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Review

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Unveiling microgreens: a comprehensive review on their nutritive value, functional benefits, and shelf life

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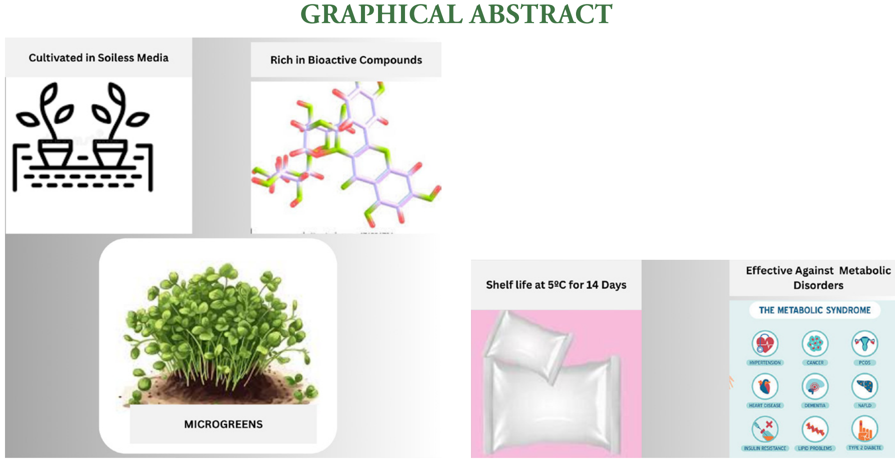
ABSTRACT: In recent years, demand and interest among consumers have increased for functional foods to avoid the risk of diseases. Latest agricultural practices have given several foods with high nutritional value. Microgreens are one of them with good nutraceutical potential. The current study aims to review the methods through which microgreens can be grown efficiently at a home scale and at the commercial level, their nutritional value, and health benefits. This study also focuses on methods of extending their shelf life through storage and packaging for sustained consumer benefits. Growth of microgreens can be facilitated under diverse medium cocopeat, rice husk, soil, or water. Beyond their rapid growth, microgreens offer a rich source of antioxidants, presenting a nutritional profile superior to that of mature plants. These greens boast substantial quantities of vitamins, minerals, phylloquinone, phenolic antioxidants, bioactive compounds, α-tocopherol, β-carotene, and a high sugar content. Their health benefits encompass reducing inflammation, lowering LDL cholesterol, regulating blood pressure, and supporting kidney and hepatic functions. Notably, microgreens are easily cultivated and harvested, both indoors and outdoors, making them accessible for home kitchen gardening. Their popularity has surged globally due to the simplicity of cultivation and maintenance. Pre-harvest and post-harvest Ca treatments are employed to enhance shelf life, ensuring quality maintenance for up to 14 days when stored at temperatures below 5ºC. Overall, microgreens represent a convenient and nutritionally dense addition to diverse diets.

GRAPHICAL ABSTRACT



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1. INTRODUCTION

In recent years, people have become more concerned about their health, particularly due to the rise in various diseases and declining life expectancy (Luo and Wang, 2021). The inclination towards fresh and chemical-free agricultural products has increased in the regular diet. This situation has prompted researchers to seek new functional foods that offer a rich array of nutrients affordably and with minimal influence from contemporary agrochemicals (Bhaswant et al., 2023). Due to the growing challenges posed by current agricultural techniques, the word "organic" has gained popularity. Continuous efforts to develop new kinds of plant food have led to the development of Microgreens. Microgreens are considered a superfood because they have many health benefits, can be easily grown in small spaces, have a quick growth cycle, and do not require any external fertilizer (Wojdyło et al., 2020). Microgreens are also called "Vegetable Confetti" (Treadwell et al., 2020). Compared with fruits, vegetables, and sprouts, microgreens have a much lower maintenance cost and a shorter growing period (Bhaswant et al., 2023). They can be grown under a variety of light conditions such as sunlight, light-emitting diode, UV-A irradiation, and UV-B radiations and have young completely grown cotyledonary leafy greens that are harvested at the first genuine leaf stage, which grow up to 3–8 cm in about 1–3 weeks after germination. They are also grown in hydroponic systems on various substrates and do not require much water, fertilizer, pesticides, or space for cultivation. This method offers a huge opportunity for commercialization. They can be developed from various varieties of cereals, millet grains, and vegetable seeds (Rizvi et al., 2022; Sharma et al., 2020).

