Journal of Cereal Science 125 (2025) 104259

Contents lists available at ScienceDirect

Journal of Cereal Science

journal homepage: www.elsevier.com/locate/jcs

Cereal and pseudocereal microgreens: Emerging functional foods for human health and sustainability

Samiddhi Gunathilake [a], Supuni Aluthge [a], Asgar Farahnaky [a], Shima Jafarzadeh [b], Mahsa Majzoobi [a,*]

[a] Department of Food Technology and Nutrition, School of Science, STEM College, Bundoora West Campus, RMIT University, Melbourne, Victoria, 3088, Australia
[b] Centre for Sustainable Bioproducts, Deakin University, Geelong, Victoria, 3216, Australia

ARTICLE INFO

Keywords:
Microgreens
Nutritional profile
Functional foods
Sustainable agriculture

ABSTRACT

Whole grain cereals and pseudocereals have long served as staple sources of energy and nutrients. However, their nutritional potential is often limited by moderate protein content, low bioavailability of key micronutrients, and anti-nutritional factors such as phytic acid. To enhance their nutritional value and expand their food applications, strategies such as sprouting, fermentation, selective breeding, and thermal processing have been explored. This review highlights microgreening as an emerging approach to transform grains into nutrient-rich ingredients by critically exploring the nutritional, bioactive, and functional properties of cereal (e.g., wheat, sorghum, barley, oats) and pseudocereal (e.g., quinoa, amaranth, chia) microgreens, which exhibit significantly higher levels of protein, minerals, and antioxidants compared to their mature forms. The review also explores key agronomic and environmental factors such as light, temperature, and growth medium, that influence their chemical composition. In addition to their health promoting properties, microgreens contribute to sustainable food systems through space efficient cultivation methods suitable for urban and even extraterrestrial agriculture. Despite their potential, challenges remain in terms of cost, shelf-life, microbial safety, marketing, and standardisation. This review highlights the need for further clinical validation, optimization of post-harvest technologies, and regulatory frameworks to fully integrate microgreens into functional food markets. Ultimately, cereal and pseudocereal microgreens represent a novel class of functional foods with the potential to address global nutritional deficiencies and support resilient food systems.

1. Introduction

While cereal grains such as wheat, rice, maize, and millet are fundamental to global food security, providing a significant portion of daily caloric and protein intake, their nutritional value can be constrained by factors such as medium to low protein content, low bioavailability of essential micronutrients, and the presence of anti-nutritional compounds like phytic acid (Sá and House, 2024). Various strategies have been explored to improve the nutritional quality of cereal grains, addressing key aspects such as protein, fibre, and micronutrient content. These methods range from conventional approaches to more advanced technologies, each with its own set of benefits and challenges. Table 1 provides an overview of the most commonly used strategies for improving the nutritional value of cereals, highlighting their core principles and applications. Meanwhile, Table 2 offers a comparative analysis, discussing the advantages and disadvantages associated with each method to help guide their practical implementation in cereal-based food production.

A promising strategy to improve the nutritional profile of cereals is through processing interventions that lower anti-nutritional components and enhance the bioavailability of key nutrients. For instance, germination or sprouting has been shown to increase amino acid content and reduce phytic acid levels, thereby enhancing minerals bioavailability. Similarly, fermentation processes can enrich cereals with beneficial compounds and improve protein digestibility (Majzoobi et al., 2023; Marco et al., 2017).

Biotechnological interventions have also been employed to improve cereal and pseudocereal nutrition. Genetic engineering techniques have been used to develop cereal varieties with enhanced nutrient profiles, such as increased lysine content in maize and sorghum. Additionally,

This article is part of a special issue entitled: Grains for One Health published in Journal of Cereal Science.
* Corresponding author.
E-mail address: mahsa.majzoobi@rmit.edu.au (M. Majzoobi).

https://doi.org/10.1016/j.jcs.2025.104259
Received 27 May 2025; Received in revised form 29 July 2025; Accepted 20 August 2025
Available online 21 August 2025
0733-5210/

biofortification strategies have been implemented to increase the concentration of micronutrients like iron and zinc in cereal grains, contributing to the alleviation of micronutrient deficiencies (Bouis and Saltzman, 2017). Moreover, advancements in processing technologies, including extrusion and enzymatic treatments, have been explored to improve the nutritional and functional properties of cereal-based foods. These methods can enhance the bioavailability of nutrients and reduce the content of undesirable compounds, thereby producing healthier cereal products (Gulati et al., 2020; A. Singh et al., 2016).

Among the various strategies explored to enhance the nutritional profile of cereal and pseudocereal grains, “microgreening” or “microgreen production” has recently emerged as a novel and promising approach. Microgreens are young, tender greens harvested at the cotyledon stage, and are known to be rich in vitamins, minerals, antioxidants, and phytochemicals (Bhaswant et al., 2023). Applying microgreening techniques to cereal grains such as wheat, barley, maize, and rice has demonstrated the potential to significantly increase their nutritional density, including elevated levels of bioavailable micronutrients and bioactive compounds (Altuner, 2024). Despite the growing interest in this area, to date there is no comprehensive review that systematically examines the application of microgreening as a strategy for enhancing the nutritional quality of cereals. This review, therefore, addresses a critical gap in the literature by evaluating current research on microgreen processing in cereals, comparing its effectiveness with other nutritional enhancement methods, and outlining its potential for sustainable food innovation.

2. Microgreens

Microgreens, sometimes called “vegetable confetti,” are young, edible seedlings harvested at the cotyledon stage, known for their vibrant colours, flavours, and nutritional density (Castellaneta et al., 2022; Kyriacou et al., 2016). Originally introduced by chefs in San Francisco during the 1980s, they have transitioned from niche culinary ingredients to widely commercialised functional foods. Today, microgreens are cultivated globally using greenhouse, vertical, and indoor farming systems, driven by consumer demand for nutrient-rich, high-value products. The global microgreens market was projected to reach USD 17.04 billion by 2025, with a compound annual growth rate (CAGR) of 7.5–8.0 % (Seth et al., 2025). Structurally, microgreens consist of a stem, cotyledon leaves, and occasionally the first true leaves, typically harvested at 3–10 cm height (Bhaswant et al., 2023; Choe et al., 2018). Their high content of vitamins, minerals, antioxidants, and bioactive compounds has earned them the label of “superfoods.” Commercially, they are available fresh or in processed forms such as powders, teas, premixes, and tablets, and are widely used in salads, soups, and gourmet cuisine (Kumar and Singh, 2024; Szopa et al., 2023).

3. Microgreens vs sprouts vs baby greens

In recent years, growing health concerns have led people to include more fresh fruits, vegetables, and green leafy foods in their diets. This shift has driven demand for functional foods that are nutrient-rich and produced with minimal exposure to pesticides, herbicides, and synthetic fertilisers. As a result, traditional practices are being revived, popularizing organic foods and micro vegetables like baby greens, sprouts, and microgreens (Fig. 1). These are valued for their exceptional nutritional benefits and health-promoting properties (Bhaswant et al., 2023).

Although microgreens are consumed at an early developmental stage similar to sprouts and baby greens, they differ significantly in cultivation methods, morphology, and harvesting period. Unlike sprouts, which are grown in dark, moisture rich environments that may encourage microbial contamination and have been associated with foodborne illnesses, microgreens are cultivated under light conditions using a growth medium. Baby greens, while also harvested early, share several cultivation requirements with mature plants, including adequate light, a growth medium, and external nutrient input. However, baby greens are typically consumed raw, distinguishing them from mature plants, which

Table 1
Common strategies to enhance the nutritional quality of cereal and pseudocereal grains.

