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Emergence of microgreens as a valuable food, current understanding of their market and consumer perception: A review

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ABSTRACT

Green leafy vegetables, especially microgreens are gaining popularity due to their high nutritional profiles, rich phytochemical content, and intense flavors. This review explores the growing commercial market for microgreens, especially in upscale dining and premium grocery outlets, highlighting consumer perceptions and their effect on market dynamics. Apart from these, the effect of modern agricultural methods that maximize the growth of microgreens is also examined. The value is anticipated to increase significantly, according to market predictions, from $1.7 billion in 2022 to $2.61 billion by 2029. Positive consumer views on microgreens health benefits drive this growth, although challenges such as varying levels of consumer awareness and income disparities affect sales. The review underscores the need for targeted research and strategic initiatives to enhance consumer understanding and improve cultivation methods to support market expansion in upcoming years.

1. Introduction

The inclusion of bioactive compounds rich in fruits and vegetables in the everyday dietary regimen is crucial for maintaining good health. According to the 'State of Food Security and Nutrition' in the world during 2023 the 735 million people worldwide suffered from undernourishment in 2023 and increased by 122 million since 2019. Moreover, the report shows that 29% of children under five suffer from stunting or wasting (Cohen, 2023). The major reasons behind it are poverty, lack of awareness about nutritious food, and unavailability of fresh fruits and vegetables. Disorders like scurvy and osteoporosis along with other non-communicable diseases like obesity, adult-onset diabetes, scurvy, osteoporosis, cardiovascular diseases, and cancer occur due to improper healthy diet (Candib, 2007). Individuals are becoming more focused on maintaining healthy eating habits and lifestyles to avoid health issues and enrich their lives. Therefore, the utilization of functional foods rich in edible leafy greens like microgreens (a treasure-trove of phytonutrients) in our daily diet, is considered to be a suitable option for the prevention/reduction of malnutrition and health disorders (Mansor & Harun, 2014).

Microgreens are immature edible greens, characterized by their intense flavor, texture, and aroma were initially used by Californian chefs for garnishing dishes and are also referred to as "vegetable confetti". The short growth cycle and nutrient-dense properties of microgreens made them very popular in the current diet culture (Pinto, Almeida, Aguiar, & Ferreira, 2015). It is cultivated by using edible seeds of different plants and is harvested when the first true leaves emerge from the sapling after the development of cotyledons and attains a height of about 1–3 in., their harvesting time varies according to the specific species of microgreens being grown (7 to 21) (Turner, Luo, & Buchanan, 2020). The amaranth, radish, parsley, mustard, chard, celery, cabbage, cilantro, chervil, kale, fennel, cress, basil, beets, arugula, and sorrel are some of the most popular microgreen kinds. Microgreens radish and amaranthus both possess colored leaves (red, green, purple, and pink) (Xiao, Lester, Luo, & Wang, 2012). Additionally, legume crops such as beans, chickpeas, and lentils, as well as grains including oats, wheat, rice, barley, and corn, can also be produced as microgreens (Paraschivu, Cotuna, Sarateanu, Durau, & Paunescu, 2021).

Even though microgreens can be easily grown, a lot of difficulties (especially fungal growth) can arise when proper cultivation practices

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are not followed (Turner et al., 2020). To improve germination, seeds are pre-soaked and are typically grown in trays containing either soil, cocopeat, vermiculite, or a combination of both soil and cocopeat. During germination, the trays are kept in a less humid, and well-lit environment, generally receiving 12–16 h of light per day. The quality, flavor, nutritional content, aroma, and color of microgreens are greatly influenced by the intensity, duration, and wavelength of light they receive (Kyriacou et al., 2016). Microgreens are highly perishable once harvested as their shelf life is limited to 2–3 days at room temperature, hence, to increase the shelf life which can last up to 14 days, it is stored at around 4 °C as soon as harvested (Sharma et al., 2022). Wet paper towels and hydroponics are advanced methods for the cultivation of microgreens, these methods are advantageous as they prevent the transmission of pests and reduce the development of fungi in the growth media (soil, cocopeat, vermiculite) (Zhang, Xiao, Ager, Kong, & Tan, 2021).