The current study aims to review the methods for growing microgreens efficiently at both home and commercial scales, as well as their nutritional value and functional benefits. Since microgreens are classified as perishable foods due to their shorter shelf life, an attempt has also been made to explore data on methods to extend their shelf life through storage and packaging for sustained consumer benefits.

1.1. Microgreen types

Microgreens, baby leaves, and sprouts are emerging trends in health care because they are nutritious, consumed raw, and require minimal or no processing (Bhaswant et al., 2023). Microgreens differ from sprouts and baby greens in their harvesting period. Table 1 describes the characteristics of microgreens and differentiates them from sprouts and baby greens. Worldwide, the demand for microgreens is increasing daily due to their wide variety of intense tastes, colours, aromas, shapes, and textures. These are well known for their aesthetics and are thus used to garnish soups, salads, sandwiches, hummus, and dips, adding a variety of flavors. During the harvesting period, the first leaves are fully expanded before becoming visible (Othman et al., 2021). Many methods have been used to harvest microgreens. Harvesting is also done using a knife or scissors, cutting below the stem and above the soil surface, except for the roots. Microgreens are cultivated on a wide range of scales among commercial crops and edible flowers. Following spectacular growth in popularity and demand, various vegetable seeds are used to grow microgreens from a variety of families (Deepa and Malladadavar, 2020).

Apiaceae family: Anise, Carrot, Celery, Coriander, and Fennel.

Lamiaceae: Basil and Mint.

Amaranthaceae: Beet, Dwarf copperleaf, Amaranth, Green amaranth, Pendant amaranth, Purple amaranth, Spiny amaranth, and Spinach.

Table 1

Characteristics of sprouts, microgreens, and baby greens (Artés-Hernández et al., 2022; Bhaswant et al., 2023; Ebert, 2022)

Conditions	Sprouts	Microgreens	Baby greens
Germination time	Harvested in 2–5 days	Harvested in 7–12 days	Harvested in 20–30 days
Height	2–5 cm	3–10 cm	10–15 cm
Form of consumption	Eaten raw	Eaten raw/slightly steamed	Eaten raw/slightly steamed
Growing media	Need to be soaked and rinsed with water No soil medium is required	Grown in soil medium/water medium/coco peat medium/ coco peat and soil medium	Grown in soil medium/water medium/coco peat medium/ coco peat and soil medium
Sunlight	No sunlight is required	Yes, sunlight is required	Yes, sunlight is required
Water requirement	Water requirement is less	Water requirement is less	Water requirement is more
Edible portions	Seed, roots, and steam seeds are also eaten	Only cotyledon leaves are consumed. Seeds and roots are not consumed	Only baby leaves are consumed. Seeds and roots are not consumed

Brassicaceae: Cauliflower, Cabbage, Mustard, Radish, Broccoli, and Turnip.

Cucurbitaceae: Cucumber, Pumpkin, Squash, and Melon.

Fabaceae: Chickpea, Fenugreek, Green gram, and Pea shoots.

Poaceae: Corn, Finger millet, Foxtail millet, Green millet, Pearl millet, Little millet, Lemon grass, and oats. Different genotypes of microgreens exhibit distinct textures, flavours, appearances, mineral and nutritional profiles. It varies in taste; some may be sweet, spicy, bitter, mild, or sour. Species are selected based on the availability of high-quality seed at a reasonable price. At the same time, these species do not require any special temperature or habitat requirements during the germination period. Species are also selected based on their colour, texture, shape, and shelf life (Ramya et al., 2022).

1.2. Media for microgreen cultivation

Microgreens are grown indoors as well as outdoors. Indoor cultivation is becoming increasingly popular, as it is easy to maintain and harvest. Several growing media, including coconut fibre, ‘vermiculite, coco peat, peat moss, and hydroponics techniques, are used instead of soil for the effective development of microgreens. Standard, sterile, loose soil is also used to grow microgreens. The research demonstrated that local organic material was just as effective as imported substrate for microgreen production. Growers commonly use trays filled with soil or various hydroponic substrates, such as coconut fiber, peat, vermiculite, and perlite. The choice of growing substrate significantly influences microgreens quality and yeild (Gunjal et al., 2024; Hoang and Vu, 2022). A study evaluated several growing substrates for Brassica microgreens: GT_1 (30% sand + 20% organic soil + 50% cocoa core), GT_2 (75% cocoa core + 25% rice husk), GT_3 (75% cocoa core + CaO) 2.2 mg/kg + acid humic 0.41%) and imported peat GT_4 (75% white sphagnum peat + 25% vermiculite (size 4–6 mm). Local organic material was found to be as effective as imported substrate for microgreen production (Hoang and Vu, 2022).

