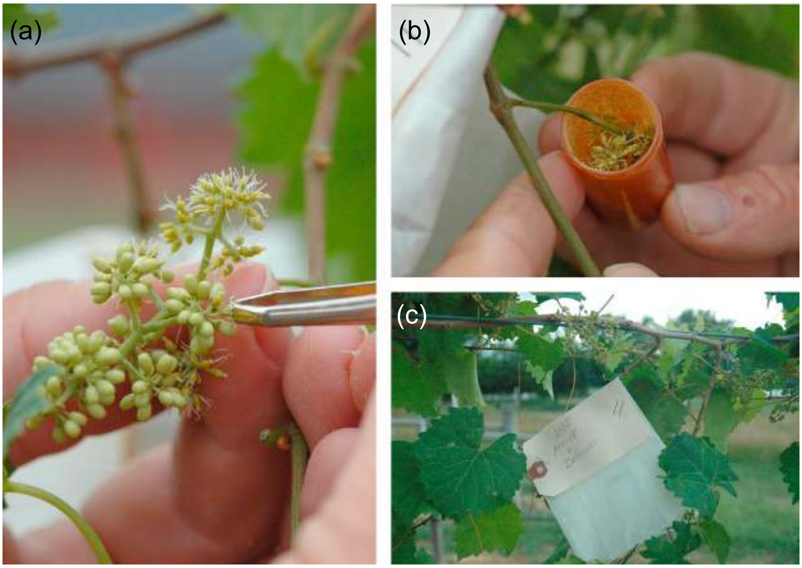


Figure 16.1 (a) Muscadine flowers are emasculated in order to facilitate controlled hybridization. (b) Previously collected pollen is then applied to the emasculated flowers. (c) Once the pollen is applied, the entire cluster is covered and tagged to eliminate undesired pollen contamination. Photos by J.R. Clark.

contain 38 (2n = 38) (Olien, 1990); therefore, the uneven chromosome number in resulting hybrids contributes to low fertility, although some fertile hybrids have been produced.

For cultivar development, complementary parents exhibiting desirable phenotypic traits are usually crossed to yield superior offspring. Emasculation procedures and resulting hybrid seed success for perfect-flowered female muscadine parents are generally considered more difficult compared to bunch grapes (J. Bloodworth and P.J. Conner, personal communication), although success has been had in some breeding programs (Figure 16.1). This difficulty is thought to be due to more damage to the ovaries in muscadines compared to bunch grapes in the emasculation procedure (Goldy and Onokpise, 2001). Pistillate muscadine parents, which do not require emasculation, have therefore been used widely as females. However, the use of pistillate parents results in a higher percentage of the offspring with pistillate flowers, which is not desirable when breeding for perfect-flowered muscadines. Seeds are collected and extracted from fruit at maturity and often treated with fungicide prior to stratification for two to four months.

Muscadine and bunch grape seed handling procedures are, in general, similar. Seeds are sowed in a greenhouse in the winter after harvest in summer or fall, using various media, often a soilless medium of a mixture of peat and perlite. Seeds germinate in 20–40 days, and seedlings within population usually can be transplanted all at one time. Desirable population sizes are normally 100–200, with larger populations utilized when recovery of the desired phenotype may be difficult, such as seeded × seedless crosses where only seedless progeny are desired. Seedlings are grown in the greenhouse and usually transplanted to the field after the frost-free date and/or when they attain adequate

Figure 16.2 Seedlings are planted 1 m apart and are trained to a trellis using strings. Photo by J.R. Clark.

size. Seedling spacing is usually approximately 1 m between vines. Training is required, and it is one of the more laborious aspects of grape breeding. Training is normally done using strings or canes to direct the seedlings onto the trellis (Figure 16.2). Pruning is required during each dormant season. Bunch grapes may be spur- or cane-pruned when mature, while muscadines are spur-pruned, utilizing a very short cordon.

Pest management of seedlings can vary greatly, depending on if they are bunch grapes or muscadines. Bunch grape seedlings (at least those derived from *V. labrusca* and *V. vinifera*) produced in the South usually require some degree of fungicide and insecticide applications to successfully produce fruit for evaluation. Muscadines can be grown with no control measures due to their higher level of resistance, although some locations can require fungicide applications for consistent seedling evaluations.

Seedlings can be evaluated in one or two fruiting years, depending on the degree of crop produced on younger seedlings. Fruit may be produced on second-year seedlings in more southern locations, but is more commonly evaluated in years three and possibly four in the mid to upper South. Seedling evaluation procedures vary depending on breeding objectives, such as fresh or processed. Selected seedlings are usually propagated for the establishment of two to three-vine plots. Softwood cuttings are most often used for muscadines, while hardwood cuttings are used for bunch grapes. The time from initial hybridization to cultivar release can range from 12 to 20 years.

Selection evaluation includes multiple location testing, preferably across the region. Adaptation differences can be substantial, and the range of potential use of a selection can greatly help in determining potential value. Fresh market potential often includes some degree of postharvest storage performance, with key items of evaluation that include retention of desirable color, firmness, weight loss in storage, and lack of pathogen development, particularly associated with dry picking scars (Barchenger et al., 2014). Processing evaluations are more difficult, as a cooperating enologist or food scientist is needed to determine processed quality. Although enological evaluations of advanced selections and new cultivars were common in the 1970s and 1980s in Arkansas, Mississippi, North Carolina, and Florida, and resulted in the release of wine cultivars Regale, Doreen, Golden Isles, and Welder, work in this area is currently very limited and greatly restricts the potential for new cultivar development for the processing market (Lane and Bates, 1987; Mortensen and Hayslip, 1977; Nesbitt et al., 1982a, 1982b).

16.3.2 Specific needs to address with breeding

Pest resistance is of paramount importance in breeding bunch grapes in the South. There is a wide range of fungal pathogens that infect bunch grapes, and unfortunately, resistance to these pathogens is lacking in most commercially important bunch grape species. Important pathogens include black rot, powdery mildew (*Erysiphe necator* Schw. [syns. *Uncinula necator* (Schw.) Burr., *E. tuckeri* Berk., *U. americana* Howe, and *U. spiralis* Berk. & Curt; anamorph *Oidium tuckeri* Berk.]), downy mildew, and anthracnose (*Elsinoë ampelina* Shear). Although muscadines are usually resistant to these diseases, others are of concern, such as macrophoma rot (*Botryosphaeria dothidea*) (Moug.: Fr.) Cesati & De Notaris (anamorph *Fusicoccum aesculi* Corda), bunch rots, ripe rot (*Glomerella cingulata*) (Stoneman) Spauld. & H. Schrenk, bitter rot (*Greeneria uvicola*) (Berk. & M.A. Curtis) Punith., and angular leaf spot (*Mycosphaerella angulata* W.A. Jenkins).

A major limiting factor to bunch grape production in the South, one not found in most of the US, is PD (Wells et al., 1987). For quite some time, this disease was called “grape degeneration” in southern states and its cause was unknown until the 1950s, even though PD had already been identified in California. It was initially thought to be a virus, but by the late 1950s, it was understood to be bacterial in nature (Halbrooks and Mortensen, 1989). This bacterial disease will kill *V. vinifera* and many *Euvitis* hybrid vines and can severely restrict production of some hybrid vines with limited tolerance. Muscadine grapes are generally considered resistant to PD, although some reports have been made of crop reduction due to infection with this pathogen (Hopkins et al., 1974). The causal bacterium is vectored by sharpshooter leafhoppers, especially the glassy-winged sharpshooter (*Homalodisca vitripennis* Germar). In addition to *V. rotundifolia*, resistance to this disease is known to occur in some native bunch grape species as well. Mortensen (1968) reported that three dominant genes were required for resistance to PD. Increasing disease resistance in new cultivars would be a welcome addition to the areas of the South most affected by PD.

Insect pests, such as grape phylloxera, grape root borer (*Vitacea polistiformis* Harris), grape berry moth (*Paralobesia viteana* Clemens), spotted wing drosophila (*Drosophila suzukii* Matsumura), and nematodes are of concern to growers in the Southern United States. However, effective control is available for most of these pests. A few species native to southern regions of the US are resistant to nematodes and have thus been used for rootstocks. “Dog Ridge” and “Salt Creek” are examples of nematode-resistant rootstocks derived from *V.* × *champinii* Planch. and *V.* × *doaniana* Munson ex Viala (Loomis and Lider, 1971).

Another area of breeding is vine adaptation to the region. The South encompasses a wide range of environments, from the upper South such as Oklahoma, Arkansas, and eastward to Virginia, to the Deep South, extending to Florida. Heat tolerance, in general, is present in existing germplasm of commercially important species, but winter hardiness can be a great concern. The upper South routinely experiences winter low temperatures of −15 °C or lower, which can lead to substantial winter injury if too much nonhardy germplasm (e.g., *V. vinifera*) is included in breeding. Fluctuating winter temperatures are also common in the region, further complicating hardiness breeding. Opportunities in expanding muscadine cultivar hardiness likely exist, if hardier germplasm from more northern areas of the South could be combined with high-quality parents and the progeny screened for hardiness in colder locations.

Fruit quality is always of paramount importance in breeding programs, but characteristics that make up quality vary greatly among bunch grape and muscadine germplasm and the intended use, such as for processing or fresh markets. Wine and juice grape breeding provides a range of challenges, including retention of acidity in high heat during ripening, achievement of desirable soluble solids, and adequate color in red wine genotypes. Fresh market breeding in bunch grapes has traditionally combined the Eastern US adaptation of *V. labrusca* and other species with the marginally adapted but primary source of high-quality traits, *V. vinifera.* Primary traits have included texture improvements, seedlessness, and fruit-cracking resistance. Muscadine breeding has focused on the improvement of cultivars for wine and juice and more commonly for fresh market. Quality improvements for fresh-market muscadines usually include fruit size, reduced skin thickness, and more crisp (nonslipskin) texture. Great progress has been made in this area, and future cultivars will expand on quality and the eating enjoyment of this native fruit. Furthermore, seedlessness in muscadines has been achieved, as found in the cultivar RazzMatazz (J. Bloodworth, personal communication). Other muscadine breeding programs are pursuing seedlessness as well (Colova-Tsolova et al., 2003; Li et al., 2010).

16.3.3 Limitations and challenges to breeding grapes in the South

Muscadines are a niche product that have loyal consumers, but also have a lack of broad consumer acceptance. The movement of northern populations to the South has significantly changed demographics in those states. Whereas many native Southerners grew up with muscadines as a common fruit, northern populations are not familiar with them. The intense fruity aroma and flavor, along with thick skins and slipskin texture, can be overwhelming to those used to neutral-flavored and thin-skinned table grapes like "Thompson Seedless." Most cultivars of muscadines have seeds that many consumers find undesirable. Muscadine vines are very productive and can produce upwards of 19–24 tons per ha. That is a significant amount of fruit that must find a market, but muscadine grapes do not have a long shelf life, usually limited to 3 weeks (James et al., 1999).

Bunch grape production is not commercially significant in most southern states, aside from regions where PD is not a major issue. Hybrid table grapes are an extremely small portion of the production. This is due not only to disease limitations, but also to limited shelf life. Longer shelf life might help expand their local markets, along with extending the marketing season. Most bunch grape production in the South is for the wine market. Although increasing in popularity throughout the United States, wine production in most southern states is lagging behind. Much of this is due to suboptimal growing conditions in some states, but also because of restrictive laws that make the act of producing and selling wine difficult. There is a substantial need for more and better cultivars to supplement or replace those currently being grown.

16.4 Cultivar development

16.4.1 Important parental southern grape species

16.4.1.1 Muscadinia Planch.

The Southern United States has an abundance of *Vitaceae* species, but few have been exploited within breeding programs. The most prominent species is *V. rotundifolia* (syn. *M. rotundifolia*), which is native from as far north as Delaware to the Gulf Coast and as far west as Southeast Oklahoma (Andersen et al., 2013; USDA-NRCS, 2014). Breeding began in Georgia in the early 1900s. Desirable traits of this species include disease resistance/tolerance, insect tolerance, broad soil adaptation, fruit-cracking resistance, and high nutraceutical content. Improvable traits include skin thickness, fruit texture, seedlessness, reduced stem scar tears, time of maturity, cold hardiness, and flavors and aromas (Goldy and Onokpise, 2001). *Vitis munsoniana* Simpson ex Munson is similar to *V. rotundifolia* but grows in more subtropical areas. The fruit has thin skin and small seeds but also small size and poor quality. *Vitis popenoei* Fennell is a tropical Muscadinia native to Southern Mexico that has been used in breeding (Conner, 2010; Olien, 1990).

16.4.1.2 Euvitis Planch.

Some of *Euvitis* grape species in the Southern US can be difficult to differentiate. Many independent species have been discredited and changed over the years, such that the literature can be a challenge to interpret. This discussion will focus on the primary species, rather than subspecies (varieties) and synonymous species names that may also exist. A few southern grape species, including *V. acerifolia* Raf., *V. monticola* Buckley, *V. mustangensis* Buckley, *V. palmata* Vahl, and *V. vulpina* L. have been used sparingly in breeding programs, but may have traits that could be used, especially for rootstock breeding. Another species, *V. labrusca*, is considered native to some upper-South states, but much of its importance is tied to the Northeast US and will not be discussed here.

Vitis aestivalis Michx. is arguably the most important single species of bunch grape in the South. "Norton" (syn. "Cynthiana"), a superior wine grape, includes this species in its parentage, as do many other cultivars. The beneficial traits of *V. aestivalis* and its subspecies are high vigor, disease resistance, resistance to fruit cracking, high fruit sugar, good wine-making properties, and environmental stress tolerance (Mortensen and Stover, 1990; Snyder, 1937). It has poor resistance to phylloxera, so it has not been used extensively in rootstock breeding (Einset and Pratt, 1975).

Vitis arizonica Engelm. has traditionally been a little-used grape species in breeding. Recently, it has been used as a source in breeding for PD resistance (Riaz et al., 2009). Of the Southern US states, it has only been identified in Texas.

