Defence Life Science Journal, Vol. 9, No. 3, April 2024, pp. 224-232, DOI : 10.14429/dlsj.9.19203

Microgreens: A Review on Bioactive Compounds, Sensory Acceptance and Utilisation in Functional Food Development

Kritika Rawat*, Monika Jain and Aastha Pahuja
Division of Food Science and Nutrition, Banasthali Vidyapith, P.O. Banasthali Vidyapith - 304 022, Rajasthan, India
E-mail: 2kritikarawat.PhD@gmail.com

ABSTRACT

Microgreens are acquired by harvesting the upper part of a young plant within a window of 10-20 days. They are rich sources of several nutrients and antioxidants. Microgreens harbour minerals like magnesium, iron, calcium, zinc, selenium, and vitamins such as α-tocopherol and ascorbic acid. Microgreen farming is attracting vegetable growers due to its short harvesting time and customer demand. But their deterioration starts just after harvest, resulting in a low shelf-life that deters their market growth. Developing functional foods with extended shelf-life using microgreens is required to further expand their market. Microgreens-based food-products hold great potential on the market. A few attempts have been made to develop microgreens-based food-products (muffins, beverages, and cookies), yet this area is still largely undiscovered. This review aims to discuss the bioactive compounds, associated health benefits, and sensory acceptance of microgreens and explore the development of novel, healthy, and tasty microgreens-based food-products.

Keywords: Micro-scale vegetable; Antioxidant; Consumer acceptance; Nutraceutical

1. INTRODUCTION

In the past few years, new functional and nutraceutical foods have emerged as society is compelled to eat healthy foods[1]. Thus, health-promoting food-products are becoming the focal point for food-based companies. The intent of such foods is not only to satisfy the consumer's hunger but also to fill up the deficit in nutrients and maintain physical and mental well-being[2].

Microgreens are emerging as a novel category of food-products that are acquired by harvesting the aerial part of a young plantlet[3] within a timeframe of 10–20 days. They contain cotyledons, stems, and the first true leaves[4] and are usually addressed as "vegetable confetti"[1]. Figure 1 shows the growth pattern of microgreens. Commonly grown microgreens include cabbage, turnip, radish, beet, carrot, pea, broccoli, lettuce, basil, fennel, and mustard[5]. As micro-scale vegetables are a significant source of bioactive compounds, consumers are getting interested in making them part of their diet[3]. When compared to mature vegetables, microgreens are four to six times more nutritionally dense[6]. Also, microgreens are associated with multiple health benefits, viz., prevention of cardiovascular diseases, protection against oxidative stress, and chronic-diseases[7].

The vegetable growers are drawn towards micro green farming as there is high customer demand, resulting in high market value. Also, the production cycle of microgreens is very short as compared to other vegetables[6]. Despite all the positive facts, a major limitation that is associated with microgreen farming is its short shelf-life, which is just one to two days[8]. The deterioration starts instantly just after the harvesting, which directly influences the marketing[9].

The short shelf-life mandates the development of microgreen-based food-products with a good shelf-life. Although they are usually eaten raw, microgreens are well-suited for developing novel food-products. Being nutrient-dense, micro green-based food-products might help alleviate the problem of hidden hunger and ensure food security. Although there is very little exploration of this area, it possesses high market potential as health-promoting food-products are becoming popular among consumers. Hence, this review aims to discuss the bioactive compounds, associated health benefits, sensory acceptance of microgreens and explores the development of novel and healthy microgreen-based food-products.

2. BIOACTIVE COMPONENTS OF MICROGREENS

The popularity of microgreens has increased promptly in the last ten years, particularly during the COVID-19 period, as consumers are prioritising eating healthy and fresh foods. Moreover, microgreens are not only a healthy option but also add beauty to the plate. The

Received : 19 June 2023, Revised : 06 April 2024
Accepted : 19 April 2024, Online published : 21 August 2024

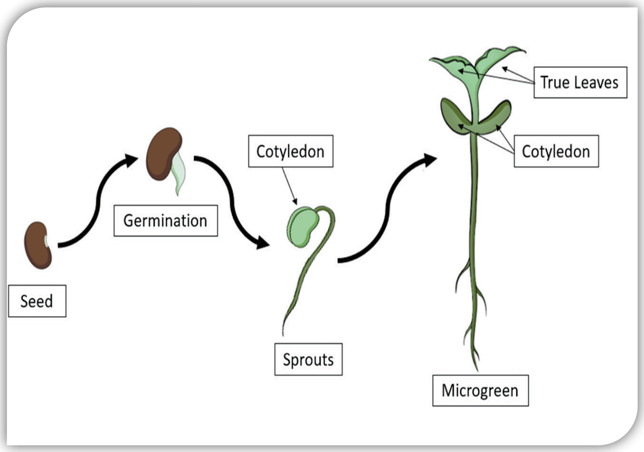

Figure 1. Growth of microgreens

presence of the health-enhancing phytonutrients such as phenolic compounds, minerals, vitamins, amino acids, and other antioxidants in microgreens makes them a suitable candidate for next-generation 'superfoods'[10]. The tissues of microgreens are an excellent source of phenolic compounds[11]. Additionally, the presence of phenols is strongly associated with astringent and bitter tastes[12]. Table 1 provides a summary of the chemical components present in different microgreen varieties.