1. Cocopeat. Coco peat is a growing medium and is commonly used for soil amendment. It is made from coconut coir. It provides adequate moisture for seed germination and supports the growth of microgreens. It increases water retention and aeration, and provides antifungal properties when used alone. Cocoa peat is denser in volume, meaning there will be fewer natural air pockets around the plant’s roots. In a study, microgreens of mung bean, adzuki bean, chickpea, coriander, fenugreek, spinach, and mustard were grown in four different growth mediums, such as soil medium, water medium, coco peat medium, and coco peat medium, in combination with soil medium, to document the germination time, harvesting periods, and daily growth. Gunjal et al. (2024) conducted a study to assess the influence of different growing mediums (soil and cocopeat) on the growth, morphological characteristics, nutritional composition, and bioactive properties of selected microgreen species, including beetroot, red amaranthus, cabbage, broccoli, pak choi, radish, sango, and flaxseed. The study highlighted the significant impact of both growing environments on microgreen quality parameters, with the cocopeat medium identified as the most suitable for microgreen production, providing an alternative to traditional growing media and enhancing overall yield. According to another study, a coco peat-based medium combined with soil and water achieved higher yield and a shorter harvesting period than the other three media: water medium, coco peat medium, and soil medium. Therefore, a coco peat-soil medium is considered the most suitable substrate for growing microgreens, as mung bean microgreens demonstrated rapid growth and high yields (Eswaranpillai et al., 2023; Mohammad et al., 2022; Ramya et al., 2022). Additionally, microgreens grown in cocoa peat not only exhibited enhanced growth but also served as a source of functional ingredients for dietary supplements and sustainable agriculture. Overall, studies have concluded that cocoa peat offers optimal moisture conditions for seed germination and fosters beneficial conditions for microgreen growth (Dalal and Siddiqui, 2019).

2. Rice husk. Rice husk is the hard covering on rice seeds. They are generally light in weight, yellowish in colour, and convex in shape. It offers high resistance to penetration of moisture and fungal decay. Rice husk decomposes slowly due to its rich silica content. It increases aeration and acts like a conditioner. In a study, a 1:1 mixture of coco peat and rice husk was prepared in containers (soilless media and growing media were used). The containers were made from waste generated by sugarcane straw. Seeds were sown evenly in containers filled with growing media. Water was given from the edges of the container. Results were higher than expected in soilless media.

The farm microgreens grown in soil demonstrate a markedly higher concentration of vitamin C than both hydroponically grown farm samples and commercial samples (Tan et al., 2020; Xiao et al., 2012).

1.3. Microgreens and nutritive value

The burgeoning demand for healthier food products is driving the increased utilization of microgreens. Microgreens are loaded with nutrients. They have an abundance of bioactive compounds, including vitamins, minerals (Cu, Zn, Se), and phytochemicals (carotenoids and phenolics)

(Sharma et al., 2020). Several varieties of microgreens have high levels of potassium, iron, zinc, magnesium, and copper, although concentration differences may occur (Xiao et al., 2012). The colour of microgreens influences consumer choice and microgreens' economic potential. The primary photosynthetic pigment that gives microgreens their colours are chlorophyll and carotenoids. Compared with sprouts, microgreens are reported to contain more pigments. Microgreens are excellent sources of important plant compounds, such as antioxidants. Compared with mature greens, microgreens have higher nutrient content, namely vitamin C, carotenoids, glucosinolates, phylloquinone, phenolic antioxidants, α-tocopherol, and β-carotene (Rasmi et al., 2025). Specific microgreens, such as cilantro, blaukraut, green daikon radish, and garnet amaranth, exhibit elevated concentrations of bioactive substances, including ascorbic acid, tocopherol, carotenoids, and phylloquinone. Compared with fully grown vegetables, microgreens consistently exhibit significantly higher nutrient concentrations, with some varieties showing levels 40 times higher than those of mature vegetable leaves (Pinto et al., 2015). Vitamin and antioxidant levels in 25 commercially available microgreen varieties were higher when compared to those recorded in the USD National Nutrition Database for fully grown vegetable leaves, and it was estimated that the amount found in microgreens was 40 times higher than that of mature vegetable leaves (Kowitcharoen et al., 2021). Ebert et al. (2022) studied the growing popularity of amaranth as a nutrient-rich leafy green beyond Asia and the Caribbean. Microgreens, recognized as functional foods with health-promoting or disease-preventing properties, have been studied extensively. The levels of phytonutrients in edible parts vary across plant growth stages, often decreasing from the seedling (sprouted or microgreen) to the fully developed stage. In this particular study, the phytonutrient content of amaranth was assessed across three stages: (a) sprouts, (b) microgreens, and (c) fully grown plants. The study revealed a significant increase in vitamin C content from amaranth sprouts to microgreens. Among 25 commercially grown microgreen crops, amaranth ranked second in total ascorbic acid content (131.6 mg/100 g FW) after red cabbage. Both provitamins A (α-carotene and β-carotene) were detected at all three growth stages, with a significant increase observed in microgreens compared to sprouts. The researchers concluded that phytonutrient content exhibited noteworthy variation among cultivars at the same growth stage and differed between growth stages (Ebert et al., 2022). As mentioned in Table 2, green pea has the lowest concentration, 12.35mg/g, while lentil microgreens have the highest concentration, 112.62 mg/gm of total chlorophyll content. Carotenoid content ranges from 4.40 to 28.37 mg/100 g, with the lowest in green peas and the highest in lentils.