V. × *champinii* Planch. (pro sp.) [*V. mustangensis* × *V. rupestris*] has been used as a source of root-knot nematode resistance in rootstock breeding. This species thrives in droughty, poor soils and can be overly vigorous in good growing conditions (Cousins, 2005; Snyder, 1937). Rootstocks derived from this species include "Dog Ridge" and "Ramsey," both of which are selections of *V.* × *champinii*, as well as "Freedom," "Salt Creek," and "Harmony," which include it in their parentage (Cousins, 2005; Loomis and Lider, 1971).

Vitis cinerea (Engelm.) Engelm. ex Millard prefers acidic soils and has good resistance to disease and phylloxera. However, it is difficult to propagate (Einset and Pratt, 1975). Barrett (1957) described the valuable breeding characteristics of *V. cinerea* as adaptation to heat and humidity, disease resistance, high vine vigor and fertility, large clusters, good quality berries without objectionable aromas and flavors, high sugar content, and good postharvest storage potential.

V. × *doaniana* Munson ex Viala (pro sp.) [*V. acerifolia* × *V. mustangensis*] is found in Oklahoma and Texas and its use has been limited to rootstock breeding (Loomis and Lider, 1971).

Vitis riparia Michx has contributed substantially to the creation of rootstock and hybrid grape cultivars, because it is easily propagated and has desirable traits. It has good cold hardiness, disease resistance, and resists phylloxera, but it does not tolerate calcareous soils (Cousins, 2005; Einset and Pratt, 1975). "Riparia Gloire" rootstock is a direct selection of *V. riparia* (Cousins, 2005). Because of its wide distribution throughout the Eastern US, breeders in other areas of the country have used *V. riparia* as a source of cold hardiness, for example, "Frontenac" (Clark, 1997).

Vitis rupestris Scheele is also called the sand grape. It occurs in the mid-South states of Arkansas, Kentucky, Tennessee, and Oklahoma (Cousins, 2005). One especially positive trait of this species for breeding is resistance to phylloxera. It also roots easily, develops a deep root system, and has high vigor, but like *V. riparia*, it does not tolerate calcareous soils (Einset and Pratt, 1975; Snyder, 1937). "St. George" rootstock is a selection of *V. rupestris* (Cousins, 2005).

Vitis shuttleworthii House is native only to Florida. It was used in breeding the cultivar Stover. This species has good disease (especially PD) and insect resistance, vine vigor, berry size, small seeds, wide climatic and soil adaptation, and high yield potential. It also has tough pulp, acidic juice, and rather small clusters. *V. shuttleworthii* has been used in rootstock breeding in Florida as well (Fennell, 1938; Mortensen and Stover, 1990; Rogers and Mortensen, 1979).

16.4.2 Southern-bred cultivars of importance

Grape and muscadine breeders have been working in the South to develop adapted cultivars for more than a century (Table 16.2). In that time, a few southern-derived cultivars have risen to enough prominence that they have positively impacted the grape industry. Most of these are muscadines, but a few bunch grapes continue to have a

Table 16.2 **An alphabetical list of bunch grape and muscadine breeders, programs, and focus of their work in the Southern United States**

Breeder	Program	Focus
Ballington, J.R.	North Carolina State Univ.	Muscadine
Bloodworth, J.	Private (North Carolina)	Muscadine
Clark, J.R.	Univ. of Arkansas	Bunch/Muscadine
Conner, P.J.	Univ. of Georgia	Muscadine
Cowart, F.M.	Univ. of Georgia	Muscadine
Dearing, C.T.	North Carolina State Univ./USDA[a]	Muscadine
Demko, C.	Private (Florida)	Bunch
Detjen, L.R.	North Carolina State Univ.	Muscadine
Dunstan, R.T.	Private (North Carolina, Florida)	Bunch
Fennell, J.L.	Private (Florida)	Bunch
Fry, B.O.	Univ. of Georgia	Muscadine
Girouard, G.	Private (Oklahoma)	Bunch
Goldy, R.G.	North Carolina State Univ.	Muscadine
Gray, D.J.	Univ. of Florida	Muscadine
Gupton, C.L.	USDA-ARS[b], Mississippi	Muscadine
Hinrichs, H.	Oklahoma State Univ.	Bunch
Ison, W.	Private (Georgia)	Muscadine
Lane, R.P.	Univ. of Georgia	Muscadine
Locke, L.F.	USDA Oklahoma	Bunch
Loomis, N.H.	USDA Mississippi	Bunch/Muscadine
Lu, J.	Florida A&M Univ.	Bunch
Meyer, H.M.	Private (Texas)	Bunch
Moore, J.N.	Univ. of Arkansas	Bunch
Moore, R. C.	Virginia Tech Univ.	Bunch
Mortensen, J.	Univ. of Florida	Bunch/Muscadine
Munson, T.V.	Private (Texas)	Bunch
Murphy, M.M.	Univ. of Georgia	Muscadine
Nesbitt, W.B.	North Carolina State Univ.	Muscadine
Oberle, G.D.	Virginia Tech Univ.	Bunch
Reimer, F.C.	North Carolina State Univ.	Muscadine
Sefick, H.J.	Clemson Univ.	Bunch
Stover, L.H.	Univ. of Florida	Bunch
Stringer, S.J.	USDA-ARS, Mississippi	Muscadine
Stuckey, H.P.	Univ. of Georgia	Muscadine
Whatley, B.T.	Tuskegee Univ.	Bunch/Muscadine
Williams, C.	North Carolina State Univ.	Muscadine
Woodroof, J.P.	Univ. of Georgia	Muscadine

[a]United States Department of Agriculture.
[b]United States Department of Agriculture-Agricultural Research Service.

place. Table grapes do not constitute a large portion of the grapes grown in the South. "Jupiter" from the University of Arkansas breeding program (Clark and Moore, 1999) is probably the most widely grown hybrid table grape in the southern US (Figures 16.3 and 16.4). Other cultivars from the University of Arkansas program are also grown throughout the upper South, such as "Mars" and "Neptune." Unfortunately, these cultivars are not considered PD-resistant and may do poorly in areas where PD is problematic. "Victoria Red" was recently released as a PD-tolerant, seeded table

Figure 16.3 "Jupiter" is a reddish-blue colored, seedless grape with a mild Muscat flavor. It is a nonslipskin type with crisp flesh texture. The vine is moderately vigorous and has moderate resistance to common fungal diseases.
Photo by J.R. Clark.

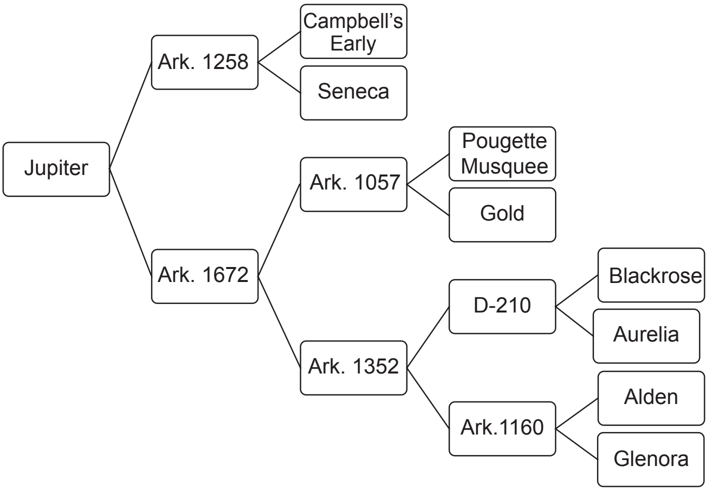


Figure 16.4 Pedigree of "Jupiter," a hybrid seedless bunch table grape from the University of Arkansas.

grape and may provide an option for local markets in the Gulf South (Moore et al., 2011). High-quality, PD-resistant wine grapes are few. "Blanc du bois" is a white wine grape bred at the University of Florida (Mortensen, 1987) (Figure 16.5). It is resistant to PD, making it popular throughout the Gulf Coast region, especially in Texas. "Norton" is a high-quality red wine grape and "Black Spanish" (also called "Lenoir") is another. The latter is grown extensively in the Gulf Coast region of Texas for red wine.

There are numerous muscadine cultivars that are reliable performers in the South (Table 16.3). "Scuppernong," the most famous and widely grown muscadine, was selected from the wild more than 250 years ago (Mortensen, 2001). Mortensen (2001) listed "Carlos," "Dixie," "Doreen," "Fry," "Jumbo," "Magnolia," "Nesbitt," "Noble," "Regale," "Summit," "Triumph," and "Welder" as proven cultivars for the South. Of these listed, some are preferred for the fresh market (i.e. "Fry," "Jumbo," "Nesbitt," "Summit," and "Triumph") and others for juice and wine production. "Supreme" and "Black Beauty" are important also, as they combine very large fruit size and improved skin and texture characteristics, although they are pistillate. The newer "Tara" and "Lane" provide high quality and large fruit size, along with perfect flowers. "Carlos" (Nesbitt et al., 1970) (Figure 16.6) and "Noble" are the prominent muscadine wine cultivars. Other cultivars have more local adaptation and can vary by state in their usage.

16.5 Southern grape breeding programs

16.5.1 Alabama

Some grape breeding was done by B.T. Whatley at Tuskegee University. A few releases were made, with the most notable being "Foxxy Lottie" in 1982 (Clark, 1997), but none became commercially important.

16.5.2 Arkansas

Grape breeding at the University of Arkansas was started by J.N. Moore in 1964. The program was focused primarily on seedless table grapes, with lesser effort on wine and juice grapes. The primary germplasm was interspecific hybrids using *V. labrusca* and *V. vinifera* (Moore, 1969). More specifically, cultivars and selections from the New York Agricultural Experiment Station were used, as well as French–American hybrids, *V. vinifera* cultivars, and an assortment of other material, including cultivars and selections from the private breeding program of R.T. Dunstan in North Carolina. J.R. Clark followed Moore in 1996 and has continued breeding hybrid table grapes, as well as initiating a fresh-market muscadine breeding program in 2006. The program is based in west-central Arkansas, a location that does not have selection pressure for PD. Twelve cultivars have been released from the program, including "Joy," "Jupiter," "Mars," "Neptune," and "Venus" tables grapes (Figure 16.7), and "Sunbelt" juice grape. One seeded table-grape cultivar, Victoria Red, was cooperatively released with Texas A&M University and Tarkington Vineyard, as it exhibited PD resistance in long-term testing near Victoria, TX (Moore et al., 2011).

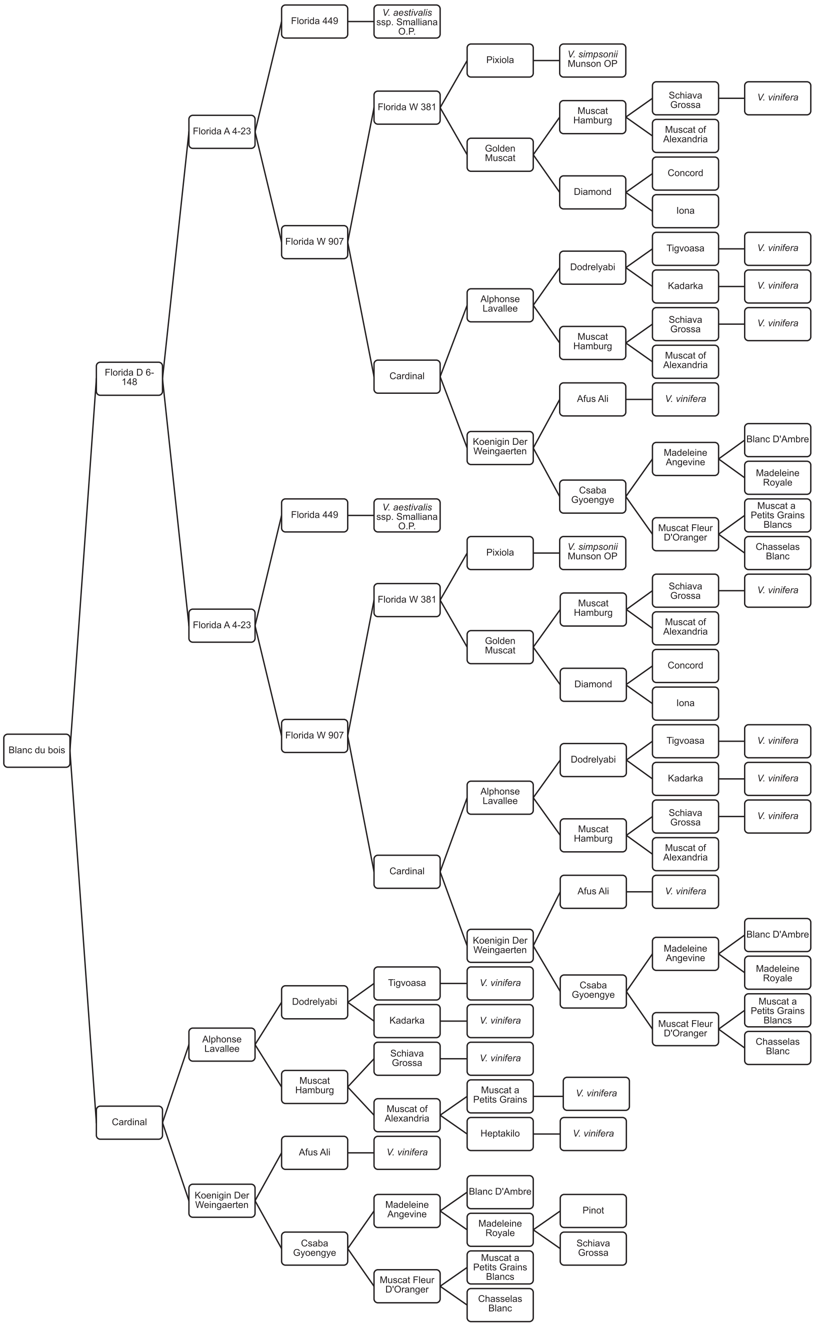


Figure 16.5 Pedigree of "Carlos" muscadine, a widely grown release from North Carolina State University. It is used extensively for wine production, but it is also considered a good all-purpose muscadine.