A comprehensive analysis of polyphenols in five microgreens of *Brassica* species identified 164 polyphenols, including 105 flavonol glycosides, 30 anthocyanins, and 29 hydroxycinnamic and hydroxybenzoic acid derivatives using ultra-high-performance-liquid-chromatography[13]. Thirteen microgreen species were investigated and twenty-eight phenolic compounds were quantified, out of which 67.6 % were flavonol glycosides; while, 24.8 % were flavones and flavone glycosides, and 7.6 % were hydroxycinnamic acids and their derivatives. Total phenolic content in thirteen varieties of microgreens varied from 691 mg/kg (Swiss chard) to 5920 mg/kg (coriander)[11]. In red cabbage micro greens, the polyphenol concentration was found to be 58.57 μmol/g. Disinapoylgentiobiose, 1,2,2'-trisinapoylgentionbiose, and sinapoyl-hexose were found to be the main three polyphenols[14]. A study elucidates that *Brassicaceae* vegetables and Swiss chard are rich in flavonol glycosides and isorhamnetin-3-gentiobioside, respectively. Whereas purple basil microgreens are abundant in luteolin-malonyl-hexose and quercetin-malonyl-glucoside, green basil microgreens contain a high concentration of a pigenin. On the other hand, coriander contains 3-*O*-rutinosides of quercetin (rutin), luteolin, and kaempferol as key flavonoids[11].

The lipophilic and hydrophilic antioxidant activity of thirteen microgreen species ranged from 303.3 (jute) to 878.3 (cress) mmolTrolox/kg and 123.5 (jute) to 287.4 (kohlrabi) mmol ascorbate equivalent/kg, respectively[11]. Among six hemp cultivars, 'Finola' had the highest concentration of total polyphenols, whereas 'Silvana' had a high content of essential amino acids and cannflavin A and B[15]. Also, glucosinolates in red cabbage microgreens were found to be 17.15 μmol/g, and progoitrin and sinigrin were found in abundance among glucosinolates[14].

Among ten microgreens, the concentration of α-tocopherol (58.6 mg/100 g) was found to be highest in radish microgreens. Mustard, fennel, and sunflower microgreens were identified as rich sources of α-tocopherol, while microgreens of fenugreek exhibited the lowest concentration. Microgreen of roselle excelled as a rich source of ascorbic acid i.e., 123.2 mg/100 g, while onion microgreen had the lowest ascorbic acid i.e., 29.9 mg/100 g[16]. Another study detected ascorbic acid levels ranging from 6.48 to 128.70 mg/100 g in fourteen microgreen species. Purple-radish, broccoli, red-cabbage, lentil, and kale microgreens showed higher ascorbic acid content while microgreens of black-sesame displayed the lowest[17].

The presence of carotenoids, flavonoids, chlorophyll, and other dietary antioxidants presumably prevents cell damage, lowering the risk of degenerative illnesses[18]. A group of researchers found that the total chlorophyll content ranged from 647.3 mg/kg (mustard) to 1852.5 mg/kg (pak choi) among thirteen different varieties. Lutein and *β*-carotene ranged from 193.5 to 827.9 mg/kg and 426.1 mg/kg to 8592.2 mg/kg, respectively[11]. In a study, the chlorophyll concentration of fourteen microgreen was found to be in a range of 12.35 mg/100 g (green peas) to 112.62 mg/100 g (lentils). A similar trend was followed for carotenoid content[17]. Microgreens exhibited β-carotene content ranging from 3.1-9.1 mg/100 g, with fennel having the highest and fenugreek the lowest. Whereas, lutein was highest in microgreens of carrot and microgreens of fennel had highest chlorophyll level.[16] The red-cabbage micro greens exhibited 12.44 μmol/g total anthocyanin concentration, and cyanidin 3-(sinapoyl)(sinapoyl) sophoroside-5-glucoside, cyanidin 3-diferuloylsophoroside-5-glucoside, and cyanidin 3-(feruloyl) sophoroside-5-glucoside were abundant among anthocyanins[14].

Lettuce microgreens exhibited elevated levels of essential minerals, including magnesium, calcium, iron, zinc, selenium, manganese, and molybdenum[19]. Potassium emerged as the dominant macro-element, succeeded by phosphorus, calcium, magnesium, and sodium, in thirty microgreens belonging to the *Brassicaceae* family. Iron was most abundant among microelements, followed by zinc, manganese, and sodium. The analysis confirmed that microgreens serve as a valuable source of both macro and microelements[20]. Microgreens contain a significant amount of nutrients as well as antioxidants, including minerals, carotenoids, vitamin C, and phenolic compounds. Due to their high vitamin and phytochemical content, they possess substantial antioxidant properties and thus have the potential to regulate plasma lipoprotein and cholesterol metabolism, pointing to the possibility of preventing chronic-illnesses[21].

3. HEALTH BENEFITS OF MICROGREENS

Chronic-diseases are usually associated with one's genetic predisposition. Other than that, they can also be caused by lifestyle preferences[22]. Taking into account the well-being consciousness of the general public, microgreens are recognised as a potential functional

Table 1. Chemical components in microgreen varieties

Microgreens varieties	Bioactive compounds	Reference
Brassica species microgreens	Polyphenols (flavonol glycosides, anthocyanins, and hydroxycinnamic and hydroxbenzacid derivatives	13
Coriander microgreens	Phenols	11
Red-cabbage microgreens	Anthocyanins (cyanidin 3-(sinapoyl)(sinapoyl) sophoroside-5-glucoside, cyanidin 3-diferuloylsophoroside-5-glucoside, and cyanidin 3-(feruloyl) sophoroside-5-glucoside) and glucosinolates, polyphenols (Disinapoylgentiobiose, 1,2,2'-trisinapoylgentionbiose, and sinapoylhexose were found to be the main three polyphenols)	14
Hemp (Finola and Silvana) microgreens	Total polyphenols, essential amino acids and cannflavin A and B	15
Mustard, fennel, and sunflower microgreens	α-Tocopherol	16
Roselle microgreens	Ascorbic acid	16
Purple-radish, broccoli, red-cabbage, lentil, and kale microgreens	Ascorbic acid	17
Pak choi microgreens	Total chlorophyll content	11
Lentils microgreens	Chlorophyll, carotenoids	17
Fennel microgreens	β-carotene, chlorophyll	14
Carrot microgreens	Lutein	14
Lettuce microgreens	Magnesium, calcium, iron, zinc, selenium, manganese, and molybdenum	19
Brassicaceae family microgreens	Macroelements: Potassium, phosphorus, calcium, magnesium, and sodium Microelements: Iron, zinc, manganese, and sodium	20