Xanthophylls (such as lutein and zeaxanthin) and carotenes (β-carotenoids and lycopene) are examples of a class of lipophilic plant pigments known as carotenoids that exhibit red, yellow, and orange colors. Carotenoids have antioxidant properties that are essential to human physiology. Carotenoids are found abundantly in vegetables, specifically in those that are brightly colored. In a study of the carotenoid profile of wheat and barley microgreens, it was observed that the microgreens phase had a higher carotenoid concentration than the seed phase. Anthocyanins, which are organic substances primarily found in plant parts such as leaves, fruits, and vegetables, provide different pigments and exhibit a wide range of anticancer, antioxidant, anti-inflammatory, and antiviral properties. Purple radish and red cabbage are found to have anthocyanins 0.148 mg/100 g and 0.246 mg/100 g, respectively. The maximum phenolic content was found in radish microgreens, and the minimum in morning glory, at 145.04 mg CGE/100 g and 9.22 mg CGE/100 g, respectively. Factors such as intrinsic, extrinsic, time of harvest, postharvest condition, and type of species can be the cause of variation in the amount of phenolic content (Stommel et al., 2015). Ascorbic acid, commonly known as vitamin C, is a bioactive phytochemical that is crucial for the body's functioning, as it acts as an antioxidant and helps fight bacterial infections, support detoxification reactions, etc. The ascorbic acid is highest in lentil microgreens, i.e., 128.70 mg/100g, and lowest in black sesame (6.84 mg/100 g). In general, ascorbic acid was found to be higher in microgreens than in baby greens, sprouts, and mature plants (Kowitcharoen et al., 2021). Agricultural practices have also been shown to play an important role in the total phenolic content (TPC) of radish microgreens (Alloggia et al., 2025).

The nutritional analysis of microgreens from selected leafy vegetables in vertical gardens, including dill, fenugreek, green amaranth, red amaranth, and spinach, revealed noteworthy content levels. Vitamin C varied from 14.66 to 80 mg/100g, vitamin A fell within 0.63–0.66 µg/g, and total carotenoid content ranged from 13.67 to 24.93 mg/100g, with Beta-carotene between 2.25 and 11.94 mg/100g. Mineral analysis indicated moderate Calcium (48.60 mg/100 g–81.50 mg/100g), appreciable iron (1.19–4.10 mg/100g), and trace phosphorus (0.018–0.060%). Carbohydrate content ranged from 1.06 to 2.63g/100g, and protein varied between 1.26 and 3.1g/100g. Crude fiber exhibited variability from 14.2% to 27.88%, while total phenols ranged between 58.32 and 84.74mg/100g. These findings highlight microgreens' moderate nutritional composition, making them suitable for daily diets and meeting the recommended daily allowances (Kusumitha et al., 2021).

In response to the unprecedented growth of the global population, there is an imperative to reassess the food system

Table 2
Bioactive compounds in microgreens grown in a controlled environment (Kowitcharoen et al., 2021; Teng et al., 2021)