Table 16.3 **Southern US-developed bunch grape and muscadine cultivars**[a]

Cultivar	Grape type	Year released	Institution or location	Inventor	Parentage
A-1710 (Tickled Pink)	Bunch	2011	Univ. of Arkansas	Clark and J.N. Moore	Moored × NY 45791
A-2640 (Sweet Magic)	Bunch	2010	Univ. of Arkansas	Clark and J.N. Moore	Ark. 1925 × Ark. 2020
Alwood	Bunch	1967	Virginia Tech. Univ.	R.C. Moore	Fredonia × Athens
Aurelia	Bunch	1963	Southeast Nurseries	Dunstan	N.C. Chaouch × Seyve-Villard 12–375
Biscayne (Fennell 113)	Bunch	1948	Florida	Fennell	*V. rufotomentosa* 9 × Feher Szagos
Blanc du bois	Bunch	1987	Univ. of Florida	Mortensen	Fla. D6–148(self of Fla. A4–23) × Cardinal
Blue Lake	Bunch	1960	Univ. of Florida	Stover	Open-pollinated selection of *V. smalliana* × Caco
Bounty	Bunch	1975	Oklahoma State Univ.	Hinrichs	Ellen Scott × Bailey
By George	Bunch	~2003	Oklahoma	Girouard	Ruby Cabernet × *V. aestivalis* JG#3 (wild selection by J. Grinstead, Rolla, MO)
Carolina Blackrose	Bunch	1964	Southeast Nurseries	Dunstan	Blackrose × Aurelia
Century I	Bunch	1973	Virginia Tech Univ.	Oberle	Villard 20–347 × Dunstan 3 (Chasselas Violet × Golden Muscat)
Chilcott	Bunch	1959	USDA Oklahoma	Locke	Open pollinated seedling of Volney
Cimarron	Bunch	1958	Oklahoma State Univ.	Hinrichs	*V. cinerea* var. *canescens* × Seneca
Conquistador	Bunch	1983	Univ. of Florida	Mortensen	(*V. smalliana* × Concord) × [(Norris × Concord) E11–40]
Daytona	Bunch	1983	Univ. of Florida	Mortensen	Fla. 133–90 × Exotic
Demko 10—17A (rootstock)	Bunch	2012	USDA-ARS	Demko	Edna × *V. simpsonii*

Continued

Table 16.3 Continued

Cultivar	Grape type	Year released	Institution or location	Inventor	Parentage
Early Giant	Bunch	1932	Stark Bros.	Wiederkehr	Parentage unknown
Eureka	Bunch	1975	Oklahoma State Univ.	Hinrichs	America × Ontario
Fairchild	Bunch	1940	Florida	Fennell	*V. tiliaefolia* × Alphonse Lavalee
Faith	Bunch	2012	Univ. of Arkansas	Clark and J.N. Moore	Ark. 1962 × Jupiter
Favorite	Bunch	~1938	Texas	Niederauer	Probably Black Spanish × Herbemont
Florida Concord	Bunch	1963	Florida	Demko	(*V. simpsonii* × Carman) × Concord
Florilush (rootstock)	Bunch	1994	Univ. of Florida	Mortensen, Harris, and Hopkins	Dogridge × Tampa
Foxxy Lottie	Bunch	1982	Tuskegee Univ.	Whatley	*V. vinifera* × *V. labrusca*
Gratitude	Bunch	2012	Univ. of Arkansas	Clark and J.N. Moore	Ark. 1925 × Ark. 1581
Henryetta	Bunch	1936	Oklahoma State Univ.	Cross	Probably a bud mutation of Brighton
Hope	Bunch	2012	Univ. of Arkansas	Clark and J.N. Moore	Ark. 1562 × Ark. 1704
Joy	Bunch	2012	Univ. of Arkansas	Clark and J.N. Moore	Ark. 1919 × Ark. 1908
Jupiter	Bunch	1999	Univ. of Arkansas	Clark and J.N. Moore	Ark. 1258 × Ark. 1672
Keating	Bunch	1959	USDA Oklahoma	Locke	Open pollinated seedling of Last Rose
La Pryor (rootstock)	Bunch	1934	Texas A&M Univ.		Unknown, probably a hybrid of *V. candicans* × *V. rupestris*
Lake Emerald	Bunch	1954	Univ. of Florida	Stover	*V. simpsoni* Pixiola × Golden Muscat
Leverkuhn (rootstock)	Bunch	~1940	Texas	Patterson	Spontaneous hybrid of *V. candicans* and unknown Armenian variety
Liberty	Bunch	1976	Univ. of Florida	Mortensen	W716 (43–47 × Golden Muscat) × Buffalo
Lollar	Bunch	1935	Munson Nurseries	Munson	Parentage unknown
Mantey	Bunch	1951	Florida	Mantey	Parentage unknown, believed to be *V. shuttleworthii* OP
Marco	Bunch	1948	Florida	Fennell	*V. rufotomentosa* 9 × Masters
Mars	Bunch	1985	Univ. of Arkansas	J.N. Moore	Island Belle × Ark. 1339

Masters	Bunch	1940	Florida	Fennell	Unknown, but considered to be *V. shuttleworthii* × Niagara
Meier Everbearing	Bunch	1922	Texas	Meier	Unknown, possibly a hybrid of some American species
Meteor	Bunch	1975	Oklahoma State Univ.	Hinrichs	Bailey × Keuka
MidSouth	Bunch	1981	Mississippi State Univ. and USDA	Overcash and Loomis	De Grasset (*V.* × *champini*) × Galibert 255–5
MissBlanc	Bunch	1982	Mississippi State Univ. and USDA	Overcash and Loomis	Galibert 261-12 × seedling of Extra × Marguerite
MissBlue	Bunch	1981	Mississippi State Univ. and USDA	Overcash and Loomis	Dog Ridge (*V.* × *champini*) × Moore early (OP seedling of Concord)
Monticello	Bunch	1973	Virginia Tech. Univ.	Oberle	USDA 4606-5 (Fredonia × Niagara) × VPI 5-32 (Fredonia × Athens)
Moored	Bunch	1969	Virginia Tech. Univ.	R.C. Moore	Fredonia × Athens
Mortensen Hardy	Bunch	1997	Treesearch Farms	Randall and Mortensen	BD12-49 × Ark. 1105
Myakka	Bunch	1947	Florida	Fennell	(*V. shuttleworthi* × *V. smalliana*) × *V. vinifera* Malaga
Neptune	Bunch	1999	Univ. of Arkansas	Clark and J.N. Moore	Ark. 1562 × Ark. 1704
Norris	Bunch	1967	Univ. of Florida	Mortensen and Stover	Fla. W987 [*V. smalliana* × *V. lincecumii*) × Cardinal] × Lake Emerald
Oconee	Bunch	1970	Clemson Univ.	Sefick	(Alden × Ellen Scott OP) × Niagara
Orlando Seedless	Bunch	1986	Univ. of Florida	Mortensen and Gray	Fla. D4-176 (Norris × Schuyler) × Fla F9-68 (Fla. A4-23 × Perlette)
Osborn	Bunch	1959	USDA Oklahoma	Locke	OP seedling of Armalaga
Phil S. Taylor	Bunch	1957	Private (Florida)	Demko	(Edna × *V. simpsoni*) × (Seyve-Villard 12375 × Concord)
Pixiola (Magruder)	Bunch	1942	Florida	Louks	OP seedling of *V. simpsoni*

Continued

Table 16.3 Continued

Cultivar	Grape type	Year released	Institution or location	Inventor	Parentage
Plymouth	Bunch	~2003	Oklahoma	Girouard	Merlot × *V. aestivalis* JG #3 (wild selection by J. Grinstead, Rolla, MO)
Price	Bunch	1973	Virginia Tech. Univ.	R.C. Moore	VPI 4 (Hector × Seibel 13035) × VPI 5-7 (Fredonia × Athens)
Reliance	Bunch	1982	Univ. of Arkansas	J.N. Moore	Ontario × Suffolk Red
Rubaiyat	Bunch	1975	Oklahoma State Univ.	Hinrichs	Seibel 5437 × Bailey
Saturn	Bunch	1989	Univ. of Arkansas	J.N. Moore, Clark, Morris	Dunstan 210 (Blackrose × Aurelia) × NY 45791 (Bath × Himrod)
Seminole	Bunch	1947	Florida	Fennell	(*V. shuttleworthii* × *V. rofotomentosa*) × (*V. candicans* × Rommel)
Southern Cross	Bunch	~2003	Oklahoma	Girouard	Merlot × *V. aestivalis* JG#3 (wild selection by J. Grinstead, Rolla, MO)
Stover	Bunch	1930	Univ. of Florida	Stover and Mortensen	Maney × Seyve-Villard 12-309
Sunbelt	Bunch	1993	Univ. of Arkansas	J.N. Moore, Morris, and Clark	Concord open pollinated
Sunset	Bunch	1975	Oklahoma State Univ.	Hinrichs	Bailey × Keuka
Suwanee	Bunch	1983	Univ. of Florida	Mortensen	C5-50 (W1521 × Villard Blanc) × Fla. F8-35 (Norris × Alden)
Tamiami	Bunch	1957	Florida	Fennell	Fennell 6 (a wild species) × Malaga
Tampa (rootstock)	Bunch	1982	Univ. of Florida	Mortensen and Stover	Fla. 43-47 (*V. aestivalis* ssp. *smalliana* open pollinated) × Niagara
Tropico	Bunch	1943	Florida	Fennell	*V. shuttleworthii* 5 × Lomanto
Valjohn	Bunch	~2003	Oklahoma	Girouard	Cabernet Franc × *V. aestivalis* JG#3 (wild selection by J. Grinstead, Rolla, MO)
Venus	Bunch	1977	Univ. of Arkansas	J.N. Moore and Brown	Alden × NY 46000

Victoria Red	Bunch	2010	Univ. of Arkansas and Texas A&M Univ.	J.N. Moore, Clark, Kamas, Stein, Tarkington, and Tarkington	Ark. 1123 × Exotic
Vinok	Bunch	1975	Oklahoma State Univ.	Hinrichs	Bailey × Keuka
Wachula	Bunch	1948	Florida	Fennell	Open pollinated seedling of *V. rufotomentosa* 9
African Queen	Muscadine	1988	Ison's Nursery	Fry and Ison	Dixieland × Sugargate
Alachua	Muscadine	1990	Univ. of Florida	Mortensen and Harris	Fry × Southland
Albermarle	Muscadine	1962	North Carolina State Univ. and USDA	Williams	Topsail × Burgaw
Black Beauty	Muscadine	1991	Ison's Nursery	Ison	Fry × 12-12-1
Black Fry	Muscadine	1986	Ison's Nursery	Fry and Ison	Fry × Cowart
Bountiful	Muscadine	1967	USDA Mississippi	Loomis	Creek × seedling of Topsail
Brownie	Muscadine	1933	Univ. of Georgia	Woodroof	OP seedling of San Monta, muscadine type
Burgaw	Muscadine	1946	North Carolina State Univ. and USDA	Dearing	Thomas × V19 R7 B2 (Scuppernong × New Smyrna)
Cape Fear	Muscadine	1946	North Carolina State Univ. and USDA	Dearing	Burgaw × V20 R36 B4 [V19 R7 B2 (Scuppernong × male) × Kilgore]
Carlos	Muscadine	1970	North Carolina State Univ.	Nesbitt, Underwood, and Carroll	Howard × NC11-173 (Topsail × Tarheel)
Chief	Muscadine	1967	USDA Mississippi	Loomis	Creek × sibling of Topsail
Chowan	Muscadine	1962	North Carolina State Univ. and USDA	Williams	Creswell × Burgaw
Clarke	Muscadine	~1930	Mississippi	Clarke and Price	Discovered in woods of Mississippi, parentage unknown
Cowart	Muscadine	1968	Univ. of Georgia	Fry and Ison	Higgins × Ga. 28
Creek	Muscadine	1938	Univ. of Georgia	Woodroof	Open pollinated seedling of San Monta
Creswell	Muscadine	1946	North Carolina	White	Parentage unknown

Continued

Table 16.3 Continued

Cultivar	Grape type	Year released	Institution or location	Inventor	Parentage
Dallas	Muscadine	1953	Dalco Nursery		Parentage unknown
Darlene (Darling)	Muscadine	1988	Ison's Nursery	Ison	5-11-3 × Carlos
Dawn	Muscadine	1938	Univ. of Georgia	Stuckey	Scuppernong × black male muscadine
Dearing	Muscadine	1957	North Carolina State Univ. and USDA	Dearing	Luola × Burgaw
Delicious	Muscadine	2009	Univ. of Florida	Gray, Li, Dhekney, Hopkins, and Sims	AA10-40 × CD8-81
Digby	Muscadine	1983	Univ. of Georgia	Fry	Jumbo × seedling 29-49
Dixie	Muscadine	1976	North Carolina State Univ. and USDA	Williams, Nesbitt, and Underwood	Topsail × NC 28-193 (Lucida × Wallace)
Dixieland	Muscadine	1976	Univ. of Georgia	Fry	Fry × S. 29-49
Dixiered	Muscadine	1976	Ison's Nursery	Fry and Ison	Seedling 44-6 × S. 44-7
Doreen	Muscadine	1981	North Carolina State Univ., USDA, and Mississippi State Univ.	Williams, Nesbitt, Underwood, and Overcash	Higgins × Dixie
Dulcet	Muscadine	1934	Univ. of Georgia	Woodroof	Open pollinated seedling of Irene
Duplin	Muscadine	1946	North Carolina State Univ. and USDA	Dearing	Stanford × V10 R15 B4[Eden × V23 R4 B2(Eden × *V. munsoniana*)]
Early Fry	Muscadine	1993	Ison's Nursery	Ison	Sweet Jenny × Ison
Eudora	Muscadine	2007	USDA-ARS Mississippi and Univ. of Florida	Stringer, Spiers, Marshall, and Gray	Fry × Southland
Excel	Muscadine	1983	Ison's Nursery	Fry and Ison	Sugargate × open pollinated seedling
Farrer	Muscadine	1983	Ison's Nursery	Fry and Ison	Sugargate × OP seedling
Florida Fry	Muscadine	1987	Univ. of Florida	Mortensen, Harris, and Hopkins	Triumph × Fla. AD3–42
Fry	Muscadine	1970	Univ. of Georgia	Fry	Ga. 19-13 × USDA 19-11