Method	Mechanism	Target nutritional traits	Examples	References
Biofortification	Genetic enhancement via conventional breeding or genetic modification	Micronutrients (Iron, Zinc, Provitamin A)	Golden rice (Provitamin A), Iron-biofortified pearl millet	Bouis and Saltzman (2017)
Germination/Sprouting	Activation of endogenous enzymes leading to breakdown of anti-nutrients and synthesis of bioactives	Increased bioavailability of minerals, improved amino acid profile	Sprouted wheat, barley, sorghum	Majzoobi et al. (2023)
Fermentation	Microbial transformation enhances digestibility and reduces anti-nutrients	B-vitamins, Amino acids, reduced phytic acid	Fermented millet, maize	Marco et al. (2017)
Enzymatic treatment	Use of enzymes (e.g., phytase, cellulase) to degrade anti-nutrients and modify macromolecules	Improved nutrient digestibility and availability, reduced phytic acid	Rice, wheat, maize	A. Singh et al. (2016)
Soaking and dehulling	Activate natural enzymes, leach anti-nutrients, remove fibre rich outer layers	Enhanced protein digestibility, improved mineral bioavailability, reduced flatulence factors	Kodo millet	S. M. Singh et al. (2024)
Thermal processing (e.g. extrusion, roasting)	Alter chemical structures, reduce anti-nutrients, improve palatability	Enhanced protein and starch digestibility, improved shelf life, reduced phytates	Maize, rice, wheat, sorghum	Gulati et al. (2020)
Nixtamalization	Cooking in alkaline solution, changes in protein structure and mineral availability	Higher calcium content, improved protein and niacin bioavailability, reduced toxins	Maize	Hassan et al. (2023)
Fortification	Addition of essential vitamins/minerals during or after processing	Elevated levels of targeted micronutrients	Maize, wheat, rice	Garg et al. (2021)
Novel breeding tools (e.g. clustered regularly interspaced short palindromic repeats)	Precision gene editing to improve nutrient content	Enhanced protein, lysine content	Gene-edited rice and maize	(Zhang et al., 2018)
Microbial inoculation in soil	Improves nutrient uptake by plants	Micronutrients (Zn, Fe), protein	Rhizobacteria-treated wheat and millet	Reis et al. (2022)
Blending with legumes or bioactive-rich ingredients	By mixing legumes which are rich in protein, essential amino acids, minerals and low GI carbohydrates	To enhance protein content, amino acid profile such as lysine. Improves antioxidant capacity and mineral bioavailability (Zn, Fe) while reducing glycaemic response	Composite flours from wheat, quinoa and chickpea	Temba et al. (2016)

Table 2
Advantages and disadvantages of the commonly used strategies to enhance the nutritional quality of cereal and pseudocereal grains.

Method	Advantages	Disadvantages	References
Germination/ Malting	Enhances bioavailability of minerals; increases vitamin content (e.g., B-complex)	Time-consuming; may reduce shelf life; microbial and chemical hazards	Majzoobi et al. (2023)
Fermentation	Improves digestibility and reduces anti-nutrients (e.g., phytic acid)	Requires controlled conditions; sensory changes	Marco et al. (2017)
Biofortification	Sustainable micronutrient delivery; benefits rural populations	Long development time; requires policy support	Bouis and Saltzman (2017)
Enzymatic Treatments	Breaks down anti-nutrients; enhances digestibility	Can be expensive; enzyme activity may vary; by-products may be generated	A. Singh et al. (2016)
Thermal processing	Reduces some anti-nutrients; can improve taste	May destroy heat-sensitive nutrients	Gulati et al. (2020)
Extrusion cooking	Combines cooking and shaping; retains nutrients under high pressure	High initial cost; risk of nutrient loss, if not optimised	Gulati et al. (2020)
Novel breeding tools (e.g. CRISPR)	Precise, rapid improvements in nutrient traits	Regulatory uncertainty in some countries; public perception issues	(Zhang et al., 2018)
Chemical treatments (e.g. Soaking with chelators)	Reduces phytic acid; improves mineral solubility	Risk of residual chemicals; environmental concerns	Mattar et al. (2022)
Blending with legumes or bioactive-rich ingredients	Balances amino acid profile; adds fibre and phytochemicals	May affect texture, flavour, and consumer acceptance	Yohannes et al. (2020)

often require cooking prior to consumption (Bhaswant et al., 2023).

Microgreens are generally harvested between 10 and 21 days after sowing, when they reach a height of approximately 3–10 cm. In comparison, baby greens are collected at a height of 10–15 cm following 15–40 days of growth, whereas sprouts are typically harvested earlier, within 3–10 days, at a size of 5–8 cm. The developmental stage at harvest further distinguishes these categories such as, sprouts are collected shortly after seed germination during the partial development of cotyledons, microgreens are harvested at full cotyledon development often with one or two true leaves, and baby greens are taken at a more advanced stage where the plant has developed multiple true leaves. Sprouts also differ anatomically from microgreens, as they include the seed, root, and stem in the edible portion, whereas microgreens are harvested above the root, resulting in a more refined texture and enhanced flavour profile. Although microgreens and baby greens develop root systems with fine root hairs, these are typically removed during harvesting. In contrast, sprouts have a minimal root structure without root hairs and are consumed in their entirety (Bhaswant et al., 2023; Choe et al., 2018; Kyriacou et al., 2016).

From a cultivation standpoint, sprouts and microgreens are generally produced without the application of agrochemicals, while baby greens may require such inputs. Additionally, microgreens and sprouts can be cultivated intensively in limited space, making them suitable for high density production, whereas baby greens require considerably more growing area due to their extended developmental needs (Bhaswant et al., 2023).

4. Cereal and pseudocereal-based microgreens

Microgreens from cereals and pseudocereals are cultivated from diverse cereal and pseudocereal species, each offering distinct nutritional and agronomic advantages. Around 80–100 crop varieties have been identified for microgreen production, with cereals such as corn, amaranth, finger millet, oats, and wheat well-suited for home-based and urban farming systems (Lekshmi and Nair, 2023). While mature cereal grains like wheat, rice, corn, barley, and oats are valued for their carbohydrates, fibre, and B vitamins (Kumar and Singh, 2024; Kyriacou et al., 2016), the microgreens derived from these species exhibit significantly different nutritional characteristics. Unlike their starch-rich seeds, cereal and pseudocereal microgreens are harvested at the cotyledon or first true leaf stage and are known to accumulate higher concentrations of bioavailable micronutrients, antioxidants, polyphenols, and vitamins. Although the direct correlation between the nutritional profile of seeds and their microgreens is not linear, the genetic makeup and quality of the seed influence the phytochemical and micronutrient content of the resulting microgreens (Kyriacou et al., 2016; Zhang et al., 2021). Pseudocereals such as quinoa, amaranth, and buckwheat provide gluten-free proteins, essential amino acids, and antioxidants (Langyan et al., 2024). Underutilised cereals and pseudocereals like sorghum, millet, quinoa and chia seeds are gaining attention due to their climate resilience and rich antioxidant and micronutrient profiles, aiding dietary diversification and food security (Lone et al., 2024).

Selection for microgreen cultivation is based on seed quality, fast growth, minimal space needs, low microbial risk, and suitability for year-round, urban or vertical farming. Nutrient density, especially in vitamins, fibre, and antioxidants, and sensory traits also influence choice. Cereals like sorghum, millet, barley, and oats are particularly notable for their β-glucan content, supporting cardiovascular health (Bhaswant et al., 2023; Lone et al., 2024).

Cereal and pseudocereal-based microgreens offer a unique nutritional profile, often characterised by higher concentrations of specific amino acids, B-vitamins, and certain antioxidants than their mature counterparts. For instance, studies have shown that wheat microgreens can exhibit increased levels of phenolic compounds and flavonoids (ferulic acid, chlorogenic acid, p-coumaric acid, vanillic acid) under certain cultivation conditions, enhancing their antioxidant potential (Kumar and Singh, 2024; Zhang et al., 2021). This distinction allows for a broader range of culinary applications and dietary options, catering to diverse consumer preferences and nutritional needs.

Given their nutritional potential and growing popularity among consumers, culinary professionals, urban gardeners, and retailers, microgreens have become a focus of increasing scientific interest. Current research continues to explore their phytochemical diversity and implications for human health.