Common name	Total chlorophyll (mg/100 g)	Carotenoids (mg/100 g)	Anthocyanin (mg CGE/100 g)	Total phenols (mg GAE/100 g)	Vitamin C (mg/100 g)
Broccoli	52.26	13.46	NA	87.56	79.11
Chinese kale	58.44	15.00	NA	130.59	81.33
Purple radish	49.80	13.12	0.148	132.78	82.58
Radish	59.21*	15.61	NA	145.04*	56.49
Rat-tailed radish	36.61	9.34	NA	143.11	48.24
Red cabbage	39.79	12.08	0.246*	112.29	89.49*
Fenugreek	57.10	14.28	NA	59.72	36.18
Green pea	12.35	4.40	NA	38.14	42.45
Lentil	112.62	28.37*	NA	89.05	128.70
Mung bean	26.13	5.86	NA	59.95	25.37
Black sesame	37.85	9.56	NA	49.03	6.84
Buckwheat	34.65	10.42	NA	268.99	62.90
Morning glory	28.29	6.92	NA	9.22	16.78
Roselle	36.37	8.87	NA	57.06	22.23

to ensure it provides ample nutrition while mitigating environmental impacts. A noteworthy concern is the prevalence of mineral malnutrition, particularly in substances like iron, as reflected in current malnutrition statistics. Addressing this nutritional gap is crucial, and the incorporation of nutrient and mineral-rich microgreens into diets emerges as a promising solution to combat diseases such as anemia (Soumya et al., 2022) evaluated the microgreens of wheatgrass (*Triticum aestivum* L.) and basil (*Ocimum tenuiflorum*) for their nutritional profiling on a dry weight basis. Wheatgrass and basil were cultivated in trays, and harvest occurred between the 8th and 21st days, followed by shade drying and conversion into powders. The examination of these microgreen samples encompassed proximate composition, mineral content, and antioxidant properties. Parameters such as moisture, ash, protein, fat, crude fiber, carbohydrate, energy, iron, calcium, zinc, vitamin C, TPC, total flavonoid content, and total antioxidant activity were meticulously assessed for wheatgrass and basil microgreens. Highlighting the superior nutrient density of microgreens compared to traditional green leafy vegetables (GLV), the study identifies wheatgrass and basil as particularly rich sources of iron (62.42mg and 89.8 mg/100gm DW, respectively), calcium (660.2mg and 380.2 mg/100gm DW, respectively), and zinc (4.16 mg and 7.1mg/100 gmDW, respectively). The comprehensive nutritional profiling provided herein aims to help consumers make informed dietary choices. Additionally, food engineers, processors, and scientists can leverage this information for product development. As microgreens gain popularity on supermarket shelves, this study offers valuable insights for producers seeking to promote nutrient-dense microgreens (Soumya et al., 2022).

With minimal space and effort, these microgreens can meet the nutritional needs of households in cities. Microgreens of *Vigna radiata L., Brassica nigra L.,* and *Trigonella foenum graecum* L. cultivated in different conditions of soil and water contain a good amount of potassium and calcium as analyzed by X-ray fluorescence (XRF). Microgreens grown in water are preferable for nutritional supplementation, offering a convenient way to provide fresh, organic leafy greens to urban families (Mohanty et al., 2021). Brassicaceae microgreens have also been reported as a valuable source of macronutrients (such as K and Ca) and micronutrients (such as Fe and Zn) by Xiao et al. (2016).

1.4. Microgreens and functional benefits

Microgreens, with their high nutrient and bioactive compound content, are emerging as a promising dietary option for improving health and potentially preventing malnutrition and chronic diseases (Teng et al., 2021).

Microgreens have emerged as nutritional powerhouses, supporting various physiological functions, according to research. These studies indicate that microgreens contribute significantly to modulating cell proliferation, suppressing tumors, reducing inflammation, and regulating cholesterol levels and blood pressure, among other physiological functions (Bhaswant et al., 2023; Galieni et al., 2020). Additionally, microgreens have bioactive compounds, including phytochemicals, minerals, and vitamin C, which exhibit antioxidant properties. This antioxidant capacity supports wound healing, immune system regulation, and collagen synthesis, contributing to various biological functions and helping combat conditions such as diabetes, cancer, and inflammation (Tallei et al., 2025; Zhang et al., 2021).

The high bioaccessibility of bioactive components endows microgreens with the ability to combat chronic diseases, making them valuable for preventing conditions such as diabetes, cancer, and inflammation (Zhang et al., 2021).

The potential of microgreens as a supplement for treating inflammation and preventing diseases can reduce the occurrence of various ailments and lower medical costs. Notably, microgreens exhibit a remarkable ability to modulate and mitigate inflammation in conjunction with the immune system. For instance, consumption of microgreens, like red cabbage, has been shown to reduce levels of C-reactive protein and TNF in the liver, thereby decreasing the risk of inflammatory reactions triggered by high-fat diets (Kalal et al., 2021). Liquorice microgreens, in particular, have demonstrated anti-inflammatory properties, inhibiting the pro-inflammatory cascade and cytotoxic effects (Marotti et al., 2021).