Fry Seedless	Muscadine	1990	Ison's Nursery	Ison and Fry	Farrer × Redgate
Georgia Red	Muscadine	1977	Univ. of Georgia	Fry	S. 42-28 × 46-32
Golden Isles	Muscadine	1987	Univ. of Georgia and Univ. of Florida	Lane and Bates	Fry × Ga. 19-6(Creek × US 53-8b)
Granny Val	Muscadine	1983	Ison's Nursery	Fry and Ison	Fry × Carlos
Hall	Muscadine	2014	Univ. of Georgia	Conner	Fry × Tara
Higgins	Muscadine	1955	Univ. of Georgia	Murphy and Fry	Yuga × a white male pollinator
Howard	Muscadine	1929	Univ. of Georgia	Stuckey	Scuppernong × black male muscadine
Hunt	Muscadine	1920	Univ. of Georgia	Stuckey	Flowers × a white male muscadine
Irene	Muscadine	1920	Univ. of Georgia	Stuckey	Thomas × black male muscadine
Ison	Muscadine	1986	Ison's Nursery	Fry and Ison	Sugargate × Senoia
Janebell	Muscadine	1988	Ison's Nursery	Ison and Fry	Fry × Senoia
Janet	Muscadine	1988	Ison's Nursery	Ison and Fry	Fry × Senoia
Jumbo	Muscadine	1970	Univ. of Georgia	Fry	Higgins × USDA 19-11
Kilgore	Muscadine	1946	North Carolina State Univ. and USDA	Dearing	Open pollinated seedling of Labama
Late Fry	Muscadine	1993	Ison's Nursery	Ison	Fry × Granny Val
Loomis	Muscadine	1989	USDA Mississippi	Loomis	Creek × US 15
Lucida	Muscadine	1933	Univ. of Georgia	Woodroof	Open pollinated seedling of Irene
Magnolia	Muscadine	1962	North Carolina State Univ. and USDA	Williams	[(Hope × Thomas) × Scuppernong)] × (Topsail × Tarheel)
Magoon	Muscadine	1959	USDA Mississippi	Loomis	Thomas × Burgaw
Majesty	Muscadine	2009	Florida A&M Univ.	Lu, Ren, and Xu	Supreme × Triumph
Morrison	Muscadine	1946	North Carolina State Univ. and USDA	Dearing	Scuppernong × white male(AF7082)
Nesbitt	Muscadine	1971	North Carolina State Univ.	Goldy and Nesbitt	Fry × Cowart
Nevermiss	Muscadine	1945	H.G. Hastings Co.	Owen	Not listed
New River	Muscadine	1946	North Carolina State Univ. and USDA	Dearing	OP seedling of San Jacinto

Continued

Table 16.3 **Continued**

Cultivar	Grape type	Year released	Institution or location	Inventor	Parentage
Noble	Muscadine	1973	North Carolina State Univ.	Nesbitt, Carroll, and Underwood	Thomas × Tarheel
November	Muscadine	1920	Univ. of Georgia	Stuckey	Scuppernong × a black muscadine
Onslow	Muscadine	1946	North Carolina State Univ. and USDA	Dearing	V22 R5 B4 (Scuppernong × male) × Burgaw
Orton	Muscadine	1946	North Carolina State Univ. and USDA	Dearing	Latham × Burgaw
Pam	Muscadine	1988	Ison's Nursery	Ison and Fry	5-11-3 × Senoia
Pamlico	Muscadine	1962	North Carolina State Univ. and USDA		Lucida × Burgaw
Pender	Muscadine	1946	North Carolina State Univ. and USDA	Dearing	Latham × V20 R36 B4 [Jukgire × V19 R7 B2 (Scuppernong × male)]
Pineapple	Muscadine	1988	Ison's Nursery	Ison and Fry	Fry × Senoia
Polyanna	Muscadine	1998	Univ. of Florida	Andersen, Mortensen, and Harris	Fry × Southland
Pride	Muscadine	1972	Univ. of Georgia	Fry	Georgia 19-13 × USDA 19-11
Qualitas	Muscadine	1920	Univ. of Georgia	Stuckey	Thomas × black male muscadine
RazzMatazz	Muscadine	2013	North Carolina	Bloodworth	Undisclosed
Redgate	Muscadine	1974	Ison's Nursery	Fry and Ison	Higgins × seedling 29-49
Regale	Muscadine	1981	North Carolina State Univ. and Mississippi State Univ.	Williams, Nesbitt, and Overcash	Hunt × Magnolia
Roanoke	Muscadine	1962	North Carolina State Univ. and USDA	Williams	Lucida × (Topsail × Tarheel)
Rosa	Muscadine	1988	Ison's Nursery	Fry and Ison	Higgins × Granny Val
Scarlett	Muscadine	1998	Univ. of Georgia	Lane	Summit × Triumph
Southern Home	Muscadine	1994	Univ. of Florida	Mortensen, Harris, Hopkins, and Anderson	Summit (*V. rotundifolia*) × P9-15(a hybrid of *V. rotundifolia*, *V. popenoei*, *V. munsoniana*, and *V. vinifera*)

Southern Jewel	Muscadine	2009	Univ. of Florida	Gray, Li, Dhekney, Hopkins and Sims	Granny Val × DB-63
Southland	Muscadine	1967	USDA Mississippi	Loomis	Thomas × seedling of Topsail
Spalding	Muscadine	1920	Univ. of Georgia	Stuckey	Flowers × white male muscadine
Stanford	Muscadine	1946	North Carolina State Univ. and USDA	Dearing	Open pollinated seedling of San Jacinto
Sterling	Muscadine	1981	North Carolina State Univ. and USDA	Williams, Nesbitt, and Underwood	NC 50-55 × Magnolia
Stuckey	Muscadine	1920	Univ. of Georgia	Stuckey	Scuppernong × a black male muscadine
Sugar Pop	Muscadine	1988	Ison's Nursery	Ison and Fry	Fry × 8-16-1
Sugargate	Muscadine	1974	Ison's Nursery	Fry and Ison	Ga. Fry × S. 29-49
Summit	Muscadine	1977	Univ. of Georgia	Lane	Fry × Ga. 29-49
Supreme	Muscadine	1988	Ison's Nursery	Ison and Fry	Black Fry × Dixieland
Sweet Jenny	Muscadine	1986	Ison's Nursery	Ison and Fry	11-2-2 × 12-12-1
Tara	Muscadine	1993	Univ. of Georgia	Lane	Summit × Triumph
Tarheel	Muscadine	1946	North Carolina State Univ. and USDA	Dearing	Luola × V36 R15 B4 [Eden × V23 R4 B2 (Eden × *V. munsoniana*)]
Topsail	Muscadine	1946	North Carolina State Univ. and USDA	Dearing	Latham × Burgaw
Triumph	Muscadine	1980	Univ. of Georgia and Univ. of Florida	Lane and Mortensen	Fry × Ga. 19-49
Wallace	Muscadine	1946	North Carolina State Univ. and USDA	Dearing	V26 R5 B4 × Willard
Watergate	Muscadine	1974	Ison's Nursery	Fry and Ison	Seedling 2-3-1 × S. 19-6-1
Welder	Muscadine	1972	Florida	Welder	Open pollinated seedling of unknown muscadine
Willard	Muscadine	1946	North Carolina State Univ. and USDA	Dearing	Stanford × V19 R7 B2 (Scuppernong × New Smyrna)
Yuga	Muscadine	1934	Univ. of Georgia	Woodroof	Open pollinated seedling of San Monta

[a]Information primarily gathered from Clark (1997), but also from various other sources.

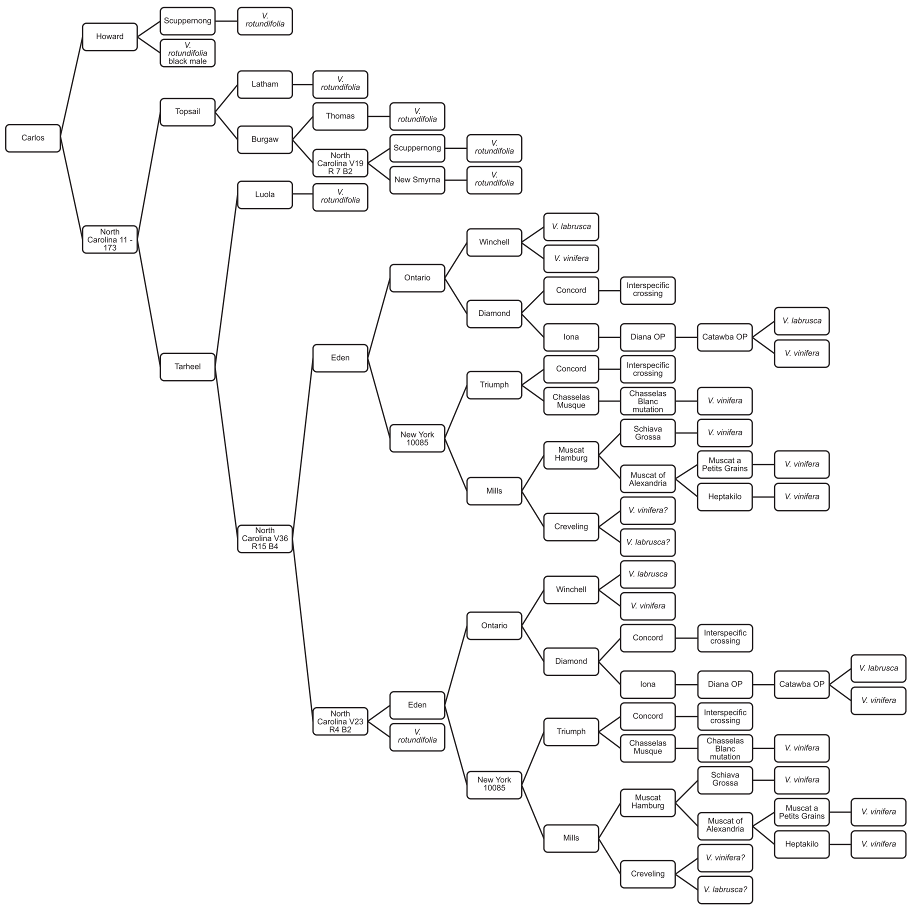


Figure 16.6 Pedigree of "Blanc du bois," a hybrid white wine grape released from the University of Florida.

16.5.3 Florida

Much of the hybrid bunch grape breeding done in the Deep South took place at the University of Florida (UF) in a program that began in the 1940s by L.H. Stover, later led by J.A. Mortenson. This was the most substantial effort undertaken to breed resistance to PD and utilized some diverse species to provide resistance (Halbrooks and Mortensen, 1989). Aside from PD resistance, the breeding objectives of the UF program included productivity, fruit cracking resistance, uniform ripening, self-fertility, seedlessness for table grapes, and adaptation to mechanized harvest (Halbrooks and Mortensen, 1989). The *V. simpsoni* cultivar Pixiola was crossed with "Golden Muscat" and yielded "Lake Emerald," and subsequent cultivars included "Blue Lake," "Norris," and "Stover," all with PD resistance. Later, the first seedless, PD-resistant cultivar was released, "Orlando Seedless," along with the wine grape cultivar Blanc du Bois. Muscadine cultivars from the UF program included "Dixie," and

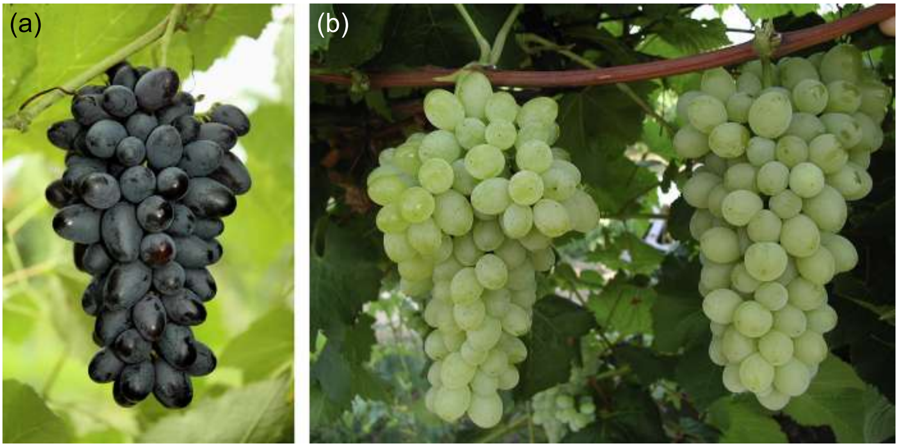


Figure 16.7 (a) "Joy" is a blue, nonslipskin, seedless grape with fruity flavor. The skin is thin, among the thinnest of any Arkansas-developed grape. (b) "Neptune" is a seedless, nonslipskin white grape that has a fruity flavor but is not foxy.

"Alachua," The muscadine cultivar Southern Home was released in 1994, which had in its parentage not only *V. rotundifolia* but also *V. munsoniana*, *V. vinifera*, and *V. popenoei*, and has a unique lobed leaf with muscadine-type fruit (Mortensen et al., 1994). Presently, D.J. Gray conducts genetic investigations using biotechnology on muscadine and bunch grapes with a focus on seedlessness, as well as disease resistance. Florida A & M University also had a breeding program under the direction of J. Lu and released the fresh-market muscadine cultivar Majesty. Private breeders contributed over the last century in Florida, including J.L. Fennell and C. Demko, Sr., who released "Dunstan," "Taylor," and "Florida Concord" (Lane, 1997). Many of these private breeders crossed native grapes with cultivars and selections from other breeders to create foundational material for other breeding programs (Fennell, 1941). Fennell released "Masters," "Tamiami," and "Tropico," all disease-resistant cultivars for subtropical growing conditions. The previously mentioned "Southern Home" is a prime example of how work from Fennell, R. Zehnder, and R.L. Farrar contributed to grape breeding today.