5. Chemical composition and nutrients of cereal and pseudocereal-based microgreens

Cereal-based microgreens have gained global attention for their vibrant colour, flavour, and rich nutritional profile. They are concentrated sources of functional bioactive compounds, offering health-promoting and disease-preventive benefits beyond basic nutrition. Rich in minerals like calcium, iron, zinc, and magnesium, their micronutrient levels remain stable across soil types. They also contain key vitamins such as α-tocopherol (E), β-carotene (A), ascorbic acid (C), and phylloquinone (K1), though concentrations vary by species (Choe et al., 2018). In addition to vitamins and minerals, these microgreens are abundant in phytochemicals including phenolics, anthocyanins, glucosinolates, and carotenoids, contributing to antioxidant, anti-inflammatory, and anticancer properties. Their superior nutrient density up to 4–40 times higher than mature plants makes them especially appealing to health-conscious consumers and suitable for urban

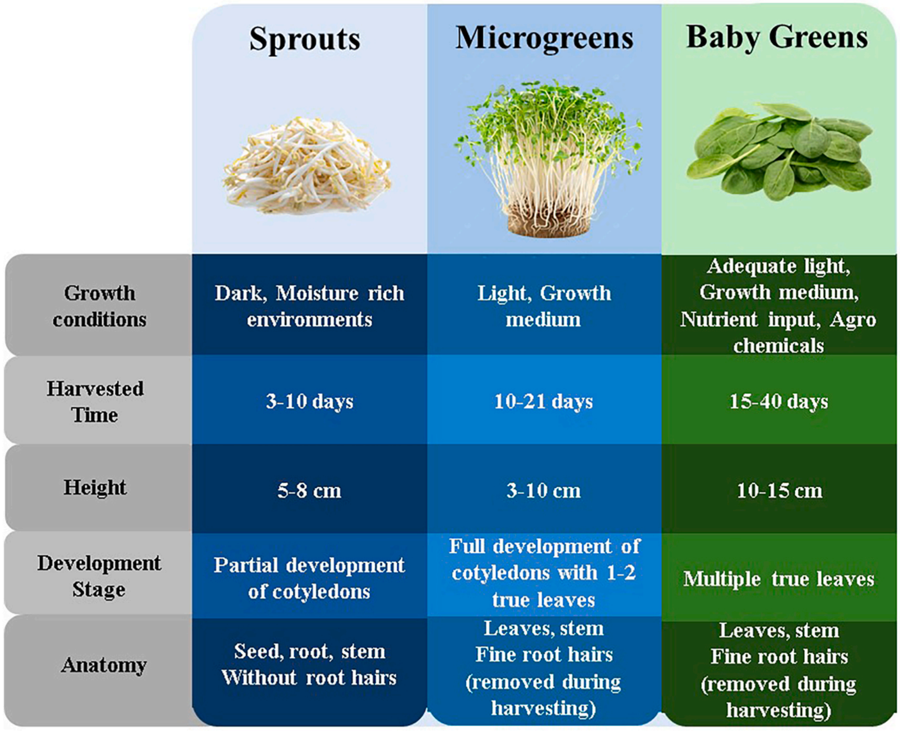

Fig. 1. Difference between sprouts, microgreens, and baby greens.

farming and space-based systems (Szopa et al., 2023; Zhang et al., 2021).

5.1. Proximate analysis

Microgreens from cereals and pseudocereals exhibit diverse proximate compositions compared to the mature grains, reflecting variations in their nutritional value (Table 3). A consistent trend observed across all species is a marked reduction in carbohydrate content in microgreens compared to their mature grain or seed forms. For instance, wheat and sorghum microgreens show decreases of 78 % and 82 % of carbohydrate respectively, from their mature grain counterparts. Chia microgreens also reflect a substantial decline of 27 % of carbohydrate content. These reductions may be attributed to the utilization of carbohydrate reserves during early germination and shoot development, where stored starch is mobilized to fuel cellular processes (Eswaranpillai et al., 2023; John et al., 2025; Kaur et al., 2021).

Cereal-based microgreens exhibit a markedly different nutritional profile compared to their mature grain forms. During germination, starch reserves stored in the seed endosperm are rapidly mobilized to support early plant growth, leading to a significant reduction in starch content in the emerging microgreens. In contrast, mature grains like wheat and maize typically contain 60–75 % starch, primarily located in the endosperm (Majzoobi et al., 2023). As the carbohydrate reserves are utilised, microgreens become enriched in vitamins, minerals, polyphenols, and antioxidants, resulting in a nutrient-dense, low-carbohydrate food source (Bhaswant et al., 2023).

Interestingly, cereal-based microgreens generally exhibit an elevated protein concentration, with wheat microgreens showing a 262 % increase over the mature seed. Chia and sorghum microgreens also show

Table 3
Proximate compositions (% dry weight) of different cereal and pseudocereal vs their microgreens.

Species (Type)	Component	Mature Seed/Grain (%)	Microgreen (%)	% Change	Reference
Wheat (Cereal)	Carbohydrates	75.60	16.66	↓ 78 %	(Eswaranpillai et al., 2023; Kaur et al., 2021)
	Protein	10.70	38.75	↑ 262 %	
	Fat	2.00	Not found	Not found	
	Fibre	1.30	Not found	Not found	
	Ash	1.40	15.93	↑ 1038 %	
Sorghum (Cereal)	Carbohydrates	71.95	12.83	↓ 82 %	(Eswaranpillai et al., 2023; Mohapatra et al., 2019)
	Protein	11.36	13.49	↑ 19 %	
	Fat	4.70	Not found	Not found	
	Fibre	2.76	Not found	Not found	
	Ash	3.17	9.75	↑ 208 %	
Chia (Pseudocereal)	Carbohydrates	43.69	32.05	↓ 27 %	John et al. (2025)
	Protein	18.20	34.70	↑ 91 %	
	Fat	25.30	6.90	↓ 73 %	
	Ash	5.00	18.0	↑ 260 %	
Red Amaranth (Pseudocereal)	Carbohydrates	45.70	Not found	Not found	(Gunjal et al., 2024; Mekonnen et al., 2018)
	Protein	16.64	2.27	↓ 86 %	
	Fat	6.42	7.51	↑ 17 %	
	Fibre	4.57	9.47	↑ 107 %	
	Ash	3.3	16.39	↑ 397 %	

increases of 91 % and 19 %, respectively. These changes are consistent with previous findings that germination enhances enzymatic activities leading to protein synthesis and accumulation of amino acids (Eswaranpillai et al., 2023; John et al., 2025; Kaur et al., 2021). However, red amaranth deviates from this trend, with its microgreen form showing an 86 % reduction in protein content, suggesting species specific metabolic shifts or developmental variations (Gunjal et al., 2024; Mekonnen et al., 2018).

Fat content generally appears lower in microgreens, but red amaranth microgreens exhibited a slight increase in fat content compared to their mature seeds (Table 3). Fibre content is shown to increase significantly, such as in red amaranth microgreens which contain 9.47 % fibre, more than double that of the mature grain. This may be due to increased cell wall biosynthesis during the early growth stages (Gunjal et al., 2024; Mekonnen et al., 2018). Ash content, indicative of total mineral content, is significantly higher in all cereal-based microgreens, compared to mature grains. Wheat microgreens showed a notable 1038 % increase of ash, followed by chia (260 %), red amaranth (397 %), and sorghum (208 %) (Table 3). This enrichment suggests that cereal-based microgreens may be potent sources of essential minerals and trace elements, consistent with previous literature noting the dense mineral profile of microgreens compared to mature plant stages (Eswaranpillai et al., 2023).

Overall, the variation in proximate composition among cereal-based microgreens underscores the importance of species selection for specific nutritional applications. Pseudocereal microgreens offer superior nutrient profiles, while cereal microgreens may serve more complementary roles in diet formulations. The findings affirm that these microgreens possess a unique and often superior nutritional profile compared to their mature seed or grain, particularly in terms of protein and mineral content. However, the variation across species also suggests the need for species specific assessments to inform dietary recommendations and potential commercial applications in the functional food industry.