food that may be used as a dietary ingredient to enhance general health[23]. Several studies have investigated the health-promoting potential of microgreens. For instance, fenugreek microgreen extract was observed to hinder the activity of α-amylase in the pancreas and increase glucose uptake by L6 myotubes[24], which is a potential strategy to manage type 2 diabetes mellitus[25]. Animals fed on a fat-rich diet supplemented with red-cabbage microgreens had substantially lower low-density lipoprotein levels as compared to animals fed on a high-fat diet[14]. Micro greens of the *Brassicaceae* family showed ant proliferative effects on tumoral cells after being exposed to *in-vitro*-gastrointestinal digestion[26].

Another study suggested that green pea, radish, soybean, rocket, and red Rambo radish microgreens extracts showed anti-proliferation of sarcoma RD-ES and A673 cell lines in 2D. The study confirmed the anti-tumour potential and pro-apoptotic effect exhibited by green pea microgreens attributed to the presence of polyphenol fractions[27].

Microgreens of red-cabbage contain sinapine[28] which improved gut health in mice on a high-fat diet and prevented gut dysbiosis[29]. The cannflavins in hemp cultivars[15] demonstrated antioxidative and anti-inflammatory properties by reducing the production of prostaglandin E2 and leukotriene production[30]. The *Brassicaceae* micro greens contain a significant amount of glucosinolates[14]. Glucosinolates are sulphur-containing secondary plant metabolites[31] and they are precursors of isothiocyanates, substances with anti-tumour effects[26]. Apparently, the intake of microgreens lowers the risks of chronic-illness and maintains gut health contributing to the overall health of an individual, due to the presence of bioactive compounds.

4. SENSORY ACCEPTANCE OF MICROGREENS

The emerging culinary trends significantly impact the supply and demand of microgreens, whereas the decision of species selection by the producer is greatly influenced by consumers' familiarity with the sensory attributes of particular species[1]. Indeed, incorporating microgreens into salads is an intelligent approach for enhancing the visual appeal and overall quality of the food[12]. Researchers stated that fenugreek microgreens are a preferable option to bitter fenugreek seeds because they are more comfortable to eat and have a high bioavailability of phytochemicals[24]. Table 2 presents the sensory acceptance of various microgreen varieties.

The researchers observed that out of six varieties, five were rated excellent for appearance acceptability. Moreover, bull's blood beet scored highest for overall acceptability, whereas pepper cress scored lowest. Pepper cress scored highest for bitterness, astringency, heat, and sourness, which resulted in its lowest flavour acceptability. Microgreens with high concentrations of

Table 2. Sensory acceptance of various microgreen varieties

Reference	Microgreen	Growth media	Highest score	Appearance acceptability	Flavour acceptability	Overall acceptability
32	Dijon mustard	Peat moss	100	86.2	54.9	61.0
	Opal basil			55.9	46.0	49.0
	Bull's blood beet			86.4	66.9	76.5
	Red amaranth			82.5	59.1	63.1
	Peppercress			77.8	39.5	39.7
	China rose radish			72.7	52.5	53.7
33	Broccoli microgreens	Commercial hydroponics	7	3.09 ± 1.27	-	3.60 ± 1.41
		Farm soil		5.53 ± 1.05	-	5.00 ± 1.15
		Farm hydroponics		5.24 ± 0.97	-	4.85 ± 1.15
12	Komatsuna	Peat moss substrate	15	8.8	6.6	7.9
	Tatsoi			9.6	6.2	7.5
	Pak choi			8.6	6.7	7.9
	Cress			6.2	3.9	4.8
	Mibuna			8.7	3.6	4.5
	Mizuna			8.9	6.7	7.2
	Swiss chard			8.5	8.5	8.1
	Amaranth			8.9	2.5	3.0
	Coriander			11.4	7.9	8.1
	Green basil			9.2	6.0	7.3
	Purple basil			9.1	5.0	6.0
	Pursane			6.6	7.0	6.7
4	Arugula	Coir fiber	9	8.0	5.8	6.0
	Broccoli			8.1	7.4	7.5
	Bull's blood beet			8.4	6.4	6.7
	Red cabbage			8.5	7.3	7.5
	Red garnet			8.6	6.6	7.2
	Tendril pea			7.7	7.8	7.9

gluco sinolates scored highly for bitterness. A strong correlative relationship was observed between overall eating quality and flavour acceptability[32].

An investigation was undertaken to assess the acceptance of farm-grown and commercially-grown microgreens. Results inferred that local soil-grown microgreens scored highest for different sensory attributes. The microgreens cultivated on the farms obtained scores ranging from 4.54 to 5.38 out of 7 for all the sensory attributes, while the commercially grown ones received scores in the range of 3.09 to 5.38. The researchers concluded that sensory qualities and nutritional quality both significantly influence the purchase intent of the consumer[33].