16.5.4 Georgia

Muscadine breeding has long been an important focus at the University of Georgia (UGA), as well as in the private sector. The UGA breeding program began in 1909 under the direction of H.P. Stuckey and J.G. Woodroof using vines selected from the wild (Conner, 2010). The program was based at Griffin, GA. Early goals of the program were to reduce shatter and to improve fruit sweetness, along with increasing berry size. These breeding efforts continued on until WWII, when the program was temporarily suspended. Probably the most important cultivar released during this period was "Hunt." The post-WWII breeding was conducted by B.O. Fry. He used the UGA material to further improve cultivars for higher soluble solid content, as well as increased berry size. Several important muscadine cultivars were released as a result of Fry's work. These include "Cowart," "Fry," "Jumbo," and "Higgins" (Conner, 2010). Even though hermaphroditic flower types in muscadine had been discovered decades earlier, "Cowart" was the first perfect-flowered release made by UGA. R.P. Lane took over the muscadine breeding program in the late 1960s. He continued to focus on large fruit size but also stressed perfect flowers. Several notable releases arose from his effort, including "Summit," "Triumph," "Golden Isles," "Scarlett," and "Tara." After a period of low program activity in the late 1990s and early 2000s, P.J. Connor assumed program leadership and relocated the effort to Tifton, GA. He continues to focus on fresh-market muscadines, although processing fruit are being explored (Conner, 2010). He is also pursuing the incorporation of seedlessness in muscadines. Conner released "Lane" and "Hall," both large-fruited, perfect-flowered cultivars (Conner, 2013, 2014). Ison's Nursery in Brooks, GA initiated a breeding program in the late 1960s that was a cooperative effort of Fry (after his retirement from UGA) and W. Ison. This program primarily utilized UGA germplasm for fresh-market muscadine improvement. The first releases from the program in the early 1970s were "Watergate" and "Sugargate." Many other developments came from the Ison effort over the next 20 plus years, including "Supreme," "Black Beauty," and "Ison." R.L. Farrar was a private breeder who produced Farrar 30, which is in the parentage of "Southern Home" (Mortensen et al., 1994).

16.5.5 Louisiana

H. Olmo, of the University of California, Davis, worked with R. Constantin and T. DiVittorio at the Louisiana State University (LSU) Hammond Research Station to generate populations that could possibly be used for wine production (Lane, 1997). J. Quebedeaux replaced DiVittorio in 1992 and continued evaluations until the program was closed due to budget cuts. Olmo made a series of crosses and provided the seed to LSU to evaluate for the potential of growing wine grapes on the Gulf Coast. No releases were made from that work, but one selection can still be found, Q21B17, which showed good potential to make excellent wine; however, the selection had some susceptibility to PD and weakened over time (J. Quebedeaux, personal communication).

16.5.6 Mississippi

The United States Department of Agriculture (USDA) conducted a grape breeding program at Meridian, MS from 1941 to 1965, led by N. H. Loomis. This program released several muscadine cultivars, including "Bountiful" and "Southland." Bunch grapes were also bred at this location. Upon termination of this effort, bunch grape selections from the program were made available for testing with oversight from J.P. Overcash and C.P. Hegwood of Mississippi State University. They tested several selections at multiple sites in Mississippi and also evaluated these for processing for wine and nonfermented uses. Three PD-resistant, seeded cultivars resulted: "Miss

Blue," "MidSouth," and "Miss Blanc" (Overcash et al., 1981, 1982). These are still grown on a small scale in Mississippi and in surrounding states. The USDA-ARS in Poplarville initiated a muscadine breeding program in the 1990s, led first by C.L. Gupton and later by S.J. Stringer. This program, along with UF, jointly released a UF-developed selection as the local-market cultivar Eudora (Stringer et al., 2011).

16.5.7 North Carolina

Muscadine breeding was first initiated as a joint program between North Carolina State University and the USDA in 1907, headed by F.C. Reimer and L.R. Detjen, and later by C.T. Dearing. Detjen was a strong proponent of muscadine breeding (Detjen, 1917). The first self-fertile muscadine genotypes were reported by Dearing in 1917, but it took more than 30 years for the program to release the first hermaphroditic cultivar. Other breeders who contributed to the North Carolina State University effort included C.F. Williams, W.B. Nesbitt, and R.G. Goldy until the program was terminated in the 1990s. The program was reactivated in the 2000s by J.R. Ballington and W.T. Bland. The program is best known for its perfect-flowered developments, the most successful being "Carlos," the most widely planted processing muscadine. Other releases included the processing cultivars Magnolia and Noble and fresh-market cultivars Sterling and Nesbitt. Private breeders have also played an important role in North Carolina grape breeding, most notably the effort of R.T. Dunstan. Dunstan began a breeding program in 1937 (Dunstan, 1962) that eventually led to "Aurelia" and "Carolina Blackrose." He also furthered the work done by H. Derman (1958) to overcome chromosome incompatibility in crosses between *Euvitis* and *V. rotundifolia* (Dunstan, 1963, 1964). J. Bloodworth conducted a muscadine breeding program also, and in 2012, released the first stenospermocarpic seedless muscadine cultivar named RazzMatazz.

16.5.8 Oklahoma

Prior to Prohibition, Oklahoma had a large number of hectares devoted to the production of grapes. F. Cross of Oklahoma A&M (later renamed Oklahoma State University (OSU)) released "Henryetta" in the 1930s. H. Hinrichs, a horticulturist at OSU, began breeding hybrid wine grapes in the 1950s. A few releases were made in the 1960 and 1970s. These include "Rubaiyat," "Cimarron," and "Sunset," among others (Stafne, 2006). L.F. Locke of the USDA Southern Great Plains Field Station in Woodward, OK also bred grapes. Three cultivars, Chilcott, Keating, and Osborn, were released in 1959. A private breeder, G. Girouard, released four red wine grape cultivars that have been tested by OSU and are being grown on a small scale in Oklahoma and California.

16.5.9 South Carolina

Grape breeding activity in South Carolina has been sporadic. Early efforts to hybridize *V. vinifera* and *V. rotundifolia* by P. Wylie around the time of the Civil War started an interest in interspecific grape breeding across the South (Detjen, 1919; Dunstan, 1963; Olmo, 1980). However, postwar turmoil halted most of his efforts (Dunstan, 1964), although a few cultivars resulted (Hedrick et al., 1908). Einset and Pratt (1975) referenced a bunch grape breeding program at Clemson University, but with few details. That program was headed by H.J. Sefick, from which “Oconee” was released (Clark, 2010). R. Zehnder was a private breeder who followed in the footsteps of Dunstan, creating numerous crosses that are still being evaluated today in various states.

16.5.10 Texas

T.V. Munson was a grape breeder in Dennison, TX. He was probably the most famous grape breeder in the South and developed the first organized breeding program in the region (Lord, 1922). He used many native grape species in developing his cultivars, including *V. lincecumii*, *V. labrusca*, *V. aestivalis*, and others (Einset and Pratt, 1975). He developed over 300 cultivars (Tarara and Hellman, 1990), a few of which are still grown today. One significant contribution was the rootstock cultivar Dog Ridge. In the 1960s, H.M. Meyer, a horticulturist with the American Refrigerator Transit Company in Harlingen, TX initiated a hybrid grape breeding program (Meyer, 1968) using *V. vinifera* (“Black Monukka,” “Thompson Seedless,” etc.) and French–American hybrids as foundation germplasm. The purpose was to develop table and juice grapes, but no cultivars were ever released.

16.5.11 Virginia

Significant breeding activities were undertaken at Virginia Tech University by R.C. Moore in the 1930s and 1940s and were later continued by G.D. Oberle. This breeding program relied on parents, including *V. labrusca* cultivars (Fredonia, Niagara, and Athens), French–American hybrids, and germplasm developed by R.T. Dunstan. The work of Moore and Oberle led to several hybrid bunch grape cultivars, including “Alwood” (Oberle and Moore, 1969), “Moored” (Oberle, 1970), “Price,” “Monticello,” and “Century I” (Oberle, 1974).

There has been no grape breeding activity of consequence from Kentucky, Tennessee, or West Virginia.

16.6 Future trends

Although breeders have introduced numerous cultivars for the Southern US, there are still opportunities for improvement. Gupton (2000) reported that improvement in many traits is possible for muscadines through breeding. Seedlessness plus thinner skins and more crisp textures could drastically change acceptance of this native fruit to a broader range of consumers beyond the Southern US. Introducing cold, hardy genes in muscadine could expand production as well. The University of Arkansas table grape breeding program has many exciting traits that have just started or have yet to make it to the marketplace. Clark (2010) stated the major objectives for table grapes in the Eastern US are resistance to fruit cracking, improved postharvest handling, improved flavors, better winter hardiness, better disease resistance, new flavor profiles, berry and cluster shapes, and skin and flesh textures. Some traits are potential novelties that could enliven local markets (Figure 16.8). Even though consumer acceptance of non-*vinifera* cultivars is always a challenge, high-quality, PD-resistant wine grapes are also a great need. Seedless table grapes that resist PD would provide substantial benefits to local markets.

Grape breeding in the Southern US has been successful due to the efforts of both public and private breeders. As is often the case, public breeding programs in the South (and elsewhere) are limited by programmatic funding, and thus, collaboration with private individuals is still a viable direction for the future. The South, perhaps more than any other region of the US, is in need of better cultivars to help expand muscadine and bunch grape production for fresh markets and wine.

Figure 16.8 Unique grape cluster shapes exist within the University of Arkansas grape breeding program. A selection from this program, A-2409, was a parent of "Funny Fingers," which was developed by International Fruit Genetics.
Photo by J.R. Clark.

References

Andersen, P.C., Crocker, T.E., Breman, J., 2013. *The muscadine grape*. Univ. Florida Ext., HS763.

Barchenger, D.W., Clark, J.R., Threlfall, R.T., Howard, L.R., and Brownmiller, C.R. Effect of field fungicide applications on storability, physiochemical, and nutraceutical content of muscadine grape (*Vitis rotundifolia* Michx.) genotypes HortScience 49, 1315–1323.

Barrett, H.C., 1957. *Vitis cinerea* as a source of desirable characters in grape breeding. Proc. Am. Soc. Hort. Sci. 70, 165–168.

Clark, J.R., 1997. Grapes. In: *The Brooks and Olmo register of fruit and nut varieties*, third ed. ASHS Press, Alexandria, Virginia, pp. 248–299.

Clark, J.R., 2010. Eastern United States table grape breeding. J. Am. Pomol. Soc. 64, 72–77.

Clark, J.R., Moore, J.N., 1999. 'Jupiter' seedless grape. HortScience 34, 1297–1299.

Conner, P.J., 2010. A century of muscadine grape (*Vitis rotundifolia* Michx.) breeding at the University of Georgia. J. Am. Pomol. Soc. 64, 78–82.

Conner, P.J., 2013. 'Lane': an early-season self-fertile black muscadine grape. HortScience 48, 128–129.

Conner, P.J., 2014. 'Hall': an early-season self-fertile bronze muscadine grape. HortScience 49, 688–690.

Colova-Tsolova, V., Lu, J., Perl, A., 2003. Cyto-embryological aspects of seedlessness in *Vitis vinifera* L. and exploiting DNA recombinant technology as an advanced approach for introducing seedlessness into vinifera and muscadine grapes. Acta. Hort. 603, 195–199.

Cousins, P., 2005. Evolution, genetics, and breeding: viticultural applications of the origins of our rootstocks. In: Cousins, P., Striegler, R.K. (Eds.), *Proceedings of the 2005 rootstock symposium. Grapevine Rootstocks: Current Use, Research, and Applications*. Southwest Missouri State Univ., pp. 1–7.

Derman, H., 1958. Sterile hybrid grape made fertile with colchicine. Fruit Var. Hort. Dig. 12, 34–36.

Detjen, L.R., 1917. Breeding southern grapes. J. Hered. 8, 252–258.

Detjen, L.R., 1919. The limits in hybridization of *Vitis rotundifolia* with related species and genera. North Carolina Agri. Expt. Sta. Tech. Bull. 17.

Dunstan, R.T., 1962. Vinifera-type grapes for the East. Fruit Var. Hort. Dig. 17, 6–8.

Dunstan, R.T., 1963. Some fertile hybrids of bunch and muscadine grapes. J. Hered. 54, 299–303.

Dunstan, R.T., 1964. Hybridization of *Euvitis* × *Vitis rotundifolia*: backcrosses to muscadine. Proc. Am. Soc. Hort Sci. 84, 238–242.

Einset, J., Pratt, C., 1975. Grapes. In: Janick, J., Moore, J.N. (Eds.), *Advances in fruit breeding*. Purdue University Press, West Lafayette, Indiana, pp. 130–153.

Fennell, J.L., 1938. Breeding experiments with the South Florida native grapes. Proc. Fla. State Hort. Soc. 51, 73–76.

Fennell, J.L., 1941. Future "ideal" grapes. J. Hered. 32, 193–197.

Fisher, C., 2014. Total U.S. wineries hits 7,762. Wine Business Monthly 21 (2), 82–85.

Goldy, R.G., Onokpise, O.U., 2001. Genetics and breeding. In: Basiouny, F.M., Himelrick, D.G. (Eds.), *Muscadine grapes*. ASHS Press, Alexandria, Virginia, pp. 51–90.

Gupton, C.L., 2000. Muscadine traits potentially useful in breeding. J. Am. Pomol. Soc. 54, 114–117.

Halbrooks, M.C., Mortensen, J.A., 1989. Origin and significance of Florida hybrid bunch grapes and rootstocks. HortScience 24, 546–550.

Hedrick, U.P., Booth, N.O., Taylor, O.M., Wellington, R., Dorsey, M.J., 1908. *The grapes of New York, New York State Agri. Expt. Sta. Fifteenth Annual Rpt*. Vol. 3, part II, J.B. Lyon, Albany, New York.

Hopkins, D.L., Mollenhauer, H.H., Mortensen, J.A., 1974. Tolerance to Pierce's disease and the associated Rickettsia-like bacterium in muscadine grape. J. Am. Soc. Hort Sci. 99, 436–439.

James, J., Lamikanra, O., Morris, J.R., Main, G., Walker, T., Silva, J., 1999. Interstate shipment and storage of fresh muscadine grapes. J. Food Qual. 22, 605–617.

Lane, R., 1977. Reversion to normal leaf type in a radiation-induced mutation of *Vitis rotundifolia*. Environ. Expt. Bot. 17, 125–127.

Lane, R., 1997. Breeding muscadine and southern bunch grapes. Fruit Var. J. 51, 144–147.