5.2. Mineral content

The mineral profiles of cereal and pseudocereal microgreens vary widely by species but generally exceed those of mature grains, making them promising for functional foods. For example, while wheat grains contain potassium (467 mg/100 g), phosphorus (317 mg/100 g), iron (4.63 mg/100 g), and zinc (3.04 mg/100 g) (Wysocka et al., 2025), wheat microgreens exhibit significantly higher levels of these minerals: potassium (782.4–6280.6 mg/100 g), phosphorus (260.86–624.36 mg/100 g), iron (45.06–156.83 mg/100 g), and zinc (4.16–8.80 mg/100 g) (Kaur et al., 2021; Kumar and Singh, 2024). Chia microgreens are rich in calcium (1840 mg/100 g) and phosphorus (2070 mg/100 g), exceeding mature seed levels (John et al., 2025). Red amaranth microgreens also contain high calcium and potassium but lower iron and zinc (Di Gioia et al., 2023). Quinoa microgreens show much higher calcium (1535 mg/100 g) and potassium (8769 mg/100 g) than mature grains (148.7 mg/100 g Ca; 1475 mg/100 g K) (Pathan and Siddiqui, 2022). While data on oat microgreens are limited, they are known to be richer in calcium, iron, and magnesium than mature oats, along with beneficial vitamins. These findings support the use of microgreens as nutrient-dense ingredients in health-promoting diets.

5.3. Bioactive compounds

Cereal and pseudocereal microgreens are increasingly recognized for their rich profiles of bioactive compounds, often surpassing those found in their mature grain counterparts (Table 4). These bioactive constituents including vitamins, phenolic compounds, and antioxidants contribute to the functional and therapeutic potential of microgreens.

Microgreens from cereals and pseudocereals are increasingly recognized for their diverse and rich profiles of bioactive compounds, contributing to their functional and therapeutic potential. They contain substantial concentrations of functional constituents such as ascorbic acid, phylloquinones, α-tocopherol, β-carotene, phenolic antioxidants, carotenoids, anthocyanins, glucosinolates, and natural sugars (Bhaswant et al., 2023). However, the chemical composition of cereal-based microgreens can vary considerably depending on factors such as cultivar type and cultivation conditions, emphasizing the need for further investigation to comprehensively characterize their nutrient profiles and optimize their nutritional value (Choe et al., 2018). Several studies have demonstrated that microgreens from cereals and pseudocereals exhibit higher levels of vitamins and antioxidant activity compared to their seed or sprout forms (Kumar and Singh, 2024). Ascorbic acid (vitamin C), is one of the essential phytochemicals present in microgreens, contributing to vital physiological functions and metabolic processes due to its antioxidant properties. Similarly, α-tocopherol (vitamin E) plays a crucial role in supporting immune function, nerve

Table 4
Comparative overview of the main bioactive compounds in cereals and pseudocereals in the form of mature and microgreens.

Plant Source	Bioactive Compounds in Mature Grains	Bioactive Compounds in Microgreens	References
Wheat	Ferulic, p-coumaric, vanillic), flavonoids (apigenin, luteolin), alkylresorcinols, lignans, phytosterols (β-sitosterol, campesterol), tocopherols, and carotenoids (lutein, zeaxanthin)	Elevated levels of chlorophyll, ascorbic acid, phenolic acids (e.g., ferulic acid, chlorogenic acid), flavonoids (e.g., rutin), and amino acids (e.g., glutamine, alanine).	(Dykes and Rooney, 2007; Kaur et al., 2021; Kumar and Singh, 2024)
Sorghum	Phenolic acids (ferulic, p-coumaric), flavonoids (luteolin, apigenin), 3-deoxyanthocyanidins, tannins, phytosterols	Notable concentrations of chlorophyll *a and b*, contributing to antioxidant potential, though ascorbic acid content is relatively lower.	(Dykes and Rooney, 2007; Eswaranpillai et al., 2023)
Barley	Phenolic acids (ferulic, caffeic), flavonoids (catechins), β-glucans, tocopherols, phytosterols, and lignans	High antioxidant capacity with significant phenolic and flavonoid contents	(Altuner, 2024; Dykes and Rooney, 2007)
Oats	Phenolic acids, avenanthramides, β-glucans, and phytosterols.	Robust antioxidant profile, high total anthocyanin content	(Altuner, 2024; Dykes and Rooney, 2007)
Amaranth	Phenolic acids (gallic, vanillic, ferulic), flavonoids (quercetin, kaempferol), squalene, tocopherols, betalains, and phytosterols	Carotenoids, anthocyanins, and ascorbic acid	(Bhaswant et al., 2023; Mekonnen et al., 2018)
Quinoa	Flavonoids (quercetin, kaempferol), phenolic acids (ferulic, caffeic, p-coumaric), saponins, phytosterols (e.g., β-sitosterol), tocopherols (α- and γ-tocopherol), betalains	Enriched in lipid-soluble antioxidants such as tocopherols and β-carotene	Bhaswant et al. (2023)
Chia	Phenolic acids (caffeic, chlorogenic, ferulic), flavonoids (quercetin, kaempferol, myricetin), tocopherols, phytosterols, squalene, omega-3 fatty acids (ALA), and antioxidant peptides	Rich in phenolic compounds	John et al. (2025)

signal transmission, and cellular protection by limiting free radical formation. Its abundance in microgreens makes them an effective dietary source for enhancing bodily function. β-Carotene, a red–orange pigment and precursor of vitamin A, is known for its antioxidant activity, including the suppression of free radicals, induction of apoptosis in cancer cells, and stimulation of immune responses via natural killer cell activation. As such, cereal-based microgreens serve as an excellent source of pro-vitamin A (Bhaswant et al., 2023).

Phenolic compounds play a pivotal role in maintaining physiological balance through their antioxidant, anti-inflammatory, antiproliferative, and anti-aging properties. Their inclusion in the human diet through cereal-based microgreens can assist in managing oxidative stress and lowering the risk of chronic diseases including cardiovascular diseases, obesity, and certain cancers (Choe et al., 2018; Kumar and Singh, 2024). These compounds, such as tannins, phenolic acids, and anthocyanins, contribute not only to antioxidant activity but also to the flavour, aroma, and colour that define the sensory profile of those microgreens (Bhaswant et al., 2023).

Chlorophyll and carotenoids, two major photosynthetic pigments abundant in cereal-based microgreens, contribute to their vibrant coloration and offer biological benefits. These pigments are found in higher concentrations in microgreens than in sprouts, enhancing both their aesthetic appeal and health promoting effects. Anthocyanins, another class of flavonoid pigments are found in various cereal-based microgreen species and are associated with diverse physiological effects. These include antioxidant, anti-inflammatory, anti-cancer, and antiviral activities, all of which contribute to improved metabolic function and overall wellness (Bhaswant et al., 2023).

Wheat microgreens have been extensively characterised, showing notable levels of chlorophyll, ascorbic acid, and antioxidant activity. Additionally, wheat microgreens are rich in phenolic acids such as ferulic acid and chlorogenic acid, along with flavonoids like rutin and amino acids including glutamine and alanine, contributing to their high total phenolic content and total antioxidant activity (Kaur et al., 2021; Kumar and Singh, 2024). Sorghum microgreens also exhibit considerable levels of photosynthetic pigments, with chlorophyll *a and b* concentrations. Although their ascorbic acid content is relatively lower, the presence of chlorophyll contributes to their antioxidant potential. Compared to wheat, sorghum displays a more moderate phytochemical profile but remains valuable as a green food supplement (Eswaranpillai et al., 2023).

Barley microgreens are particularly noted for their antioxidant capacity with high phenolic and flavonoids contents. These compounds are known to play a role in scavenging free radicals and reducing oxidative stress, making barley microgreens beneficial for cardiovascular and metabolic health. Oat microgreens demonstrate a robust antioxidant profile, comparable to or exceeding that of barley. Additionally, they possess a high total anthocyanin content, which may confer anti-inflammatory and anti-carcinogenic properties (Altuner, 2024). Pearl millet microgreens stand out for their enzymatic antioxidant defence system and micronutrient content. The presence of antioxidant enzymes like catalase, peroxidase, and ascorbate peroxidase helps maintain redox balance, while the phytic acid found in pearl millet microgreens suggests a mineral chelating capacity, which is significant for both nutritional and health-related applications (Dhaka et al., 2023).