The analysis of the sensory parameters of the twelve microgreens inferred that the acceptability of micro greens was largely affected by their sensory attributes. Results indicated that the appearance resulted in high consumer appreciation; on the other hand, the overall acceptability was influenced by the flavour and texture. Particularly, microgreens that displayed reduced levels of sourness, astringency, and bitterness were well-received among participants. Among all the varieties, cress and mibuna were accepted the least, whereas coriander and Swiss chard were highly accepted[12]. Acceptance of broccoli microgreens grown in commercial, local soil-grown, hydroponically-grown, and local hydroponically-grown was assessed. Locally grown microgreens, regardless of the medium, were favoured by the panel. In contrast, commercially grown microgreens scored the lowest for all sensory characteristics[34].

The acceptability and sensory perception of six micro green species were evaluated. It was observed that all species were found to be acceptable. Microgreen species that were red in colour scored highest for appearance acceptability. For flavour acceptability, tendril pea microgreens scored highest; however, arugula microgreens scored lowest. A similar trend was observed for overall acceptability. The data from principal component analysis revealed a positive association between high acceptability and high purchase intent by the consumer. On the other hand, a negative association was observed between high acceptability and food neophobia. The results of the study also stated a relationship between purchase intent and awareness about microgreens[4].

From the sensory assessment data of microgreens, it can be inferred that acceptance and willingness to purchase microgreens are majorly affected by sensory attributes, especially appearance, and flavour. Also, awareness about microgreens among consumers may potentially increase their purchases.

5. FUNCTIONAL FOODS DEVELOPED USING MICROGREENS

Consumers are in search of a product that contributes to health benefits. Many consumers believe that they have unique nutritional needs that drive them towards personalised diets. Hence, if they find a new food product relevant to their lifestyle, they tend to become early adopters of the product. Consumers' beliefs about health and food are a major cause of the emergence of new brands in the market, which creates opportunities for product developers and entrepreneurs. Also, it is essential to maintain the organoleptic properties of formulated functional food-products as it impacts their acceptance amongst consumers[35]. Functional foods are perceived as health-enhancing products designed to positively impact biological functions beyond regular food by providing physiologically active substances. To develop such foods, it is crucial to preserve organoleptic properties, extend shelf-life, and ensure the stability of the functional ingredient[36]. The utilisation of microgreens can be done to develop novel functional food-products. Although not many studies are present that explores the potential substitution of microgreens in order to develop novel food-products. Table 3 summarises the food-products formulated by utilising different microgreen species.

Baked goods become a potential candidate to develop functional foods as they are enjoyed around the globe[35]. A high-fibre and antioxidant-rich muffin was prepared by incorporating wheatgrass powder. As muffins are consumed globally, they could be potential carriers of bioactive compounds and dietary fibre. The moisture, total dietary fibre, protein, ash, and total phenolic content of muffins showed a substantial augmentation with the increase in wheatgrass incorporation, whereas, carbohydrates and fat content showed a decreasing trend. Also, the increased total phenolic content contributes to increasing antioxidant activity with an increase in WG supplementation[37]. Likewise, wheatgrass and beetroot-fortified wheat flour cupcakes were prepared. Chemical analysis revealed that carbohydrate content decreased after beetroot and wheatgrass fortification, whereas protein, ash, and dietary fibre followed an increasing pattern[38]. In order to prepare a protein- and iron-rich food product, wheat flour cookies were incorporated with multi-grain flour and wheatgrass powder. The proximate analysis revealed a hike in moisture, protein, fat, and ash content, whereas carbohydrate content decreased with increasing supplementation of wheatgrass[39]. By incorporating powder of wheatgrass and mung-bean microgreens in rice flour, gluten-free eggless-muffins were prepared. Wheatgrass and mung-bean incorporated muffins had higher contents of protein, dietary fibre, flavonoids, phenolics, and antioxidant properties. Muffins with wheatgrass were found to be abundant in total, free, and bound phenolic acids, whereas muffins with mung-beans had higher total, free, and bound flavonoids[40].

A group of researchers optimised a microgreen-based juice containing fenugreek micro greens, kinnow-mandarin, aloe vera, sorbitol, and stevia. The optimised beverage had high protein, vitamin C, sodium, and potassium content. Also, a substantial amount of phenols, beta-carotene, and antioxidants were present in the beverage[41]. Similarly, another group of researchers optimised a microgreen-fruit-based beverage using Response Surface Methodology (RSM), which comprises spinach microgreen, pomegranate, pineapple, and sugar. A significant amount of protein, potassium, sodium, iron, vitamin C, total carotenoids, and total phenols were reported in the optimised beverage. In addition, the beverage showed high antioxidant activity. The presence of bioactive compounds in the beverage has anti-inflammatory potential[42]. Soups are usually consumed as appetisers. Instant soups are dried foods that are protected from enzymatic and oxidative spoilage. The optimisation of the wheatgrass soup mix was done using RSM. The developed soup was found to have beneficial characteristics when compared to commercial instant soups. The protein, fibre, total phenolics, total flavonoids, and DPPH activity surpassed in the optimised soup. Hence, due to the presence of enhanced nutrients, wheatgrass instant soup can be classified as a potential functional food[43].

Researchers aimed to prepare wheatgrass-based functional pasta. Pasta was prepared by supplementing wheatgrass juice. With the incorporation of wheatgrass juice, the optimum cooking duration of pasta was decreased, however, an increment was observed in water absorption capacity. The incorporation of wheatgrass juice enhanced the nutritional quality and antioxidant activity of pasta. An evident increase in protein, phenolics, flavonoids, chlorophyll, and antioxidant activity was observed in wheatgrass-fortified pasta[44]. Thus, it comes to light that the incorporation of microgreens enhanced the nutritional and antioxidant quality of the formulated foods, and their consumption will potentially enhance the well-being of the individuals.