Lane, R.P., Bates, R.P., 1987. Golden Isles muscadine grape for wine. HortScience 22, 165–166.

Li, Z.T., Dhekney, S.A., Gray, D.J., 2010. Molecular characterization of a SCAR marker purportedly linked to seedlessness in grapevine (*Vitis*). Mol. Breed 25, 637–644.

Loomis, N.H., Lider, L.A., 1971. Nomenclature of the 'Salt Creek' grape. Fruit Hort. Dig. 25, 41–43.

Lord, E.L., 1922. Grape varieties. Proc. Fla. State. Hort. Soc. 35, 127–130.

Meyer, H.M., 1968. Promising grape hybrids for Texas. Fruit Var. Hort. Dig. 22, 53–55.

Moore, J.N., 1969. Fruit breeding in Arkansas. Fruit Var. Hort. Dig. 23, 23–25.

Moore, J.N., Clark, J.R., Kamas, J., Stein, L., Tarkington, F., Tarkington, M., 2011. 'Victoria red' grape. HortScience 46, 817–820.

Mortensen, J.A., 1968. The inheritance of resistance to Pierce's disease in *Vitis*. Proc. Am. Soc. Hort Sci. 92, 331–337.

Mortensen, J.A., 1987. Blanc du bois, a Florida bunch grape for white wine. Agric. Expt. Sta. Inst. Food Agric. Univ. Fla. Circ. S-340.

Mortensen, J.A., 2001. Cultivars. In: Basiouny, F.M., Himelrick, D.G. (Eds.), *Muscadine grapes*. ASHS Press, Alexandria, Virginia, pp. 91–105.

Mortensen, J.A., Harris, J.W., Hopkins, D.L., Andersen, P.C., 1994. 'Southern Home': an interspecific hybrid grape with ornamental value. HortScience 29, 1371–1372.

Mortensen, J.A., Hayslip, N.C., 1977. 'Welder' muscadine grape. HortScience 12, 267–268.

Mortensen, J.A., Stover, L.H., 1990. Best combiners during 40 years of breeding *Vitis* cultivars resistant to Pierce's disease. Proc. 5^{th} Int. Symp. Grape Breed Vitis (special issue), 271–277.

Nesbitt, W.B., Carroll, D.E., Overcash, J.P., Hegwood, C.P., Stojanovic, B.J., 1982a. Doreen muscadine grape. HortScience 17, 278.

Nesbitt, W.B., Carroll, D.E., Overcash, J.P., Stojanovic, B.J., 1982b. Regale muscadine grape. HortScience 17, 276–278.

Nesbitt, W.B., Underwood, V.H., Carroll Jr, D.E., 1970. Carlos, a new muscadine grape cultivar. North Carolina Agric. Expt. Sta. Bull. 441.

Oberle, G.D., 1970. The Moored grape. Fruit Var. Hort. Dig. 24, 74.

Oberle, G.D., 1974. New varieties from the Virginia fruit breeding program. Fruit Var. J. 28, 50–58.

Oberle, G.D., Moore, R.C., 1969. The alwood grape. Fruit Var. Hort. Dig. 28, 34–35.

Olien, W.C., 1990. The muscadine grape: botany, viticulture, history, and current industry. HortScience 25, 732–739.

Olmo, H., 1980. Selecting and breeding new grape varieties. Calif. Agric. 34 (7), 23–24.

Overcash, J.P., Hegwood Jr, C.P., Stojanovic, B.J., 1981. 'MidSouth' and 'Miss Blue' – two new bunch grape cultivars. Miss. Agric. For. Expt. Sta. Res. Rep. 6 (18).

Overcash, J.P., Hegwood Jr, C.P., Stojanovic, B.J., 1982. 'Miss Blanc' a new bunch grape cultivar. Miss. Agric. For. Expt. Sta. Bull. 909.

Pastrana-Bonilla, E., Akoh, C.C., Sellappan, S., Krewer, G., 2003. Phenolic content and antioxidant capacity of muscadine grapes. J. Agric. Food Chem. 51, 5497–5503.

Riaz, S., Tenscher, A.C., Graziani, R., Krivanek, A.F., Ramming, D.W., Walker, M.A., 2009. Using marker-assisted selection to breed Pierce's disease-resistant grapes. Am. J. Enol. Vitic. 60, 199–207.

Rogers, D.J., Mortensen, J.A., 1979. The native grape species of Florida. Proc. Fla. State Hort. Soc. 92, 286–289.

Snyder, E., 1937. Grape development and improvement. In: *USDA yearbook of agriculture*, pp. 631–664.

Stafne, E.T., 2006. 'Rubaiyat' and Oklahoma's winegrape legacy. J. Am. Pomol Soc. 60, 159–163.

Striegler, R.K., Morris, J.R., Carter, P.M., Clark, J.R., Threlfall, R.T., Howard, L.R., 2005. Yield, quality, and nutraceutical potential of selected muscadine cultivars in southwestern Arkansas. HortTechnology 15, 276–285.

Stringer, S.J., Marshall, D.A., Gray, D.J., 2011. 'Eudora' muscadine grape. HortScience 46, 143–144.

Tarara, J.M., Hellman, E.W., 1990. The Munson grapes—a rich germplasm legacy. Fruit Var. J. 44, 127–130.

USDA-NASS, 2013. Fruits and nuts: 2012 and 2007. In: *2012 census of agriculture*.

USDA-NRCS, 2014. *The PLANTS database*. National Plant Data Team, Greensboro, North Carolina. Available from http://plants.usda.gov. [Accessed 19 September 2014].

Wells, J.M., Raju, B.C., Hung, H.Y., Weisburg, W.G., Mandelco-Paul, L., Brenner, D.J., 1987. *Xyllela fastidosa* gen. nov. sp. nov.: Gram-negative, xylem-limited, fastidious plant bacteria related to *Xanthomonas* spp. Intl. J. Syst. Bacteriol. 37, 136–143.

Grapevine breeding in the Midwest

17

P. Hemstad, G. Breeder
University of Minnesota, Horticultural Research Center, Excelsior, MN, USA

17.1 Introduction

Grape breeding in the Midwestern United States has been primarily concentrated in the northern part of the region, known as the Upper Midwest. When the Midwest was settled in the mid-nineteenth century, settlers brought grapevines with them from the East Coast of the U.S. While Concord did well in Iowa and Illinois, most *Vitis labrusca*-based cultivars (*Vitis labruscana*) fared quite poorly under the harsh climatic conditions of Minnesota, Wisconsin, and the Dakotas, where winter temperatures can sometimes drop as low as –40 °C. These severe conditions motivated grape breeders to create a series of new cultivars with extreme cold hardiness (Alderman, 1962).

The following sections review the important breeding programs that have been undertaken in various Midwestern states over the last one hundred and forty years.

17.2 Minnesota

17.2.1 Louis Suelter, Carver, Minnesota

Some of the earliest efforts to develop a grape cultivar hardy enough to be grown without winter protection in the Upper Midwest were done by the German immigrant, Louis Suelter. Suelter lived near Carver, MN, and in the 1870s, he crossed a supposedly white-fruited form of *Vitis riparia* with Concord (Pfaender, 1912).

V. riparia is native to a large portion of North America, including most of the Upper Midwest. It is arguably the most cold hardy grape species in the world, with the possible exception of *Vitis amurensis* from China (Pierquet and Stushnoff, 1980). It is a very vigorous species with small clusters of tiny black berries. The vine tends to have good resistance to downy and powdery mildews but is usually quite susceptible to the foliar form of phylloxera (Swenson, 1985). *V. riparia* is commonly known as the “Riverbank Grape” and does thrive in riparian habitats. Unlike several other American species, *V. riparia* readily propagates from cuttings.

Suelter named four new cultivars out of the 29 seedlings resulting from his cross of *V. riparia* × Concord, including one named Suelter and another named after his wife, Beta (Table 17.1). Beta became quite successful commercially and is a dependably hardy juice and jelly grape for Minnesota and the surrounding states. The acidity is too high for Beta to be used as a table grape. The same generally holds true for wine, although there was a substantial interest in using Beta for wine during Prohibition

Grapevine Breeding Programs for the Wine Industry. http://dx.doi.org/10.1016/B978-1-78242-075-0.00017-X

Table 17.1 **Notable Midwest grape cultivars**

Variety	Color	Parentage	Breeder	Place introduced	Year introduced	Principal uses	Where grown
Beta	Black	(*Vitis riparia* × Concord)	Louis Suelter	Carver, MN	1881	Juice, jelly	MN, SD, ND, China
Bluebell	Black	(Beta × Unknown)	M.J. Dorsey, A.N. Wilcox	University of Minnesota	1944	Juice, jelly	MN, SD, ND, WI
Edelweiss	White	(MN 78 × Ontario)	Elmer Swenson, C. Stushnoff, P. Pierquet	Minnesota	1978	Wine, table	NE, MN, IA, WI, SD, IL, VT
St. Croix	Black	(ES 283 × ES 193)	E. Swenson	Osceola, WI	1981	Wine	MN, SD, IA, WI, IL, NE, VT, CT, Quebec
Valiant	Black	(Fredonia × *V. riparia*)	Ron Peterson	South Dakota State University	1982	Wine, juice, jelly	SD, ND, MN, WY, Manitoba, Alberta
St. Pepin	White	((MN 78 × S 1000) × Seyval)	E. Swenson	Osceola, WI	1983	Wine	MN, SD, IA, WI, IL, NE
La Crosse	White	((MN 78 × S 1000) × Seyval)	E. Swenson	Osceola, WI	1983	Wine	MN, SD, IA, WI, IL, NE
Frontenac	Black	(*V. riparia* #89 × Landot 4511)	Peter Hemstad, J. Luby, P. Pierquet	University of Minnesota	1996	Wine, jelly	MN, SD, ND, IA, WI, IL, NE, NY, OH, MI, Ontario, Quebec, China
Prairie Star	White	(ES 2-7-13 × ES 2-8-1)	E. Swenson, T. Plocher, R. Parke	Wisconsin	2000	Wine	MN, SD, IA, WI, IL, VT, NE
Sabrevois	Black	(ES 283 × ES 193)	E. Swenson, G. Benoit	Quebec	2000	Wine	Quebec, MN, IA, WI, SD

Louise Swenson	White	(ES 2-3-17 × Kay Gray)	E. Swenson, T. Plocher, R. Parke	Wisconsin	2001	Wine	MN, SD, IA, WI, IL, VT, NE
Brianna	White	(Kay Gray × ES 2-12-13)	Elmer Swenson, Ed Swanson	Nebraska	2002	Wine	NE, MN, IA, WI, SD, ND, VT
La Crescent	White	(St. Pepin × E.S. 6-8-25)	P. Hemstad, J. Luby, E. Swenson	University of Minnesota	2002	Wine, jelly	MN, SD, ND, IA, WI, IL, NE, NY, VT
Somerset Seedless	Pink	(ES 5-3-64 × Petite Jewel)	E. Swenson et al.	Osceola, WI	2002	Table	MN, WI, SD, IA, VT, Quebec, Baltic states
Frontenac Gris	Gray	Mutation of Frontenac	P. Hemstad, J. Luby	University of Minnesota	2003	Wine	MN, SD, ND, IA, WI, IL, NE, NY, VT, Ontario, Quebec
Petite Amie	White	(ES 2-11-4 × DMP2-54)	Dave Macgregor and E. Swanson	Nebraska/ Minnesota	2004	Wine	NE, MN, IA, WI, SD, VT
Marquette	Black	(MN 1094 × Ravat 262)	P. Hemstad, J. Luby	University of Minnesota	2006	Wine	MN, SD, ND, IA, WI, IL, NE, NY, VT, WA, OR, Quebec, Ontario, Nova Scotia, China
Osceola Muscat	White	((ES 56 × OP) × SV 23-657)	E. Swenson, M. Hart	Osceola, WI	2010	Wine	MN, WI, IA, Quebec, New Brunswick
Petite Pearl	Black	(MN 1094 × ES 4-7-26)	T. Plocher	Minnesota	2010	Wine	MN, SD, ND, IA, WI, IL, VT, NE, Quebec

when any alcohol was at a premium. Today, Beta is still grown on a small scale, primarily on farmsteads in the Great Plains. Strangely enough, it is also one of the most commonly grown rootstocks in Northern China.

Suelter somewhat optimistically summed up his breeding work in 1884 with the following statement:

> *"I have produced several new types of vine through hybrid breeding, which will bring forth a completely new revolution in winegrowing, for as far north as the wild vines will thrive, my hybrids will flourish also, for they are just as hardy all winter in the great coldness in the northern part of America as the wild growing riparia. They require no protection …"*

17.2.2 University of Minnesota

Grape breeding began at the University of Minnesota's Fruit Breeding Farm (now known as the Horticultural Research Center, or HRC) in Excelsior, MN in 1908 (Snyder, 1982). This limited early work was led by Professor Samuel Green, and the primary objective was the improvement of the leading grape of the time, Beta. There was certainly no interest at the time in developing cold hardy wine grapes since alcohol consumption was frowned upon. (In fact, the measure imposing a prohibition against alcohol in the U.S. in 1920 was labeled the "Volstead Act" after Senator Volstead from Minnesota.)

Beta was crossed at the University of Minnesota with many of the leading Eastern *V. labruscana* cultivars. This work was continued by Professors M.J. Dorsey (active 1911–1921) and A.N. Wilcox (active 1923–1963), and the result was that four new cultivars were released in 1944: Moonbeam, Red Amber, Blue Jay, and Bluebell (Wilcox, 1946; Figure 17.1(a); Table 17.1). The first three are almost extinct 70 years later. Bluebell, however, has gained a degree of popularity as a Northern Concord type, since Concord itself is too late ripening and winter tender to do well in Minnesota. Bluebell is quite disease-resistant and makes an excellent juice and jelly. It may also have some limited wine potential in a sweet rosé style. Bluebell is certainly an improvement on Beta, so that goal was realized.