Among pseudocereals, amaranth microgreens contain lower levels of chlorophyll compared to wheat or sorghum. They also contain carotenoids, anthocyanins, and ascorbic acid. Despite the modest concentrations, these compounds are relevant for eye health, inflammation reduction, and free radical scavenging. Quinoa microgreens show enrichment in lipid-soluble antioxidants such as tocopherols and β-carotene. These bioactive compounds are linked to protective roles against lipid peroxidation and age-related diseases, highlighting the potential in nutraceutical development (Bhaswant et al., 2023). Chia microgreens are rich in phenolic compounds and their amino acid profile is notably broad, including essential and semi-essential amino acids such as leucine, lysine, valine, phenylalanine, threonine, glutamic acid, aspartic acid, alanine, and arginine. This comprehensive profile makes chia microgreens a valuable plant-based protein source for balanced nutrition (John et al., 2025).

In summary, the diverse and wide spectrum of phenolic compounds, chlorophylls, flavonoids, vitamins, and antioxidant enzymes found in cereal-based microgreens highlights their value as functional food ingredients, supporting their inclusion into health promoting diets and nutraceutical formulations. Owing to the high bioavailability of these bioactive constituents, cereal-based microgreens also present an effective natural alternative to synthetic nutrient supplementation in individuals with specific deficiencies (Bhaswant et al., 2023).

6. Factors affecting the chemical composition and physiological properties of cereals and pseudocereals microgreens

The growing demand for microgreens has highlighted the need for year-round production, which relies on optimizing their growing conditions. By fine-tuning these conditions, producers can enhance yield, nutritional profiles, taste, texture, growth speed, and resource efficiency. The growth and biochemical composition of cereal-based microgreens are highly sensitive to environmental and agronomic factors, including light intensity and duration, temperature, humidity, water availability, soil or growth medium quality, nutrient levels, and even seasonal variations and cultivar selection (Table 5). Effectively managing these variables is crucial to ensuring consistent quality and maximizing the commercial potential of microgreens year-round (Choe et al., 2018; Kumar and Singh, 2024).

6.1. Light intensity

Light conditions play a critical role in influencing the biochemical composition and physiological properties of cereal-based microgreens. The concentrations of sugars and polyalcohols in certain cereal-based microgreens were significantly affected by the duration of photoperiod

Table 5
Effects of environmental factors on microgreens from cereals and pseudocereals.

Environmental Factor	Grains	Observed Effects	Reference (DOI)
Light	Wheat	Exposure to red and blue LED light enhances growth parameters and nutritional value in wheat sprouts.	Virdi et al. (2021)
Temperature	Buckwheat	Cooler temperatures combined with longer photoperiods increase phytochemical accumulation and antioxidant activity.	Johnson et al. (2024).
Humidity	Quinoa	Optimal relative humidity (40–60 %) supports healthy growth and prevents stress in quinoa cultivation.	Pathan and Siddiqui (2022)
Water Availability	Multiple microgreens	Adequate water supply enhances plant biomass and nutrient uptake; water stress reduces growth and yield.	Garg et al. (2021)
Season	General Cereal Microgreens	Seasonal variations affect the accumulation of secondary metabolites, influencing nutritional quality.	Kumar and Singh (2024)
Soil Nutrients	Various Microgreens	Nutrient-rich soils enhance the concentration of essential minerals and phytochemicals in microgreens.	Virdi et al. (2021); Kaur et al. (2021)

exposure, highlighting the dynamic sensitivity of sugar metabolism to light conditions. Similarly, previous studies revealed that changes in photoperiods caused fluctuations in soluble protein levels, with extended light exposure reducing soluble protein content (Kumar and Singh, 2024). Moreover, the same authors reported that the macro element composition, including potassium, sodium, calcium, and magnesium levels of wheat microgreens, exhibited significant increases under longer photoperiods of 22 h. In addition to mineral composition, the metabolomic profile of wheat microgreens was found to vary, with distinct metabolites being upregulated or downregulated depending on photoperiod length, suggesting that longer exposure to light can substantially alter metabolic pathways.

Virdi et al. (2021) observed that wheat microgreens exhibited variations in average height and yield under different photoperiods, with extended light exposure influencing both morphological and nutritional traits. This study demonstrated that extending the photoperiod significantly enhances the chlorophyll content of microgreens. The same study found that prolonged photoperiods, particularly 22 h, led to a decrease in soluble protein content while enhancing antioxidant potential, as reflected by increased DPPH radical scavenging activity and ferric reducing antioxidant power. These findings underscore the role of light intensity duration in modulating oxidative stress responses in wheat microgreens.

Dhaka et al. (2023) investigated the influence of growing conditions on the vegetative development of pearl millet microgreens. In their study, the plants were cultivated under warm yellow light and irrigated daily until the emergence of the first true leaves. The use of indoor grow lamps, particularly LED lighting systems, has become a common practice among microgreens growers as an alternative to natural sunlight. According to their study, LEDs offered the advantage of customizable spectral composition, enabling growers to tailor light wavelengths to optimize plant photoreceptor activity, enhance productivity, control plant morphology, and improve nutritional quality. Moreover, LED systems are highly energy-efficient and environmentally sustainable compared to traditional lighting technologies.

6.2. Growth medium

Growing medium play significant role in influencing the growth, nutritional composition, and bioactive properties of cereal-based microgreens. Virdi et al. (2021) reported that wheat microgreens exhibited significant differences in average height, yield, and antioxidant activity, such as DPPH radical scavenging capacity, when cultivated in various nutrient media. Supporting this, Kaur et al. (2021) found that wheat microgreens grown in coco peat with nutrient solution (CNS) had the highest yield (4.88 %–7.87 %) compared to those grown in soil or water. Additionally, wheat microgreens cultivated in soil showed elevated levels of key minerals like magnesium, potassium, calcium, and manganese, while those grown in CNS and water demonstrated higher contents of phosphorus, iron, copper, and sodium. Significant variability in ash, protein, and moisture content was also observed, attributed to both environmental and varietal factors. The amino acid composition was notably higher in wheat microgreens grown with CNS, whereas chlorophyll content was influenced by both the growing medium and wheat variety. Furthermore, soil grown wheat microgreens exhibited the highest levels of phenolic acids and antioxidant activity, indicating that soil fosters greater accumulation of bioactive compounds (Kaur et al., 2021).

6.3. Temperature

Temperature during growing and storage is a critical environmental factor influencing the biochemical composition, metabolomic profile, and agronomic performance of cereal-based microgreens. According to previous studies, elevated growing temperatures led to a reduction in the soluble protein content of wheat microgreens and caused notable shifts in their macro-element composition. Those studies also revealed temperature dependent differential expression of metabolites, suggesting that certain bioactive compounds are either upregulated or downregulated in response to thermal stress (Kumar and Singh, 2024). In support of these findings, Islam et al. (2021) demonstrated that wheat and barley microgreens grown under moderate day/night temperatures of 20/15 °C achieved greater height and yield compared to those cultivated at more extreme temperatures (10/5 °C and 30/25 °C), indicating the importance of thermal balance for optimal growth. Similarly, Dhaka et al. (2023) assessed the germination response of pearl millet microgreens across a temperature range of 20–30 °C and found that maximum germination rates were achieved at 28 °C. Both extremely low and high temperatures significantly reduced germination rates, confirming the sensitivity of seed development and early vegetative growth to thermal conditions. In common buckwheat, cooler temperatures combined with longer light exposure enhanced the accumulation of phytochemicals and antioxidant activity, suggesting that lower growth temperatures may improve nutritional quality (Johnson et al., 2024).

Postharvest storage temperatures also play a crucial role in preserving the nutritional quality of cereal-based microgreens. Research on Tartary buckwheat microgreens revealed that storage at lower temperatures (around 5 °C) effectively maintained their quality and shelf life. Higher storage temperatures led to increased weight loss, electrolyte leakage, and microbial growth, which negatively impacted the overall quality and reduced the shelf life of the microgreens (Bhaswant et al., 2023).

These findings underscore the need for precise temperature control during growth and storage to optimize not only yield and growth efficiency but also the nutritional and metabolic quality of cereal-based microgreens across various species.