6. FUTURE APPROACHES

Microgreens are an entirely new category of edible plants that may alleviate a variety of deficiencies and dramatically improve one's health. The biochemical composition leads to the conclusion that microgreens can treat a variety of diseases. Hence, it can be an interesting health-promoting food option for humans[45]. Food items with antioxidant potential may play a crucial

Table 3. Formulated food-products by utilising different microgreen species

Formulated products	Ingredients	Best selected proportion	Enhanced Nutrients and bioactive compounds	References
Wheatgrass powder in corporated muffins	Wheat flour, milk, butter, sugar, baking powder and soda, vanilla flavour, and salt	Wheat flour (95%) and wheatgrass powder (5%)	Phenolic compounds	37
Beetroot and wheatgrass incorporated cup-cakes	Wheat flour, shortening, baking powder, milk, sugar, beetroot and wheatgrass powder, and vanilla essence	T1 {wheat flour (90%), beetroot (5%) and wheatgrass powder (5%)}	Protein, fat, ash, dietary fibre	38
Microgreen fruit-based beverage	Fenugreek microgreen juice, kinnow-mandarian juice, aloevera juice, sorbitol and stevia	Fenugreek microgreen juice (15%), kinnow-mandarian juice (55%) and aloe vera juice (21.5%)	Protein, sodium, potassium, vitamin C, beta-carotene, phenols	41
Microgreen fruit-based beverage	Spinach microgreen juice, pomegranate juice, pineapple juice and sugar	Spinach microgreen juice (15%), pomegranate juice (66.82%), pineapple juice (16.18%)	Protein, potassium, iron, sodium, vitamin C, total phenols total carotenoids	42
Cookies incorporated with wheatgrass powder	Multigrain flour (ragi, soybean, whole wheat, jowar, Bengal gram, bajra and oats), wheatgrass powder, jaggery powder, shortenings, milk, baking powder	T1 {multigrain atta (95%) and wheatgrass powder (5%)}	Protein, fat, and ash	39
Wheatgrass based instant soup mix	Wheatgrass powder, dried tomato, wheat bran, and spice mix	Wheatgrass powder (0.80 g), tomato powder (5.18 g), wheat bran (0.84 g)	Protein, fat, crude fibre	43
Muffins incorporated with wheatgrass and mung-bean micro greens powder	Wheatgrass/mung-bean Micro greens powder, rice flour, sugar, baking powder, oil, and protein emulsion	Muffin with 2% wheatgrass powder incorporation	Protein, ash, fat, dietary fibre, total phenolic and flavonoids	40
Wheatgrass juice incorporated pasta	Wheatgrass juice added during mixing process	Pasta prepared using 100% wheatgrass juice	Protein, ash, fibre, total phenolic and flavo noids, and total chlorophyll	44

role in fighting against illnesses caused by oxidative stress. Recently, interest has developed in designing new functional foods that, besides providing basic nutrition, additionally provide health-benefits[46]. Over the past decades, even space agencies have recognised functional foods as a potential food to improve the health quality of space programme participants[2]. Several researchers have explored the potential of microgreens as 'beyond the earth's diet', due to the fact that they can be easily grown in the spacecraft environment and have a short growing period[47]. Microgreens are gluten-free[40] so they can be used to develop functional foods targeting celiac disease patients. Microgreens can, therefore, be used as an ingredient to develop functional foodstuff or beverages.

Microgreens experienced acceptance among consumers; similarly, microgreen-based functional foods hold great market potential due to their enhanced shelf-life, taste, and ability to fulfil consumer's needs. Further utilisation of microgreens in developing food-products will enhance the depth of knowledge about their ability to prevent chronic-diseases, and animal or human trials can be carried out in order to support the claim. Microgreen-based food-products are a growing research aspect, as a few studies are present about them, and hence there is good scope in the coming future.

7. CONCLUSION

Microgreens are gaining popularity as they contain high-levels of antioxidants and nutrients that are linked to health-promoting effects. Bioactive compounds contribute to the prevention of chronic-illness, but the short shelf-life contributes as a limiting factor in the market value. Thus, to expand the microgreens market, it becomes crucial to develop food-products with a good shelf-life and good taste in order to maintain consumer acceptance. Various endeavours have been undertaken to develop food-products by utilising microgreens. But only a few studies are present, and there is great scope for further research. In a nutshell, this review article provides insight into the bioactive components, health-benefits, sensory acceptance, and utilisation of microgreens in different food-products.