Grape breeding at the University of Minnesota was a low priority in the mid-twentieth century, and apple breeding was the focus of research at the time. Things slowly began to change in 1969 when Mr Elmer Swenson was hired to work at the HRC. Mr Swenson had been doing his own breeding work since 1943 (see section 17.3.1 on his work below), and he brought several of his selections with him to the University for testing. Lacking a formal education, Elmer was hired as a "gardener" to maintain the fruit research plantings. His interest in fruit extended beyond grapes and he was also keenly interested in the apple-breeding work being conducted there.

Upon his retirement from the University in 1978, two grapes were jointly released by Elmer Swenson and the University of Minnesota: Swenson Red (Figure 17.1(c)) and Edelweiss (Swenson et al., 1978; Figure 17.1(d); Table 17.1). Swenson Red (MN 78 × S. 11803) was a grape Elmer initially wanted to name NorVin for "northern vinifera". His rationale was that this was a vinifera-quality grape that could be grown in northern areas. Swenson Red is indeed a very high-quality seeded table grape with

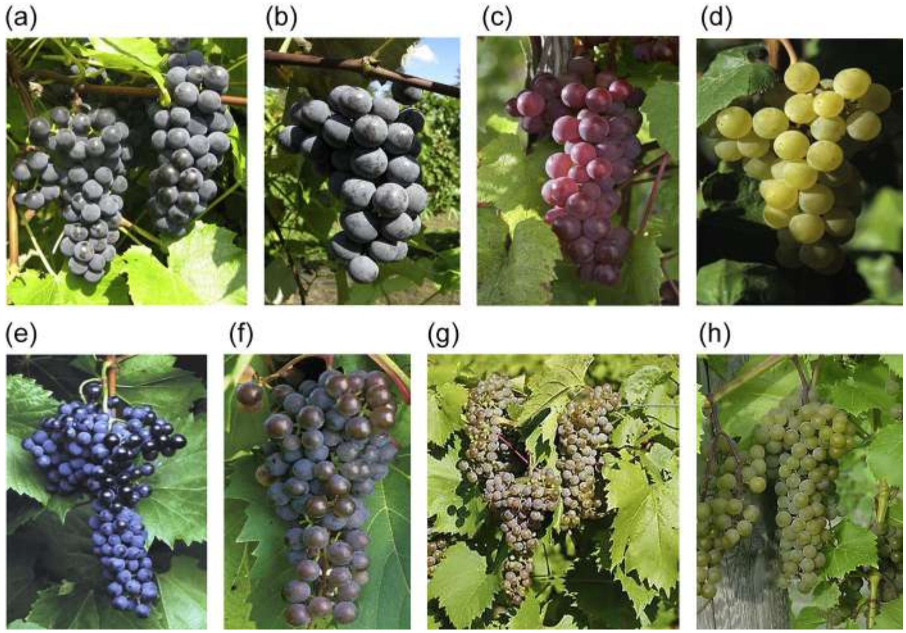


Figure 17.1 Grape cultivars introduced from breeding programs in the Midwest U.S.
(a) St. Croix; (b) Bluebell; (c) Swenson Red; (d) Edelweiss; (e) Frontenac; (f) Frontenac gris; (g) Frontenac blanc; (h) La Crescent.
Photos (a), (b), and (h) by Peter Hemstad, University of Minnesota; Photos (c), (d), (e), (f) by David L. Hansen, University of Minnesota; Photo (g) by Alain Breault.

an excellent meaty texture, a delicate fruity taste, and outstanding storage ability. Unfortunately, Swenson Red is not reliably hardy in Minnesota and is also quite susceptible to downy mildew. It is not widely grown today, although it is still available as a backyard table grape.

The other cultivar released in 1978, Edelweiss, has become much more popular than Swenson Red. Edelweiss has some significant drawbacks as a table grape, especially because it has a thin skin, which easily cracks when handled, and a very limited storage life. Those are not really issues when used as a wine grape, and it has become fairly popular in that capacity. This is especially true in Nebraska, where Edelweiss has become one of the leading white wine cultivars. Edelweiss is marginally winter hardy in central Minnesota, but is very resistant to downy and powdery mildew. If left on the vine to fully mature, Edelweiss becomes extremely foxy, so winemakers usually carefully monitor its maturity and pick it before it is fully ripe. When picked early, it can make a light, fruity white wine that can be quite popular, especially when finished slightly sweet.

Another development in the late 1970s at the University of Minnesota was the contribution of a graduate student named Patrick Pierquet. Mr Pierquet worked with Elmer Swenson at the HRC and did his master's thesis on *V. riparia*. He collected a large number of *V. riparia* accessions from Minnesota and the surrounding areas, including the extreme northern edge of its range in Manitoba (Pierquet and Stushnoff, 1980). In addition, Mr Pierquet made a number of crosses using *V. riparia* or other cold hardy grapes like Mandan or Suelter crossed with either *V. vinifera* cultivars or French–American hybrids. Mr Pierquet received his degree and then left the University before these seedlings could be evaluated.

Preliminary evaluation of these crosses was conducted by James Luby and David Bedford in the early 1980s. In 1984, funding was greatly increased for the University of Minnesota's grape breeding program by the passage of an act in the state legislature, spearheaded by the Minnesota Grape Growers Association. This resulted in the hiring of a full-time grape breeder in 1985, Peter Hemstad (the author of this chapter). Mr Hemstad continued the evaluation of Pierquet's earlier crosses while greatly expanding the acreage of grapes at the HRC. Hundreds of grape accessions were brought in from nurseries and repositories in the 1980s and 1990s to augment the University of Minnesota's collections and provide future germplasm for breeding. A small-scale experimental winemaking program was also set up to supplement the breeding work. As a result of these efforts, Frontenac (*V. riparia* #89 × Landot 4511) (Figure 17.1(e); Table 17.1) was released by the University of Minnesota in 1996 (Hemstad and Luby, 2000).

Frontenac was a seedling from a cross originally made by Patrick Pierquet in the late 1970s. It was evaluated by Peter Hemstad and James Luby, who considered it very promising as an F1 hybrid from the wild. It has proven to be a successful cultivar and is now widely grown commercially throughout the Midwest and into Canada as well. Some of its positive attributes are that it is dependably cold hardy in central Minnesota, it is quite productive, has a very manageable semi-upright growth habit, is quick to become established, and is tolerant of a wide range of soil types. It is nearly immune to downy mildew and fairly resistant to powdery mildew. It is, however, susceptible to black rot. Black rot is not a major disease in Minnesota, but this becomes more of an issue when Frontenac is grown further south. Frontenac is tolerant of the root form of phylloxera but susceptible to the foliar form. Overall, it is considered quite forgiving from a grower's perspective.

On the wine side, Frontenac has some very appealing aspects, including a characteristic black cherry aroma, usually accompanied by aromas of berry and plum. Like most interspecific hybrids, Frontenac lacks tannin structure when compared to *V. vinifera* cultivars. Frontenac has proven to be very versatile in the wine cellar with wineries making successful red wines, rosés, and ports. By far the biggest drawback to Frontenac overall is its high titratable acidity. This can usually be managed by a combination of good viticultural practices, such as cluster thinning and delaying harvest until the fruit is fully mature. Red wines must usually either be put through malolactic fermentation or finished off dry to balance the high acidity. Frontenac may be particularly useful as a port-style cultivar, since its high acidity is masked by the sweetness of that type of wine.

Shortly after the release of Frontenac as a new cultivar, a single bud mutation was discovered by Peter Hemstad at the HRC. This single shoot had gray fruit rather than the original black (Figure 17.1(f); Table 17.1). Eventually this sport was patented in 2003 by the University of Minnesota as Frontenac Gris, and there are now hundreds of thousands of vines grown throughout the Midwest and East Coast. Frontenac Gris has a characteristic peach aroma accompanied by citrus and tropical fruit. The juice composition is essentially the same as the original Frontenac, meaning high soluble solids and high acidity. The vine is indistinguishable from Frontenac in the vineyard, which simplifies management for growers with both versions.

More recently, a further mutation of Frontenac Gris was found—a completely white version now known as Frontenac Blanc (Figure 17.1(g); Table 17.1). Frontenac Blanc was originally discovered in Quebec by Alain Breault and Giles Benoit, but additional independent discoveries have also been made by Ray Winter in Janesville, MN and at the University of Minnesota. It has become apparent that the Frontenac group is highly mutable, and reversions have also been found from Frontenac Gris back to Frontenac or even with two colors on one cluster. These various clones are currently being grown and evaluated at the University of Minnesota, and in the future, clones with different characteristics may become commercially available for growers. Initial results with Frontenac Blanc indicate that it appears to be distinct enough from Frontenac Gris for growers and wineries to consider having all three forms.

Another white wine cultivar developed by the University of Minnesota is La Crescent (St. Pepin × (*V. riparia* × Muscat of Alexandria)) (Figure 17.1(h); Table 17.1), which was introduced and patented in 2002 (Hemstad and Luby, 2003). La Crescent was the result of cooperation between Elmer Swenson and the University of Minnesota. The University of Minnesota was a source of pollen for Mr Swenson on several occasions, so it was not unusual for Peter Hemstad to request pollen from an interesting (*V. riparia* × Muscat of Alexandria) selection he noticed on a visit to Elmer's vineyard in Wisconsin (E.S. 6-8-25). Rather than sending pollen, Mr Swenson kindly offered to use the pollen on a pistillate cultivar (St. Pepin) the following spring. It was from these seeds that Hemstad selected MN 1166, which was eventually named La Crescent.

La Crescent was introduced primarily because it is an excellent combination of both very high wine quality and cold hardiness. Many of the best white wines from northern areas in the US have been made from this cultivar, and it has won numerous "best of show" awards in national and international wine competitions. While not technically a Muscat, La Crescent wine is highly aromatic with complex aromas of apricot, tangerine, and pineapple. Because of its high acidity, La Crescent is best as a semi-sweet or sweet wine, which tends to have universal appeal.

In the vineyard, La Crescent does have some issues. For one thing, it is susceptible to both downy mildew and foliar phylloxera. Fortunately, the downy mildew is confined to the leaves and does not affect the fruit. Unfortunately, the fruit itself is subject to poor set and occasional berry drop (shelling) before harvest. This shelling negates the potential that La Crescent might otherwise have for true ice wine production. In addition, the vine has a somewhat rank growth habit that makes it unsuitable for the popular vertical shoot positioning (VSP) training system. Perhaps the best training system for this vigorous cultivar is the Geneva Double Curtain.

The latest introduction from the University of Minnesota's grape breeding program has been Marquette (MN 1094 × Ravat 262) (Figure 17.2; Table 17.1) in 2006. MN 1094 is a very vigorous and cold hardy selection that has proven to be a good parent. Ravat 262 is an obscure, weak-growing French–American hybrid that has made excellent red wine in Ohio. It is thought to be derived from a cross involving Pinot noir.

Figure 17.2 Marquette, a cultivar introduced by the University of Minnesota in 2006. Photo by Sara Granstrom, Lincoln Peak Vineyard.

Marquette itself is a very good performer in both the vineyard and wine cellar when grown in the Upper Midwest, New England, or Quebec. It is currently (2014) the most widely planted cultivar in Minnesota, after having surpassed Frontenac.

The vine of Marquette is moderately vigorous with a somewhat upright growth habit that makes the vine amenable to a variety of training systems, including VSP and high cordon (HC), but yields have tended to be higher with HC. Disease resistance is quite good overall, but Marquette is slightly susceptible to downy mildew, powdery mildew, black rot, and foliar phylloxera. Marquette is reliably hardy on a good site in central Minnesota.

Marquette is capable of making high-quality wines with more depth and complexity than typically found in interspecific hybrids. Aromas frequently include cherry, cassis, and black pepper. The color is usually dark but not inky. Marquette fruit ripens early and usually comes in with a high Brix and an acidity that is high, relative to most *V. vinifera* cultivars but moderate compared to other *V. riparia*-based cultivars, such as Frontenac. As a result, Marquette is considered relatively easy to work with by local winemakers. The best Marquette wines have been bone dry and aged in oak barrels for upwards of a year before bottling.

The first four wine grapes introduced by this program are now the four most widely planted cultivars in Minnesota, and future introductions of advanced selections currently being evaluated should further stimulate the local industry.

In addition to the applied breeding work being done at the University of Minnesota, a substantial effort is also currently underway, led by Dr James Luby, to develop genetic markers for use in MAS (marker-assisted selection). In the future, MAS should significantly enhance and expedite the current breeding efforts and lead to more wine cultivars well-adapted to Midwest conditions.

17.2.3 David Macgregor, Lake Sylvia, Minnesota

David Macgregor worked closely with Elmer Swenson for many years, starting during the time when both were working at the University of Minnesota in the 1970s. Mr Macgregor went on to make many crosses of his own at his property near Lake Sylvia, MN. One selection from these efforts, DM 8313.1(ES 2-11-4 × DMP2-54), caught the eye of Ed Swanson, who was testing it in Nebraska. Swanson convinced Macgregor to release DM 8313.1 as Petite Amie or "little friend" in 2004. Petite Amie has been gaining in popularity as a white Muscat variety, making highly aromatic wine that has been useful for blending or, in some cases, as a varietal.

17.2.4 Tom Plocher, Minnesota

Tom Plocher of Hugo, MN worked with the late Elmer Swenson for many years, starting in the 1980s (Plocher and Parke, 2001). In the 1990s, Mr Plocher and his friend Bob Parke tested the suitability of several of Swenson's selections for wine production. As a result of their studies, Plocher and Parke encouraged fellow breeder Elmer Swenson to release Prairie Star and Louise Swenson in 2000 and 2001, respectively (Table 17.1).

Prairie Star was released as a cold hardy cultivar capable of making a good quality, fairly neutral white wine with moderate acidity levels. This has proven to be the case, and several wineries in Minnesota and surrounding states make commercial wines out of Prairie Star. One of the drawbacks of this cultivar is a strong tendency for "millerandage," or poor fruit set. As a varietal, Prairie Star can frequently benefit from blending to compensate for a lack of aromatic intensity.

Louise Swenson was originally thought of as a good blending partner for Prairie Star due to its pleasant aromatic structure. This blend is still sometimes made, but Louise Swenson has not been overly popular due to its slow growth and lack of vigor. On the positive side, it is very disease resistant under Midwest conditions.

Plocher and Parke also collaborated on writing an important book on cold climate viticulture entitled "Northern Winework," which is widely regarded as one of the best guides for northern growers (Plocher and Parke, 2001).