6.4. Season

Harvesting season has a considerable impact on the phytochemical composition and pigment profile of wheat microgreens. The total chlorophyll content in wheat microgreens varied significantly between harvests conducted in different seasons, with a chlorophyll *a* to b ratio of 1:0.27 in winter and 1:0.34 in summer, indicating changes in pigment accumulation due to seasonal conditions. The phenolic acid concentrations also fluctuated with harvest time, suggesting that seasonal variations influence secondary metabolite synthesis (Kumar and Singh, 2024).

7. Functional properties and health benefits of cereal and pseudocereal microgreens

Microgreens from cereal and pseudocereal grains are emerging as functional foods due to their dense nutrient composition and favourable organoleptic properties. Some nutritional, health benefits and functional properties of microgreens are summarised in Fig. 2. These include high levels of vitamins (e.g., C, E, K), carotenoids, polyphenols, and minerals in concentrated amounts compared to their mature counterparts (Szopa et al., 2023). Their tender texture and vibrant colour add to their appeal, while their bioactive compounds such as flavonoids and phenolic acids exhibit antioxidant, anti-inflammatory, and antimicrobial properties (Castellaneta et al., 2022).

The cultivation of microgreens supports sustainable agriculture and can be integrated into vertical farming and hydroponic systems, which reduce land use and allow for year-round production with minimal resource inputs. These practices contribute to biodiversity by encouraging the use of diverse seeds, including underutilised cereals and pseudocereals. Cereal-based microgreens are increasingly valued for their role in promoting health and preventing chronic diseases. Their rich antioxidant profiles help combat oxidative stress, which is linked to conditions such as cardiovascular disease, cancer, and

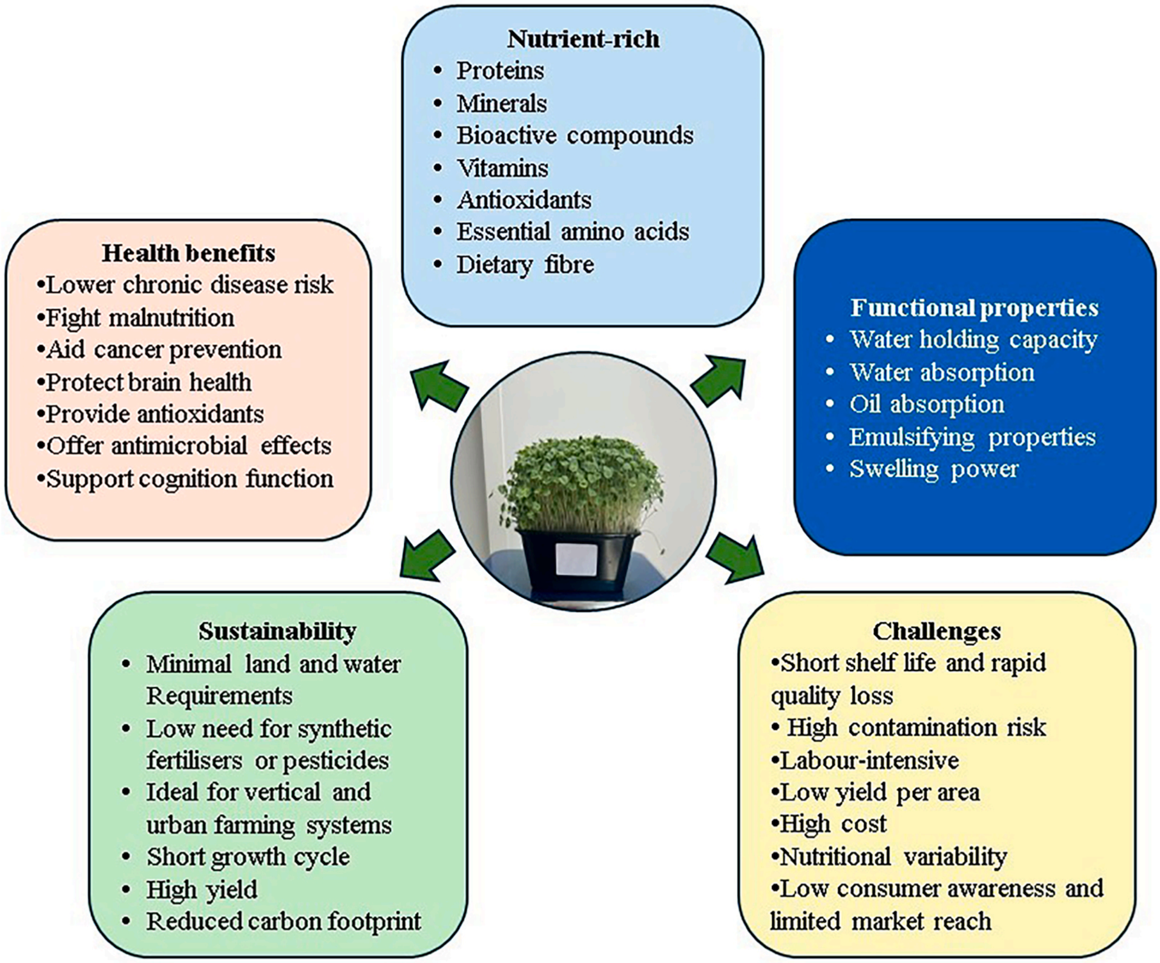

Fig. 2. Advantages and disadvantages of microgreens from cereals and pseudocereals.

Fig. 3. Food applications of microgreens from cereals and psudocereals.

neurodegenerative disorders. Some microgreens have also demonstrated potential in improving glucose metabolism, lipid profiles, and reducing inflammation, critical for managing obesity and type 2 diabetes (Bhaswant et al., 2023).

Moreover, studies have suggested that regular consumption of microgreens may support cognitive function and delay age-related cognitive decline due to their neuroprotective compounds. Their high micronutrient density (including iron, zinc, folate, and magnesium) also contributes to addressing micronutrient deficiencies, particularly in vulnerable populations or in regions with limited access to fresh produce (Kyriacou et al., 2016).

8. Food applications of cereal-based microgreens

Initially used as garnishes, cereal-based microgreens have now entered a wider range of food products (Fig. 3). They are increasingly incorporated into juices, smoothies, soups, salads, flatbreads, sandwiches, and wraps. Their appealing flavour and texture contribute significantly to sensory quality. Beyond fresh applications, they are also being developed into value-added products such as cookies, noodles, snacks, and chips, further expanding their commercial potential (Castellaneta et al., 2022; John et al., 2025). Although heat treatment during processing may lead to partial degradation of heat-sensitive compounds, several studies have reported that microgreens still enhance the nutritional profile of the final product by contributing minerals, fibre, pigments, and stable antioxidants (Bhaswant et al., 2023). Their functional and sensory contributions further support their use in value-added products. These microgreens are especially beneficial in remote or resource-limited settings where they can be cultivated indoors or under challenging conditions, supporting local food production and nutritional security (Kumar and Singh, 2024). Notably, microgreens are being considered for space nutrition due to their fast growth cycles and nutrient density, offering a potential solution for maintaining astronaut health on long-duration missions (Bhaswant et al., 2023).

9. Challenges and downsides of cereal-based microgreens

The main challenges of microgreens are listed in Fig. 2. One of the primary challenges of microgreens is their short shelf life, typically lasting only 7–14 days under optimal conditions. Their delicate tissues and high respiration rates make them highly perishable, especially in the absence of advanced cold chain logistics. Mechanical damage during post-harvest handling (e.g., washing and drying) further accelerates spoilage. Additionally, rapid senescence and low yields in cereal-based microgreens reduce their commercial viability, especially when compared to more established leafy vegetable microgreens (Bhaswant et al., 2023; Kyriacou et al., 2016).

Another significant concern is food safety. The warm, humid environments used to grow microgreens combined with dense planting and raw consumption create favourable conditions for microbial contamination, including pathogens like *E. coli* and *Salmonella*. Without stringent hygiene and safe handling practices, these products can pose health risks to consumers. Research into safer alternatives to conventional sanitising agents such as sodium hypochlorite is urgently needed (Lekshmi and Nair, 2023).