REFERENCES

1. Kyriacou, M.C.; Rouphael, Y.; Di Gioia, F.; Kyratzis, A.; Serio, F.; Renna, M.; De, Pascale, Stefania & Santamaria, Pietro. Micro-scale vegetable production and the rise of microgreens. *Trends Food Sci. Technol.,* 2016, **57**(11), 103-15. doi: 10.1016/j.tifs.2016.09.005
2. Vergari, F.; Tibuzzi, A. & Basile, G. An overview of the functional food market: From marketing issues and commercial players to future demand from life in space. In bio-farms for nutraceuticals: Advances in experimental medicine and biology, edited by M.T. Giardi, G. Rea & B. Berra. Springer, New York, NY, 2010, pp. 308-321. doi: 10.1007/978-1-4419-7347-4_23
3. Petropoulos, S.A.; El-Nakhel, C.; Graziani, G.; Kyriacou, Marios & Rouphael, Youssef. The effects of nutrient solution feeding regime on yield, mineral profile, and phytochemical composition of spinach microgreens. *Horticulturae,* 2021, **7**(7), 162-76. doi: 10.3390/horticulturae7070162
4. Michell, K.A.; Isweiri, H.; Newman, S.E.; Bunning, M.; Bellows, L.L.; Dinges, M.M.; Grabos, L.E.; Rao, S.; Foster, M.T.; Heuberger, A.L.; Prenni, J.E.; Thompson, H.J.; Uchanski, M.E.; Weir, Tiffany & Johnson Sarah. Microgreens: Consumer sensory perception and acceptance of an emerging functional food crop. *J. Food Sci.,* 2020, **85**(4), 926-35. doi: 10.1111/1750-3841.15075
5. Stoleru, T.; Ionita, Alexandrina & Zamfirache, Maria-Magdalena. Microgreens—A new food product with great expectations. *Rom. J. Biol.,* 2016, **61**(1&2), 7-16.
6. Li, T.; Lalk, G.T.; Arthur, J.D.; Johnson, Madeline & Bi, Guihong. Shoot production and mineral nutrients of five microgreens as affected by hydroponic substrate type and post-emergent fertilization. *Horticulturae,* 2021, **7**(6), 129-46. doi: 10.3390/horticulturae7060129
7. Mishra, G.P.; Dikshit, H.K.; Aski, M.; Sangwan, S.; Stobdan, T.; Singh, A. & Praveen, S. Microgreens: A novel food for nutritional security. In conceptualizing plant-based nutrition: Bioresources, nutrients repertoire and bioavailability, edited by S. V. Ramesh & S. Praveen. Springer Nature, Singapore, SG, 2022, pp. 123-156. doi: 10.1007/978-981-19-4590-8_7
8. Xiao, Z.; Lester, G.E.; Luo, Yaguang & Wang, Qin. Assessment of vitamin and carotenoid concentrations of emerging food-products: edible microgreens. *J. Agric. Food Chem*., 2012, **60**(31), 7644-51. doi: 10.1021/jf300459b
9. Mir, S.A.; Shah, Manzoor, Ahmad & Mir, Mohammad, Maqbool. Microgreens: Production, shelf-life, and bioactive components. *Crit. Rev. Food Sci. Nutr.,* 2017, **57**(12), 2730-36. doi: 10.1080/10408398.2016.1144557
10. Bhaswant, M.; Shanmugam, D.K.; Miyazawa, T.; Abe, Chizumi & Miyazawa, Teruo. Microgreens- A Comprehensive-Review of Bioactive Molecules and Health Benefits. *Molecules,* 2023, **28**(2), 867-91. doi: 10.3390/molecules28020867
11. Kyriacou, M.C.; El-Nakhel, C.; Graziani, G.; Pannico, A.; Soteriou, G.A., Giordano, M., Ritieni, A.; De, Pascale, Stefania & Rouphael, Youssef. Functional quality in novel food sources: Genotypic variation in the nutritive and phytochemical composition of thirteen microgreens species. *Food Chem.,* 2019, **277**(3), 107-18. doi: 10.1016/j.foodchem.2018.10.098
12. Caracciolo, F.; El-Nakhel, C.; Raimondo, M.; Kyriacou, M.C.; Cembalo, L.; De, Pascale, Stefania & Rouphael, Youssef. Sensory attributes and consumer acceptability of 12 microgreens species. *Agronomy,* 2020, **10**(7), 1043-58. doi: 10.3390/agronomy10071043
13. Sun, J.; Xiao, Z.; Lin, L.Z.; Lester, G.E.; Wang, Q.; Harnly, James & Chen, Pei. Profiling polyphenols in five Brassica species microgreens by UHPLC-PDA-ESI/HRMS. *J. Agric. Food Chem.,* 2013, **61**(46), 10960-10970. doi: 10.1021/jf401802n
14. Huang, H.; Jiang, X.; Xiao, Z.; Yu, L.; Pham, Q.; Sun, J.; Chen, P.; Yokoyama, W.; Yu, L.L.; Lou Yaguang, Sunny & Wang, Thomas. Red cabbage microgreens lower circulating Low-Density Lipoprotein (LDL)ALRI, liver cholesterol, and inflammatory cytokines in mice fed a high-fat diet. *J. Agric. Food Chem.,* 2016, **64**(48), 9161-71. doi: 10.1021/acs.jafc.6b03805
15. Pannico, A.; Kyriacou, M.C.; El-Nakhel, C.; Graziani, G.; Carillo, P.; Corrado, G.; Ritieni, A.; Rouphael, Youssef & De, Pascale, Stefania. Hemp microgreens as an innovative functional food: Variation in the organic acids, amino acids, polyphenols, and cannabinoids composition of six hemp cultivars. *Food Res. Int*., 2022, **161**(11), 111863. doi: 10.1016/j.foodres.2022.111863
16. Ghoora, M.D.; Babu, Dandamudi, Rajesh & Srividya, Nagarajan. Nutrient composition, oxalate content and nutritional ranking of ten culinary microgreens. *J. Food Compost. Anal*., 2020, **91**(4), 103495-505. doi: 10.1016/j.jfca.2020.103495
17. Kowitcharoen, L.; Phornvillay, S.; Lekkham, P.; Pongprasert, Nutthachai & Srilaong, Varit. Bioactive composition and nutritional profile of microgreens cultivated in Thailand. *Appl. Sci.,* 2021, **11**(17), 7981-90. doi: 10.3390/app11177981
18. Toydemir, G.; Subasi, B.G.; Hall, R.D.; Beekwilder, J.; Boyacioglu, Dilek & Capanoglu, Esra. Effect of food processing on antioxidants, their bioavailability and potential relevance to human health. *Food Chem. X*; 2022, **14**(6), 1-15. doi: 10.1016/j.fochx.2022.100334
19. Pinto, E.; Almeida, A.A.; Aguiar, Ana & Ferreira, Isabel. Comparison between the mineral profile and nitrate content of microgreens and mature lettuces. *J.*