In addition to his work with Elmer Swenson and Bob Parke, Mr Plocher has also made numerous crosses of his own. The one cultivar he has formally introduced to date is Petite Pearl (Table 17.1). Petite Pearl is a half sister of the well-known cultivar Marquette, and it comes from a cross of (MN 1094 × ES 4-7-26). Petite Pearl is notable for its cold hardiness, good wine quality, early ripening, and moderate acid levels. There are several commercial plantings of Petite Pearl, and time will tell if its popularity will reach that of the similar cultivar Marquette.

17.3 Wisconsin

17.3.1 Elmer Swenson, Osceola, Wisconsin

Elmer Swenson (1913–2004; Figure 17.3) is considered the father or grandfather of grape growing in the Upper Midwest. He, in turn, was partially inspired by his own grandfather Larson, who had a small planting of grapes on his dairy farm near Osceola, WI. Another source of inspiration was T.V. Munson's 1909 book, "The Foundations of American Grape Culture," which Elmer read as a young boy (Krosch, 2005).

The foundation of Mr Swenson's program was MN 78, a University of Minnesota selection he received from Professor A.N. Wilcox in 1944. The parentage of MN 78 is believed to be Beta × Witt. MN 78 figures prominently in the background of nearly all of Elmer's cultivars. For quality parents, he initially used cultivars from Cornell's breeding program, such as Ontario, Seneca, and Golden Muscat, which he received in the early 1940s. In the late 1940s, Swenson began to acquire a number of French–American hybrids, which had recently been imported to the U.S., and several of them were used as parents, especially Seibel 1000 (Rosette) and Seyval (Krosch, 2005).

Swenson started making crosses in 1943 and continued in relative obscurity until 1969 when he went to work for the University of Minnesota (see below). After retiring

Figure 17.3 Grape breeder Elmer Swenson.
Photo by Peter Hemstad, University of Minnesota.

from the University, Elmer continued grape breeding on his farm in Wisconsin for the rest of his life and introduced several additional cultivars. He also freely allowed others to name his selections if they found them to be of value. His main goal was to see his grapes widely planted and he was very generous with his material. Swenson was a keen observer with an excellent memory for the background and characteristics of each of his selections. He was primarily interested in developing table grapes since he did not drink alcohol himself, but of course he was quite pleased when others found his grapes useful for winemaking. His pioneering work inspired many other grape breeders around the U.S. and beyond.

The first cultivar Elmer released after leaving the University of Minnesota was St. Croix (E.S. 283 × E.S. 193) (Figure 17.1(a); Table 17.1) in 1981. St. Croix was named after the beautiful St. Croix River that forms the border between Minnesota and Wisconsin. St. Croix has proven to be a successful red wine cultivar, with some of the best examples coming from Connecticut and Minnesota. Growers generally pick St. Croix slightly before full maturity to avoid the potential development of off aromas. The soluble solids and acidity levels are both fairly low. The vine is easy to manage on a HC system, but it does have a tendency to get downy mildew in some years. Maturity is quite early, so it ripens dependably in short season areas.

Sabrevois is a sister seedling of St. Croix that was named by Giles Benoit of Quebec in 2000 (Table 17.1). The vine is very healthy and in some ways superior to St. Croix, but the wine has proven to be somewhat difficult to work with except as a rosé.

Swenson released another set of sister seedlings in 1983, St. Pepin and La Crosse ((MN 78 × S 1000) × Seyval) (Table 17.1). Despite being pistillate, St. Pepin has proven to be the more successful of the two. St. Pepin is hardier than La Crosse and makes a more interesting wine that many people enjoy. St. Pepin has also been used successfully for ice wine production in Wisconsin and Minnesota, since the berries adhere very well to the rachis. La Crosse has performed well in slightly warmer parts of the Midwest, such as Nebraska and Iowa.

In later years, several of Elmer's selections were named by others with his permission. Notable examples of this include Prairie Star, Louise Swenson, Brianna, and Osceola Muscat, which are all described elsewhere in this chapter. Swenson also released a seedless table grape he named Petite Jewel in 2000 and another seedless selection Somerset Seedless in 2002 (Table 17.1). Somerset Seedless has become fairly popular, since it is one of the very few seedless grapes that can be grown in the Upper Midwest. It has a pleasant flavor and an attractive appearance, but the seed remnant can be noticeable in some years.

17.3.2 Mark Hart, Bayfield, Wisconsin

Mr Mark Hart has a vineyard situated in northern Wisconsin, within sight of Lake Superior, making it one of the coolest sites in the Midwest. Understandably, Mr Hart is breeding for early ripening in both wine and table grapes. He has used material from Elmer Swenson and the University of Minnesota as the foundation for his work. While he has not yet released anything from his own crosses, he was instrumental in the introduction of the Swenson selection ES 8-2-43 as Osceola Muscat in 2010 (Table 17.1).

Osceola Muscat helps fill the need for a cold hardy white Muscat cultivar but has issues in some years with poor set, splitting, and bunch rot.

While (technically speaking) an amateur breeder, Hart has visited vineyards and research institutes around the world and has a very extensive knowledge of the viticultural literature. He also worked with Elmer Swenson for a number of years before his death in 2004.

17.4 Nebraska

17.4.1 Ed Swanson, Nebraska

Mr Ed Swanson of Pierce, NE began breeding grapes in 1996, inspired by Elmer Swenson of Wisconsin. He has tested many of Swenson's selections in Nebraska and was instrumental in naming Brianna (E.S. 7-4-76) in 2002. Brianna is now gaining in popularity throughout the Upper Midwest due to its early ripening and winter hardiness. Brianna also makes a pleasant white wine with tropical fruit aromas. On the negative side, Brianna has small clusters and can sometimes develop off aromas if overripe. It can also be a slow grower on high pH soils. Brianna tends to be a low sugar cultivar but does have very workable acidity levels.

Swanson's own crosses have frequently involved high-quality red *V. vinifera* cultivars. His first introduction was Temparia (*V. riparia* × Tempranillo). Temparia was released on a limited basis in 2008 and has made some very good wines, but it has also been shown to have a problematic combination of high pH and high titratable acidity.

17.5 South Dakota

17.5.1 Niels Hansen, South Dakota State University

Niels Hansen was a Danish-American immigrant who had a passionate interest in plants, including everything from apricots and plums to melons and roses. He is perhaps best known for introducing alfalfa to the U.S. Professor Hansen went on a series of eight wide-ranging plant exploration trips from the 1890s to the 1930s. These trips were primarily to China, Russia, and Northern Europe and were some of the first such expeditions funded by the USDA. His last trip in 1934 was even at the invitation of the Soviet Union (Kephart, 2014). As a result of these journeys, Hansen brought back hundreds of potentially useful accessions of plants. Many of these introductions were then used in breeding by Hansen and others.

Hansen's work with grapes was limited to a few crosses using either Beta or wild *V. riparia* selections that he had collected in North Dakota and Montana as the source of cold hardiness. These were crossed with good quality *V. labrusca*-based cultivars from the East coast. Hansen did not test his seedlings very thoroughly before release, so he ended up introducing more than two dozen new grape cultivars, with the expectation that the marketplace would ultimately determine which were superior (Luby and

Fennell, 2006). He gave them American Indian names such as Chontay, Supaska, Eona, Azita, and Mandan (Hansen, 1927, 1937). None of these introductions ever became commercially popular, but Mandan was later used in the University of Minnesota's grape breeding program, and Eona was used by the private breeder Elmer Swenson. Hansen considered his grape cultivars an important step toward moving away from burying vines over the winter, which he described as "horticulture on crutches".

17.5.2 Ron Peterson, South Dakota State University

Dr Ron Peterson was in charge of fruit breeding at South Dakota State University (SDSU) from 1956 to 1987 (Luby and Fennell, 2006). During that time, he introduced a number of new fruit cultivars, including one grape cultivar, Valiant, in 1982 (Table 17.1). Valiant, tested as SD7121, is now grown commercially in a number of vineyards in South Dakota, North Dakota, and Minnesota. It is also grown on a small scale by growers in the prairie provinces of Canada. Valiant is a cross of (Fredonia × *V. riparia*), and it is one of the most cold hardy grapevine cultivars in the world, hardy to at least −40 °C. It makes an excellent juice and jelly with a foxy flavor derived from Fredonia. It has also made a successful dessert wine. The clusters and berries of Valiant are quite small and it is very prone to downy mildew and splitting when grown in a wetter climate than South Dakota. Both sugar levels and acidity levels are high.

17.5.3 Dr Anne Fennel, South Dakota State University

While not directly involved in applied breeding, Dr Anne Fennel of SDSU has been researching the mechanisms and genetic regulation of grapevine acclimation, dormancy, and hardiness for many years. Her work has primarily focused on *V. riparia* and its derivatives (Fennell, 2004). More recently, she has been actively involved in the search for genetic markers related to these traits as part of a large interstate project known as "VitisGen."

17.6 North Dakota

17.6.1 North Dakota State University

North Dakota State University initiated a new grape breeding program in 2010 under the direction of Dr Harlene Hatterman-Valenti. The goals of the program include cold hardiness and early ripening, along with low acidity and good wine quality. Many of the original parents used in this breeding program were selections and cultivars from the work of Elmer Swenson or the University of Minnesota. Seedlings are being grown at two sites near Fargo and Minot, ND. Future introductions from this program may give rise to cultivars suitable for very short season areas with extremely cold winters.

17.7 Missouri

17.7.1 Dr Chin-Feng Hwang, Southwest Missouri State University

Southwest Missouri State University initiated a new grape breeding program in 2010, which is currently under the leadership of Dr Chin-Feng Hwang. One of the main goals of this program is to improve upon Missouri's best-known cultivar, Norton (syn. Cynthiana, Virginia Seedling). Norton is believed to be a chance seedling derived from *V. aestivalis* that was originally developed in Virginia and has been grown in Missouri since the mid-1800s. The current program seeks to improve upon Norton by crossing it with high quality *V. vinifera* cultivars, such as Cabernet Sauvignon. Dr Hwang is also actively researching genetic markers for use in MAS.

17.8 Illinois

17.8.1 University of Illinois

Dr Herbert Barrett was a prolific grape breeder at the University of Illinois in the 1960s. He was instrumental in the use of interspecific French Hybrids in breeding new cultivars suitable for Midwest conditions. Dr Barrett also collected superior clones of wild species, such as *V. cinerea*, and used those in breeding for disease resistance. One noteworthy introduction was the table grape Lady Patricia (McCollum, 1968). Unfortunately, funding for this promising program was eliminated around 1966. Cornell University inherited the remains of the University of Illinois program and benefited greatly from the influx of this promising germplasm. Several of Cornell's later introductions are directly attributable to University of Illinois material, including the popular cultivar Traminette.

In 2003, horticulturist Bill Shoemaker started breeding wine grapes at the University of Illinois' St. Charles Horticulture Research Center in St. Charles, IL. This work is ongoing.

17.9 Conclusions

Grape breeding in the Midwest and, more specifically, the Upper Midwest, has had a major impact on the local grape and wine industry. While this part of the U.S. was initially felt to have winters that were too harsh for successful viticulture, the pioneering efforts of Louis Suelter and Niels Hansen, followed by Elmer Swenson, the University of Minnesota, and others, have proven that to be incorrect. Today, there is a thriving Midwestern wine industry based largely on these new cultivars. The influence of these breeders has also been felt well beyond the Midwest, and their cultivars are now being grown in many other parts of the world where extreme cold hardiness, disease resistance, and high wine quality are desired.

References

Alderman, W.H., 1962. Development of horticulture on the Northern Great Plains. Great Plains Reg. Amer. Soc. Hort. Sci.
Fennell, A., 2004. Freezing tolerance and injury in grapevines. J. Crop Improv. 10, 201–235.
Hansen, N.E., 1927. Plant introductions. S. Dak. State Coll. Agr. Mech. Arts Expt. Sta. (Brookings) Bull. 224.
Hansen, N.E., 1937. Fruits, old and new and northern plant novelties. S. Dak. Coll. Agr.Mech. Arts Expt. Sta. (Brookings) Bull. 309.
Hemstad, P.R., Luby, J.J., 2000. Utilization of *Vitis riparia* for the development of new wine varieties with resistance to disease and extreme cold. Acta Hort. 528, 487–490.
Hemstad, P.R., Luby, J.J., 2003. La Crescent, a new cold hardy, high quality, white wine variety. Acta Hort. 603, 719–722.
Kephart, K., 2014. The Remarkable Dr Niels Hansen, South Dakota's Great Plant Explorer. Article found on www.northscaping.com.
Krosch, P., 2005. With a Tweezers in One Hand and a Book in the Other. Minn. Grape Growers Assoc., St. Paul.
Luby, J., Fennell, A., 2006. Fruit breeding for the Northern Great Plains at the university of Minnesota and South Dakota State University. HortScience 41, 25–26.
McCollum, J.P., 1968. Lady Patricia, a new dessert grape variety. Ill. Res. 10 (2), 19.
Pfaender, W., 1912. The Beta grape and its origin. Minn. Hortic. 40 (1), 13.
Pierquet, P., Stushnoff, C., 1980. Relationship of low temperature exotherms to cold injury in *V. riparia* MICHX. J. Am. Soc. Enol. Vit. 31, 1–6.
Plocher, T., Parke, R., 2001. Northern Winework. Northern Winework, Inc., Hugo, MN.
Snyder, L.C., 1982. History of the Department of Horticultural Science and Landscape Architecture 1849-1982. Minn. Agr. Expt. Sta., St. Paul.
Swenson, E.P., 1985. Wild *V. riparia* from northern U.S. and Canada- breeding source for winter hardiness in cultivated grapes—a background of the Swenson hybrids. Fruit J. 39, 28–31.
Swenson, E.P., Pierquet, P., Stushnoff, C., 1978. 'Edelweiss' and Swenson Red' grapes. HortScience 15, 100.
Wilcox, A.N., 1946. Grape breeding at the Minnesota station. Fruit Hort. Dig. 1, 28–34.

Index

Note: Page numbers followed by "f" and "t" indicate figures and tables respectively.

D

E

F

G

K

L

M

N

O

X

Y

Z