High production costs further limit scalability. Controlled environments, specialised lighting, quality substrates, and energy use lead to a higher cost of production than traditional crops. These factors make microgreens economically challenging for small-scale or resource-limited farmers (Kyriacou et al., 2016). Labour-intensive management and the need for precision in environmental parameters such as light, humidity, and temperature add further complexity (Zhang et al., 2021).

From a nutritional standpoint, the content of vitamins, minerals, and bioactive compounds in microgreens varies significantly depending on species, growth conditions, and harvest time. This nutritional variability complicates the development of consistent health claims and regulatory approvals. Moreover, there is a lack of research specifically on the nutritional properties and processing potential of cereal-based microgreens, especially in relation to drying and packaging methods.

Finally, consumer awareness and market penetration remain limited. Many consumers are unfamiliar with microgreens or view them as niche or premium products due to their price and appearance. Broader acceptance requires effective marketing and education on their nutritional benefits. In addition, the absence of standardised quality and safety regulations can further undermine consumer trust and market development.

10. Future aspects

Microgreens from cereals and pseudocereals have emerged as innovative, low-calorie sources of essential nutrients and bioactive compounds, capturing significant interest in recent years. However, several critical research gaps must be addressed to fully unlock their potential in promoting human health. These include validating their health benefits through rigorous animal models and human clinical trials, determining the bioavailability of their bioactive components, understanding their mechanisms of action on inflammatory pathways and the gut microbiome, and refining cultivation and post-harvest techniques to better preserve their nutritional value (Choe et al., 2018).

Despite the growing interest in microgreens production technology, key aspects such as pre- and post-harvest handling, packaging innovations, and strategies for shelf-life extension remain underdeveloped. While preliminary studies suggest that microgreens may help prevent and manage chronic metabolic disorders, these findings are limited and highlight the need for comprehensive, evidence-based research to confirm their health benefits and explore their potential role in personalized medicine (Bhaswant et al., 2023). Future research should focus on innovative production techniques, including genotypic analyses, seed treatments, elicitation, and biofortification, as well as enhancing post-harvest processing methods such as seed sanitation and shelf-life optimization. These advancements will require cross-disciplinary collaboration to maximize the impact of microgreens in health and nutrition.

In an exciting development, NASA scientists are investigating the potential for cultivating microgreens in space, given their ability to thrive with minimal substrates and provide fresh, nutrient-dense food sources while also enhancing oxygen production and astronaut well-being in microgravity environments. This makes microgreens a promising asset for long-duration space missions, highlighting their versatility and potential beyond Earth-bound applications (Lekshmi and Nair, 2023).

11. Conclusion

Cereal and pseudocereal-based microgreens represent a promising class of functional foods, combining high nutritional density, desirable sensory attributes, and broad applicability in both fresh and processed food products. Their rich profiles of vitamins, minerals, antioxidants, and phytochemicals position them as valuable dietary components in the prevention and management of chronic diseases such as cardiovascular disorders, diabetes, and neurodegenerative conditions. These health-promoting attributes, alongside their compatibility with sustainable and space-efficient farming systems, make them especially relevant in the context of global food and nutrition security.

Beyond their traditional use as garnishes, the incorporation of microgreens into value-added products reflects their growing market potential and adaptability to diverse culinary contexts. Their ability to be cultivated in limited spaces, including urban settings and remote environments, enhances their accessibility and relevance for populations with restricted access to fresh produce.

Continued interdisciplinary collaboration between agronomists, food scientists, and policy-makers is needed to unlock the full potential of microgreens as nutrient-dense and sustainable food ingredients and optimize their cultivation, assess varietal differences in bioactive content, and validate their long-term health effects through clinical trials. Cereal-based microgreens are an emerging class of functional foods with the capacity to contribute to global nutrition, an environmentally sustainable, and economically viable solution for future food systems.

CRediT authorship contribution statement

Samiddhi Gunathilake: Writing – original draft, Resources, Investigation, Data curation. **Supuni Aluthge:** Writing – original draft, Methodology, Investigation. **Asgar Farahnaky:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Shima Jafarzadeh:** Writing – review & editing, Validation, Methodology. **Mahsa Majzoobi:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Funding declaration

No funding to declare.

Declaration of competing interest

The authors declare no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

Altuner, F., 2024. Antioxidant activity and biochemical contents of some cereal microgreens. Cogent Food Agric. 10 (1). https://doi.org/10.1080/23311932.2024.2419426.

Bhaswant, M., Shanmugam, D.K., Miyazawa, T., Abe, C., Miyazawa, T., 2023. Microgreens—A comprehensive review of bioactive molecules and health benefits. Molecules 28 (2), 867. https://doi.org/10.3390/molecules28020867.

Bouis, H.E., Saltzman, A., 2017. Improving nutrition through biofortification: a review of evidence from HarvestPlus, 2003 through 2016. Global Food Secur. 12, 49–58. https://doi.org/10.1016/j.gfs.2017.01.009.

Castellaneta, A., Losito, I., Leoni, B., Santamaria, P., Calvano, C.D., Cataldi, T.R.I., 2022. Glycerophospholipidomics of five ddible oleaginous microgreens. J. Agric. Food Chem. 70 (7), 2410–2423. https://doi.org/10.1021/acs.jafc.1c07754.

Choe, U., Yu, L.L., Wang, T.T.Y., 2018. The science behind microgreens as an exciting new food for the 21st century. J. Agric. Food Chem. 66 (44), 11519–11530. https://doi.org/10.1021/acs.jafc.8b03096.

Dhaka, A.S., Dikshit, H.K., Mishra, G.P., Tontang, M.T., Meena, N.L., Kumar, R.R., Ramesh, S.V., Narwal, S., Aski, M., Thimmegowda, V., Gupta, S., Nair, R.M., Praveen, S., 2023. Evaluation of growth conditions, antioxidant potential, and sensory attributes of six diverse microgreens species. Agriculture 13 (3), 676. https://doi.org/10.3390/agriculture13030676.

Di Gioia, F., Hong, J.C., Pisani, C., Petropoulos, S.A., Bai, J., Rosskopf, E.N., 2023. Yield performance, mineral profile, and nitrate content in a selection of seventeen microgreen species. Front. Plant Sci. 14, 1220691. https://doi.org/10.3389/fpls.2023.1220691.

Dykes, L., Rooney, L.W., 2007. Phenolic compounds in cereal grains and their health benefits. Cereal Foods World 52 (3), 105–111. https://doi.org/10.1094/CFW-52-3-0105.

Eswaranpillai, U., Murugesan, P., Karuppiah, P., 2023. Assess the impact of cultivation substrates for growing sprouts and microgreens of selected four legumes and two grains and evaluation of its nutritional properties. Plant Sci. Today 10, 160–169. https://doi.org/10.14719/pst.2058.

Garg, M., Sharma, A., Vats, S., Tiwari, V., Kumari, A., Mishra, V., Krishania, M., 2021. Vitamins in cereals: a critical review of content, health effects, processing losses, bioaccessibility, fortification, and biofortification strategies for their improvement. Front. Nutr. 8, 586815. https://doi.org/10.3389/fnut.2021.586815.

Gulati, P., Brahma, S., Rose, D.J., 2020. Impacts of extrusion processing on nutritional components in cereals and legumes: carbohydrates, proteins, lipids, vitamins, and minerals. In: Extrusion Cooking. Elsevier, pp. 415–443. https://doi.org/10.1016/B978-0-12-815360-4.00013-4.

Gunjal, M., Singh, J., Kaur, J., Kaur, S., Nanda, V., Mehta, C.M., Bhadariya, V., Rasane, P., 2024. Comparative analysis of morphological, nutritional, and bioactive properties of selected microgreens in alternative growing medium. South Afr. J. Bot. 165, 188–201. https://doi.org/10.1016/j.sajb.2023.12.038.

Hassan, S.M., Forsido, S.F., Tola, Y.B., Bikila, A.M., Ahmed, Z., 2023. Effect of nixtamalization on the nutritional, anti-nutritional, functional, physicochemical and mineral properties of maize (Zea mays) tortillas. J. Food Chem. Nanotechnol. 9 (3), 132–140. https://doi.org/10.17756/jfcn.2023-159.