Microgreens, including red cabbage and those from the Fabaceae family, possess therapeutic components with diverse medicinal properties. Fabaceae microgreens derived from liquorice, for instance, are promising sources of bioactive compounds with antimicrobial, antiviral, antitumor, antidiabetic, anti-inflammatory, immunoregulatory, hepatoprotective, and neuroprotective activities (Marotti et al., 2021).

Iron deficiency, a widespread nutritional deficiency, poses a significant health concern. Microgreens, such as fenugreek, have been investigated for their iron bioavailability compared to their mature counterparts. Fenugreek microgreens exhibited higher iron levels, indicating increased bioaccessibility and suggesting their potential as a valuable dietary addition to enhance iron status (Kathi et al., 2022).

Obesity, a global health concern, has prompted investigations into preventive measures, including the potential role of microgreens. Broccoli microgreen juice, for instance, has shown a preventive effect on obesity by reducing body weight, adipocyte size, insulin levels, and enhancing glucose tolerance in mice fed a high-fat diet (Li et al., 2021).

Various types of microgreens, such as fenugreek, broccoli, and barley microgreens, have demonstrated anti-diabetic effects. Fenugreek microgreens, with elevated levels of phenolic content, flavonoids, and antioxidants, exhibited inhibitory effects on α-amylase in $HepG_2$ cells and increased glucose uptake in L6 cells in the presence of insulin (Wadhawan et al., 2018). Similarly, lyophilized broccoli microgreen powder showed hypoglycemic effects in mice fed a high-fat diet and/or treated with streptozotocin. Barley microgreens, rich in various phytochemicals, improved glucose metabolism in rats with streptozotocin- and/or aflatoxin-induced diabetes (Khattab et al., 2022; Mohamed et al., 2022a, 2022b).

Epidemiological studies have associated the consumption of microgreens with a reduced occurrence of cardiovascular diseases. In vivo studies have shown that supplementing animals with microgreens in a high-fat diet-induced obesity model led to a significant reduction in low-density lipoprotein levels, hepatic cholesterol ester, and expression of inflammatory cytokines in the liver. This reduction was correlated with the inhibition of enzymes involved in triglyceride synthesis, indicating the potential of microgreens to modulate weight control and cholesterol metabolism, ultimately preventing chronic cardiovascular diseases (Jiang et al., 2001).

As part of a strategy to promote heart health, the consumption of microgreens is highly recommended due to their rich nutrient and phytocompound content. Various studies have investigated the efficacy of microgreens in reducing lipid and cholesterol levels, resulting in reduced body weight, low-density lipoprotein levels, hepatic cholesterol ester, and expression of inflammatory cytokines in the liver (Huang et al., 2016).

The burgeoning issue of kidney disorders, categorized under chronic metabolic syndrome, presents a challenge for individuals with impaired kidney function. Patients with chronic kidney disorders are advised to limit their intake of high-potassium foods to manage their condition. Microgreen production offers a potential solution, as cultivation parameters can be manipulated to produce low-potassium-content microgreens, addressing the dietary restrictions of kidney-impaired patients. Studies have successfully cultivated chicory and lettuce microgreens with substantially lower potassium content, maintaining nutritional quality and aligning with medical recommendations (Renna and Paradiso, 2020).

Microgreens have shown promise in the prevention and treatment of cancer. Thai red-tailed radish microgreen extract exhibited anti-migratory effects in human breast adenocarcinoma and human hepatocellular carcinoma cells, inducing apoptosis and preventing cancer cell proliferation. Additionally, extracellular vesicles derived from certain microgreens have demonstrated the potential to inhibit colon cancer cells more effectively than microgreen extracts (Kaimuangpak et al., 2022; Saengha et al., 2021).

In conclusion, microgreens hold immense potential to address chronic metabolic disorders, representing a promising frontier at the intersection of nutrition and health. As functional foods, microgreens have diverse therapeutic properties, from preventing and treating diabetes, kidney disorders, and cancer to promoting cardiovascular health, reducing inflammation, combating obesity, and addressing iron deficiency. The integration of microgreens into dietary recommendations may become a pivotal aspect of public health initiatives worldwide as research continues to unveil the intricacies of these tiny nutrient powerhouses.

1.5. Shelf life of microgreens

Microgreens have gained prominence recently because of their ease of indoor cultivation and high nutritional value. However, their marketing and commercial cultivation are limited, primarily attributed to their short shelf life. The interplay between temperature and storage duration significantly affects the shelf life and quality of microgreens. Maintaining a consistent temperature and employing an efficient storage system can extend the shelf life of microgreens (Xiao et al., 2012).