Food Compos. Anal., 2015, **37**(2), 38-43. doi: 10.1016/j.jfca.2014.06.018

20. Xiao, Z.; Codling, E.E.; Luo, Y.; Nou, X.; Lester, Gene & Wang, Qin. Microgreens of *Brassicaceae*: Mineral composition and content of 30 varieties. *J. Food Compos. Anal.,* 2016, **49**(6), 87-93. doi: 10.1016/j.jfca.2016.04.006
21. Zhang, Y.; Xiao, Z.; Ager, E.; Kong, Lingyan & Tan, Libo. Nutritional quality and health benefits of microgreens, a crop of modern agriculture. *J. Future Foods,* 2021, **1**(1), 58-66. doi: 10.1016/j.jfutfo.2021.07.001
22. Jambor, T.; Knizatova, N.; Valkova, V.; Tirpak, F.; Greifova, H.; Kovacik, Anton & Lukac, Norbert. Microgreens as a functional component of the human diet: A review. *J. Microbiol. Biotechnol. Food Sci.,* 2022, **12**(1), 1-5. doi: 10.55251/jmbfs.5870
23. Sharma, S.; Shree, B.; Sharma, D.; Kumar, S.; Kumar, V.; Sharma, Rakesh & Saini, Rajni. Vegetable microgreens: The gleam of next-generation superfoods, their genetic enhancement, health benefits, and processing approaches. *Food Res. Int.,* 2022, **155**(5), 1-8. doi: 10.1016/j.foodres.2022.111038
24. Wadhawan, S.; Tripathi, Jyoti & Gautam, Satyendra. *In vitro* regulation of enzymatic release of glucose and its uptake by Fenugreek microgreen and Mint leaf extract. *Int. J. Food Sci. Technol*., 2018, **53**(2), 320-26. doi: 10.1111/ijfs.13588
25. Khamis, M.; Talib, F.; Rosli, N.S.; Dharmaraj, S.; Mohd, K.S.; Srenivasan, S.; Abdul, Latif, Zubaidi & Utharkar, Mahadev, Rao . In vitro α-amylase and α-glucosidase inhibition and increased glucose uptake of *Morindacitrifolia* fruit and scopoletin. *Res. J. Pharm. Technol.,* 2015, **8**(2), 189-93. doi: 10.5958/0974-360x.2015.00034.7
26. De-la Fuente, B.; López-García, G.; Máñez, V.; Alegría, A.; Barberá, Reyes & Cilla, Antonio. Antiproliferative effect of bioaccessible fractions of four *Brassicaceae* microgreens on human colon cancer cells linked to their phytochemical composition. *Antioxidants,* 2020, 9(5), 1-15. doi: 10.3390/antiox9050368
27. Truzzi, F.; Whittaker, A.; Roncuzzi, C.; Saltari, A.; Levesque, Mitchell & Dinelli, Giovanni. Microgreens: Functional food with antiproliferative cancer properties influenced by light. *Foods*, 2021, **10**(8), 1-20. doi: 10.3390/foods10081690
28. Johnson, S.A.; Prenni, J.E.; Heuberger, A.L.; Isweiri, H.; Chaparro, J.M.; Newman, S.E.; Uchanski, M.E.; Omerigic, H.M.; Michell, K.A.; Bunning, M.; Foster, M.T.; Thompson, Henry & Weir, Tiffany. Comprehensive evaluation of metabolites and minerals in 6 microgreen species and the influence of maturity. *Curr. Dev. Nutr.,* 2021, **5**(2), 180-92. doi: 10.1093/cdn/nzaa180
29. Li, Y.; Xu, Y.J.; Tan, Chin, Ping & Liu, Yuanfa. Sinapine improves LPS-induced oxidative stress in hepatocytes by down-regulating MCJ protein expression. *Life Sci*., 2022, **306**(4), 1-12. doi: 10.1016/j.lfs.2022.120828
30. Bautista, J.L.; Yu, Shu & Tian, Li. Flavonoids in *Cannabis sativa*: Biosynthesis, bioactivities, and biotechnology. *ACS Omega*, 2021, **6**(8), 5119-23. doi: 10.1021/acsomega.1c00318
31. Alrifai, O.; Mats, L.; Liu, R.; Hao, X.; Marcone, Massimo & Tsao, Rong. Effect of combined light-emitting diodes on the accumulation of glucosinolates in Brassica microgreens. *Food Production, Processing and Nutrition,* 2021, **3**(1), 1-16. doi: 10.1186/s43014-021-00072-y
32. Xiao, Z.; Lester, G.E.; Park, E.; Saftner, R.A.; Luo, Yaguang & Wang, Qin. Evaluation and correlation of sensory attributes and chemical compositions of emerging fresh produce: Microgreens. *Postharvest Biol. Technol.,* 2015, **110**(12), 140-48. doi: 10.1016/j.postharvbio.2015.07.021
33. Tan, L.; Nuffer, H.; Feng, J.; Kwan, S.H.; Chen, H.; Tong, Xiao & Kong, Lingyan. Antioxidant properties and sensory evaluation of microgreens from commercial and local farms. *Food Sci. Hum. Wellness*, 2020, **9**(1), 45-51. doi: 10.1016/j.fshw.2019.12.002
34. Chen, H.; Tong, X.; Tan, Libo & Kong, Lingyan. Consumers' acceptability and perceptions toward the consumption of hydroponically and soil grown broccoli microgreens. *J. Agric. Food Res*., 2020, **2**(5), 1-9. doi: 10.1016/j.jafr.2020.100051
35. Birch, Catherine & Bonwick, Graham. Ensuring the future of functional foods. *Int. J. Food Sci. Technol*, 2019, **54**(5), 1467-85. doi: 10.1111/ijfs.14060
36. Williams, J.; D'Cunha, N.M.; Kellett, J.; Georgousopoulou, E.V.; McKune, A.J.; Mellor, Duane & Naunovski, Nenad. Physicochemical, antioxidant and sensory properties of mango sorbet containing L-theanine as a potential functional food product. *J. Food Sci. Technol*., 2022, **59**(12), 4833-43. doi: 10.1007/s13197-022-05570-6
37. Rahman, R.; Hiregoudar, S.; Veeranagouda, M.; Ramachandra, C.T.; Nidoni, U.; Roopa, R.S.; Kowalski, Ryan & Ganjyal, Girish. Effects of wheat grass powder incorporation on physiochemical properties of muffins. *Int. J. Food Prop.,* 2015, **18**(4), 785-95. doi: 10.1080/10942912.2014.908389
38. Sharma, S.; Peter, S.; Parimita; Phughe, Trupti & Ahmad, Sarfraz. Studies on cupcakes incorporated with beetroot and wheatgrass powder. *Int. J. Food Sci. Nutri.,* 2019, **4**(4),206-8. doi:10.13140/RG.2.2.29619.17443
39. Shashank, V.M.; Kiran, P.S.; Sunil, B.; Kumar, Anand & Sowjanya, Salla. Development of multigrain cookies by incorporating wheatgrass powder. *Int. J. Chem. Stud.,* 2021, **9**(1), 866-69. doi: 10.22271/chemi.2021.v9.i1l.11336