Islam, M.Z., Park, B.-J., Lee, Y.-T., 2021. Influence of temperature conditions during growth on bioactive compounds and antioxidant potential of wheat and barley grasses. Foods 10 (11), 2742. https://doi.org/10.3390/foods10112742.

John, S., Gunathilake, S., Aluthge, S., Farahnaky, A., Majzoobi, M., 2025. Unlocking the potential of chia microgreen: physicochemical properties, nutritional profile and its application in noodle production. Food Bioprocess Technol. 18, 5605–5620. https://doi.org/10.1007/s11947-025-03792-y.

Johnson, M.A., Kumar, M., Thakur, S., 2024. Effect of variation in temperature and light duration on morpho-physiology and phytochemical content in sprouts and microgreens of common buckwheat (*Fagopyrum esculentum* Moench). Plant Foods Hum. Nutr. 79, 875–885. https://doi.org/10.1007/s11130-024-01221-7.

Kaur, N., Singh, B., Kaur, A., Yadav, M.P., Singh, N., Ahlawat, A.K., Singh, A.M., 2021. Effect of growing conditions on proximate, mineral, amino acid, phenolic composition and antioxidant properties of wheatgrass from different wheat (*Triticum aestivum L.*) varieties. Food Chem. 341, 128201. https://doi.org/10.1016/j.foodchem.2020.128201.

Kumar, A., Singh, N., 2024. A systematic review exploring the variation in the compositional make-up and phytochemical constituents of wheatgrass and pulse microgreens as a function of diverse growing condition. EFood 5 (5), 1–19. https://doi.org/10.1002/efd2.70003.

Kyriacou, M.C., Rouphael, Y., Di Gioia, F., Kyratzis, A., Serio, F., Renna, M., De Pascale, S., Santamaria, P., 2016. Micro-scale vegetable production and the rise of microgreens. Trends Food Sci. Technol. 57, 103–115. https://doi.org/10.1016/j.tifs.2016.09.005.

Langyan, S., Khan, F.N., Kumar, A., 2024. Advancement in nutritional value, processing methods, and potential applications of pseudocereals in dietary food: a review. Food Bioprocess Technol. 17 (3), 571–590. https://doi.org/10.1007/s11947-023-03109-x.

Lekshmi, G., Nair, B.R., 2023. *Microgreens:* a future super food. In: Sustainable Development and Biodiversity, pp. 103–122. https://doi.org/10.1007/978-981-19-5841-0_5.

Lone, J.K., Pandey, R., Gayacharan, 2024. Microgreens on the rise: expanding our horizons from farm to fork. Heliyon 10 (4), e25870. https://doi.org/10.1016/j.heliyon.2024.e25870.

Majzoobi, M., Wang, Z., Teimouri, S., Pematilleke, N., Brennan, C.S., Farahnaky, A., 2023. Unlocking the potential of sprouted cereals, pseudocereals, and pulses in combating malnutrition. Foods 12 (21), 3901. https://doi.org/10.3390/foods12213901.

Marco, M.L., Heeney, D., Binda, S., Cifelli, C.J., Cotter, P.D., Foligné, B., Gänzle, M., Kort, R., Pasin, G., Pihlanto, A., Smid, E.J., Hutkins, R., 2017. Health benefits of fermented foods: microbiota and beyond. Curr. Opin. Biotechnol. 44, 94–102. https://doi.org/10.1016/j.copbio.2016.11.010.

Mattar, G., Haddarah, A., Haddad, J., Pujola, M., Sepulcre, F., 2022. New approaches, bioavailability and the use of chelates as a promising method for food fortification. Food Chem. 373, 131394. https://doi.org/10.1016/j.foodchem.2021.131394.

Mekonnen, G., Woldesenbet, M., Teshale, T., Biru, T., 2018. *Amaranthus caudatus* production and nutrition contents for food security and healthy living in menit shasha, menit goldya and maji districts of bench maji zone, south Western Ethiopia. Nutri. Food Sci. Int. J. 7 (3), 1–7. https://doi.org/10.19080/NFSIJ.2018.07.555712.

Mohapatra, D., Patel, A.S., Kar, A., Deshpande, S.S., Tripathi, M.K., 2019. Effect of different processing conditions on proximate composition, anti-oxidants, anti-nutrients and amino acid profile of grain sorghum. Food Chem. 271, 129–135. https://doi.org/10.1016/j.foodchem.2018.07.196.

Pathan, S., Siddiqui, R.A., 2022. Nutritional composition and bioactive components in quinoa (*Chenopodium quinoa Willd.*) greens: a review. Nutrients 14 (3), 558. https://doi.org/10.3390/nu14030558.

Reis, M.N.O., Vitorino, L.C., Lourenço, L.L., Bessa, L.A., 2022. Microbial inoculation improves growth, nutritional and physiological aspects of *Glycine max* (L.) merr. Microorganisms 10 (7), 1386. https://doi.org/10.3390/microorganisms10071386.

Sá, A.G.A., House, J.D., 2024. Protein quality of cereals: digestibility determination and processing impacts. J. Cereal. Sci. 117, 103892. https://doi.org/10.1016/j.jcs.2024.103892.

Seth, T., Mishra, G.P., Chattopadhyay, A., Deb Roy, P., Devi, M., Sahu, A., Sarangi, S.K., Mhatre, C.S., Lyngdoh, Y.A., Chandra, V., Dikshit, H.K., Nair, R.M., 2025. Microgreens: functional food for nutrition and dietary diversification. Plants 14 (4), 526. https://doi.org/10.3390/plants14040526.

Singh, A., Sharma, V., Banerjee, R., Sharma, S., Kuila, A., 2016. Perspectives of cell-wall degrading enzymes in cereal polishing. Food Biosci. 15, 81–86. https://doi.org/10.1016/j.fbio.2016.05.003.

Singh, S.M., Joshi, T.J., Sivaranjani, S., Rao, P.S., 2024. Effect of hydrothermal pre-treatment on dehulling and nutritional characteristics of kodo millet. J. Food Meas. Char. 18 (9), 7700–7713. https://doi.org/10.1007/s11694-024-02758-6.

Szopa, A., Motyka, S., Ekeirt, H., 2023. Chia sprouts and microgreens as a new nutraceutical raw materials and their health-promoting impact in modern dietetics. Curr. Issues Pharm. Med. Sci. 36 (1), 33–43. https://doi.org/10.2478/cipms-2023-0008.

Temba, M.C., Njobeh, P.B., Adebo, O.A., Olugbile, A.O., Kayitesi, E., 2016. The role of compositing cereals with legumes to alleviate protein energy malnutrition in Africa. Int. J. Food Sci. Technol. 51 (3), 543–554. https://doi.org/10.1111/ijfs.13035.

Virdi, A.S., Singh, N., Bains, K.K., Kaur, A., 2021. Effect of photoperiod and growth media on yield and antioxidant properties of wheatgrass juice of Indian wheat varieties. J. Food Sci. Technol. 58 (8), 3019–3029. https://doi.org/10.1007/s13197-020-04805-8.

Wysocka, K., Cacak-Pietrzak, G., Sosulski, T., 2025. Mineral concentration in spring wheat grain under organic, integrated, and conventional farming systems and their alterations during processing. Plants 14 (7), 1003. https://doi.org/10.3390/plants14071003.

Yohannes, T.G., Makokha, A.O., Kanensi, O.J., Tenagashaw, M.W., 2020. Developing and nutritional quality evaluation of complementary diets produced from selected cereals and legumes cultivated in gondar province, Ethiopia. Curr. Res. Nutri. Food Sci. J. 8 (1), 291–302. https://doi.org/10.12944/CRNFSJ.8.1.27.

Zhang, Yanqi, Xiao, Z., Ager, E., Kong, L., Tan, L., 2021. Nutritional quality and health benefits of microgreens, a crop of modern agriculture. J. Future Foods 1 (1), 58–66. https://doi.org/10.1016/j.jfutfo.2021.07.001.

Zhang, Yi, Massel, K., Godwin, I.D., Gao, C., 2018. Applications and potential of genome editing in crop improvement. Genome Biol. 19 (1), 210. https://doi.org/10.1186/s13059-018-1586-y.