1.5.1. Effect of temperature

Different microgreens exhibit varying shelf lives under specific storage conditions. Even at 20 ºC, microgreens have a shelf life of only 3–5 days (Mir et al., 2017), but proper cultivation and storage can extend their shelf life to up to 14 days. Studies recommend preserving microgreens at temperatures below 5ºC (Kou et al., 2013; Xiao et al., 2012). For instance, broccoli microgreens stored for 14–21 days when cultivated in a growth chamber at 5°C (Sun et al., 2015). Storing radish ruby, tatsoi, radish green, cabbage red, and brussels sprouts at temperatures between 1.6 and 4.44°C yields a shelf life of 13–14 days, while parsley Italian, cress upland, parsley curled, and celery have an extended shelf life of 20–21 days. The surrounding temperature of 5°C enhances the shelf life of broccoli, cabbage, kale, radish, sunflower, and pea microgreens under refrigeration systems (Dayarathna et al., 2023; Renna and Paradiso, 2020).

In another observation, low-temperature storage (5 and 10°C) was found to be crucial for extending the shelf life of packaged mustard microgreens. Storage at 15, 20, and 25°C resulted in quicker degradation, with mustard microgreens stored at 15°C degrading after 7 days and those at 20 and 25°C degrading after only 2 days (Dalal and Siddiqui, 2019).

Regulating respiration rates extends shelf life, enhancing the marketability of this highly perishable product. In a study aimed at exploring the respiration rate and shelf life of microgreens, weekly assessments of visual quality were conducted concurrently with respiratory rate measurements, using the scoring system established by Rennie et al. (2001), which is based on the physical condition of microgreens. The rating scale ranged from 1 (poor) to 5 (excellent), with a designation of "3" indicating acceptable quality. An observed inverse relationship was observed, indicating that a more rapid decline in visual quality correlates with an elevated respiratory rate. All plants achieved a perfect score of five for early visual quality. Across all species, visual quality consistently proved superior at 4°C compared to 10°C on each assessment date (Berba and Uchanski, 2012).

1.5.2. Effect of pre/post-harvest treatment

To enhance the shelf life and postharvest quality of microgreens, calcium treatments are applied. Calcium, crucial for cell wall structure and membrane integrity, improves root and shoot growth. Calcium chloride treatment has been found to decrease soil pH and sugar levels while increasing protein and starch concentrations in microgreens (Brahmakshatriya et al., 2022). Pre-harvest spray with 10 mmol L^{-1} calcium chloride, without a postharvest wash, is the most effective treatment for broccoli microgreens, reducing tissue electrolyte leakage and microbial growth while preserving overall quality during storage (Kou et al., 2015).

Chlorine-treated microgreens stored under controlled conditions at 20–30°C exhibit varying shelf lives: broccoli microgreens last 21 days, radish microgreens 8–16 days, and mung bean, lentil, pearl millet, and red cabbage microgreens 10 days. Additionally, applying aloe vera gel or spraying it onto radish microgreens extends their shelf life by 8 days when stored at 5°C in a closed laboratory room (Dhaka et al., 2023).

Consequently, another study suggests that employing a storage temperature of 5°C, low-density polyethylene (LDPE) bags, and a washing treatment involving ClO_2 + citric acid holds promise as effective processing methods to extend the shelf life and preserve the quality of tartary buckwheat microgreens (Yan et al.., 2022). Chemical treatments included ethanol vapor, acetaldehyde vapor, citric acid, ascorbic acid, citric acid + ethanol, and citric acid + ascorbic acid, with water as a control. The packaging materials tested were polystyrene and LDPE. Microgreens were stored at 10 ± 1°C for 16 days. The study found that sunflower microgreens can be stored for up to 12 days at 10°C, with better shelf life and nutritional quality when packed in polystyrene compared to LDPE (Dalal and Siddiqui, 2019).

The degradation of freshly cut microgreens is attributed to stress rather than natural aging, given their highly breathable nature. Various factors, including pre-harvest and postharvest treatments, as well as different packaging materials and modified atmosphere packaging, were considered as variables influencing the shelf life of fresh-cut microgreens (Paradiso et al., 2018).