40. Kaur, N.; Singh, Balwinder & Kaur, Amritpal. Influence of wheatgrass and mung-bean microgreens incorporation on physicochemical, textural, sensory, antioxidant properties and phenolic profile of gluten-free eggless rice muffins. *Int. J. Food Sci. Technol.,* 2022, **57**(5), 3012-20.
doi: 10.1111/ijfs.15625
41. Sharma, P.; Sharma, A.; Rasane, P.; Dey, A.; Choudhury, A.; Singh, J.; Kaur, S.; Dhawan, Kajal & Kaur, Damanpreet. Optimization of a process for microgreen and fruit-based functional beverage. *An. Acad. Bras. Cienc.,* 2020, **92**(3), 1-15.
doi: 10.1590/0001-3765202020190596
42. Sharma, A.; Rasane, P.; Dey, A.; Singh, J.; Kaur, S.; Dhawan, K.; Kumar, Ashwani & Joshi, Hari, Shankar. Optimization of a process for a microgreen and fruit-based ready-to-serve beverage. *Int. J. Food Stud*., 2021, **10**(2), 141-56.
doi: 10.7455/ijfs/10.si.2021.a4
43. Jabeen, N.M.; Kumar, G.P.; Devanna & Manjunath. Development and optimization of wheatgrass-based instant soup mix using response surface methodology. *Int. J. Food Nutr. Sci.,* 2021, **10**(1), 10-15.
doi: 10.4103/ijfans.ijfans_5_21
44. Bawa, K.; Singh, A.; Brar, J.K.; Surasani, Vijay, Kumar, Reddy & Pandiselvam, Ravi. Influence of wheatgrass juice on techno-functional properties and bioactive characteristics of pasta. *J. Food Qual.,* 2022, **2022**(8), 1-12.
doi: 10.1155/2022/3891983
45. Rizvi, A.; Sharma, Monica & Saxena, Sangeeta. Microgreens: A Next Generation Nutraceutical for Multiple Disease Management and Health Promotion. *Genet. Resour. Crop Evol.,* 2022, **70**(12), 311-32.
doi: 10.1007/s10722-022-01506-3
46. Hajira, Bibi & Khan, Imran. Effect of sorghum and barley-containing bread on plasma total polyphenols, antioxidant status and inflammation in healthy subjects. *J. Food Sci. Technol.,* 2022, **59**(12), 4935-44.
doi: 10.1007/s13197-022-05582-2
47. Teng, Z.; Luo, Y.; Pearlstein, D.J.; Wheeler, R.M.; Johnson, C.M.; Wang, Qin & Fonseca, Jorge. Microgreens for Home, Commercial, and Space Farming: A comprehensive update of the most recent developments. *Annu. Rev. Food Sci. Technol.,* 2022, **14**(12), 539-62.
doi: 10.1146//annurev-food-060721-024636

CONTRIBUTORS

Ms Kritika Rawat obtained her Master of Science degree with major in Foods and Nutrition from Govind Ballabh Pant University of Agriculture & Technology, Pantnagar, Uttarakhand. Presently, She is working as a Research Scholar in the Division of Food Science and Nutrition, Banasthali Vidyapith, Rajasthan. Her area of interests include: analysis of food and product development. For this article, she was involved in manuscript writing.

Dr Monika Jain is working as a Professor in the Division of Food Science and Nutrition, Banasthali Vidyapith, Rajasthan. Her research interests include: public health nutrition, micronutrients malnutrition, sensory analysis, and food product development. For this article, she was involved in improving the manuscript grammatically and proof reading.

Ms Aastha Pahuja obtained her Master of Science degree from Banasthali Vidyapith, Rajasthan. Presently, She working as a Research Scholar in the Division of Food Science and Nutrition, Banasthali Vidyapith, Rajasthan. Her area of interests includes public health nutrition, and product development.
For this work she contributed in the preparation of the image, manuscript reviewing, and made intellectual contributions in manuscript writing.