1.5.3. Effect of packaging material

Different packaging materials and storage conditions also influence the shelf life of microgreens. Microgreens, owing to their high moisture content, are highly delicate and prone to a short shelf life. Research indicates that postharvest deterioration in the physical and chemical quality of microgreens can be mitigated through effective storage conditions, appropriate packaging, the use of nanoparticles, physiological treatments, and molecular approaches. The choice of storage conditions and packaging materials significantly impacts the quality and shelf life of microgreens. employing bioplastic clamshells, cardboard clamshells, bioplastic bags, paper boxes, and certain polymer classifications could extend the shelf life and diminish antimicrobial activity when stored at controlled temperatures.

Polyethylene terephthalate (PET) clamshells and LDPE self-seal bags enhance the shelf life of radish microgreens at 5°C. Cold storage at 4°C or 10°C for radish microgreens results in a shelf life of 7–15 days. Oxygen transmission rate (OTR) film packaging and polyethylene/vacuum packaging both demonstrate prolonged shelf life during refrigerated storage at 1–10°C for alfalfa and amaranth microgreens (Riggio et al., 2019). Using polyethylene bags for packing and storing at 4°C extends the storage life of Chinese toon tender shoot microgreens to 25 days (Zhu and Gao, 2017). Storing *Melientha suavis* in a container at 10°C, packed with various materials, results in a shelf life of 12 days (Turner et al., 2020).

Tan et al. (2022) conducted an assessment of the antioxidant levels and sensory quality of microgreens sourced from both commercial and local farms. Commercially available microgreens were packaged in plastic ziplock bags without specified harvest dates, while farm samples were gathered on the day of delivery and placed in paper ziplock bags. Laboratory analyses were performed on the day of purchase, and additional samples were stored at 4°C for a sensitivity study over 3 days. The study revealed no significant differences in phenol concentration or antioxidant capacity among the various broccoli microgreens. However, microgreens from local farms had higher chlorophyll concentrations than their commercial counterparts. Participants were instructed to visually inspect, smell, and taste each sample, providing ratings for liking, smell, appearance, taste, and overall preference on a 7-point Likert scale ranging from very bad (1) to very good (7). The sensory evaluation indicated that microgreens from local farms presented superior sensory qualities. Therefore, the study suggests that consumers or restaurants may benefit from choosing microgreens from local farms to enhanced the sensory experience (Tan et al., 2020).

Among a variety of packaging materials, including plastic bags (bioplastic clamshells, cardboard clamshells), bioplastic bags, paper bags, paper boxes, and various polymer types such as PET, polylactic acid (PLA), polypropylene, polystyrene, LDPE, and high-density polyethylene, clamshell and bag packaging materials were observed to provide a shelf life of 8–10 days at 4°C for microgreens harvested in a closed room. These packaging materials notably affect changes in oxygen (O_2) and carbon dioxide (CO_2) content, corrosion rates, and electrolyte leakage (Sharma et al., 2023; Yan et al., 2022).

2. CONCLUSION

Microgreens have gained popularity in recent years due to their exceptional nutritional content and sensory attributes. Packed with nutrients, minerals, vitamin C, carotenoids, phenolic compounds, and bioactive substances, microgreens boast a robust antioxidant capacity. They fall under the category of "functional food," representing a promising addition to our daily diets. Compared to sprouts and baby leaves, microgreens stand out for their higher nutritional value. Their consumption has been shown to benefit glucose homeostasis and prevent atherosclerosis. The optimal growth medium for microgreens has been identified as a combination of soil and coco peat. Beyond their nutritional merits, microgreens have become popular for their ability to thrive in indoor spaces, ease of maintenance, and fresh consumption. However, their short shelf life has limited their market presence. When refrigerated at 5ºC, post-harvest microgreens can last for 3–5 days. Applying pre- and post-harvest calcium treatments has been effective in extending their shelf life. While microgreens are recognized for their nutritional value, further research is needed to explore their potential as a holistic form of personal medicine. Evidence-based studies are crucial to understanding the complete spectrum of health benefits associated with microgreens. Providing comprehensive information on nutritional characteristics, bioactive compounds, sensory qualities, storage, and methods for shelf-life extension is essential for raising community awareness.

Additionally, the utilization of microgreens in space environments warrants further investigation. Overcoming the challenge of their short shelf life requires focused research to enhance shelf life, increase consumption, and expand the market for microgreens.

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AUTHORS' CONTRIBUTION

S.Y. contributed to the literature search, data acquisition, and analysis, and manuscript writing. M.A. contributed to the manuscript writing and approval of the final version. S.S. contributed to the literature search, data acquisition, analysis, and manuscript writing. All authors have critically reviewed this and previous versions of the paper.

CONFLICTS OF INTEREST

All authors declare that they have no conflicts of interest.

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