The concentration of bioactive compounds in plants is known to decrease as they mature (Chira, Chira, & Delian, 2013). However, the short growth cycle of microgreens prevents any significant reduction in the concentration of bioactive compounds. The study by the United States Department of Agriculture (2020) also supported that microgreens exhibit substantially greater concentrations of vitamins and carotenoids that are typically 30–40 times greater than those found in mature fruits and vegetables (Choe, Yu, & Wang, 2018). They are also rich sources of antioxidant phytochemicals, like phenols, carotenoids, vitamins (A, C, E), and minerals (Cu, Mg, and Zn) (Teng, Liao, & Wang,

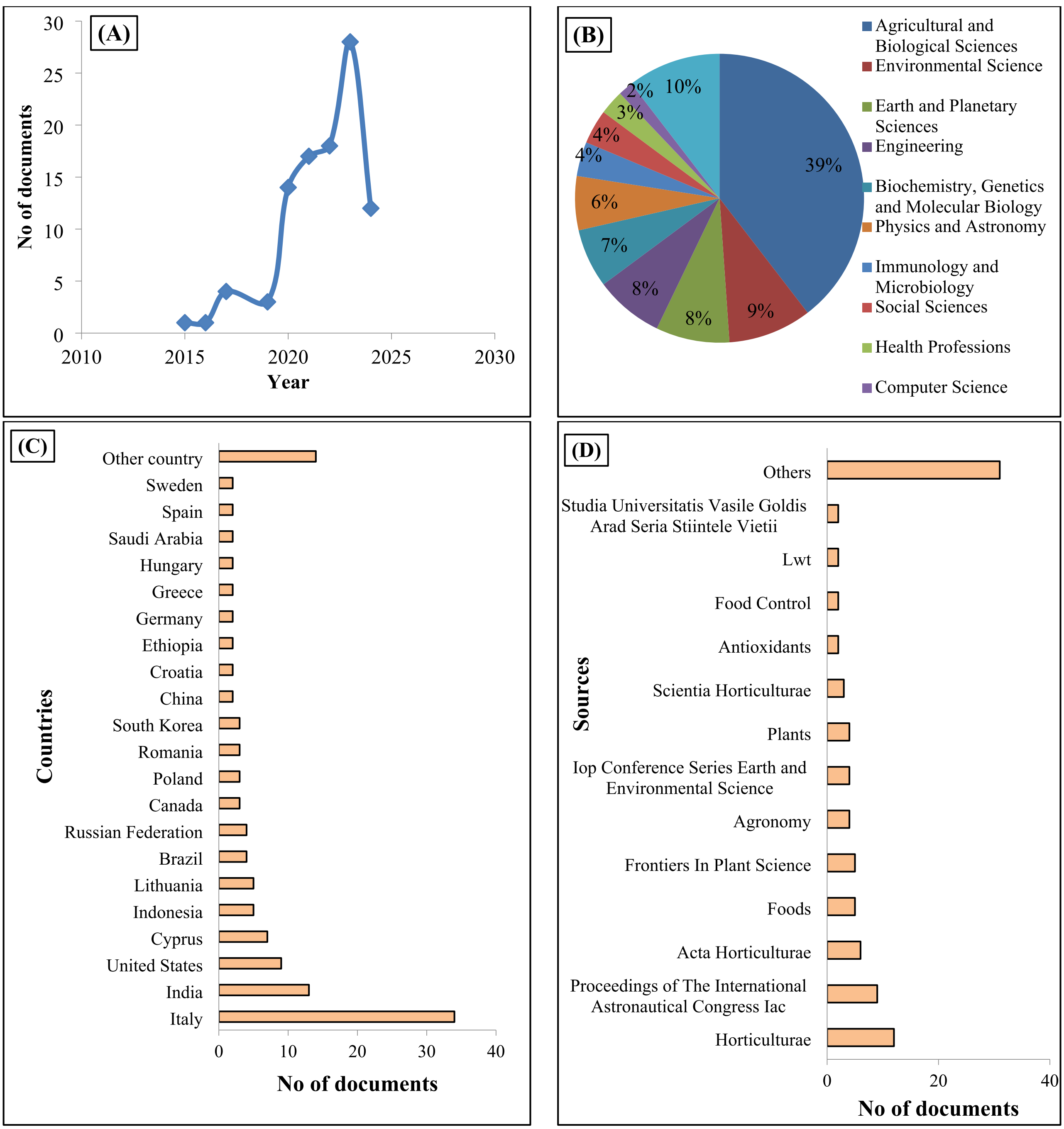

Fig. 1. Research trend in the area of microgreens showing (A) the number of scientific documents published during years (2015–2024); (B) the number of documents published research area wise; (C) the number of documents published country wise and; (D) the number of documents published by source wise.

2021). Due to the presence of higher bioactive compounds, rather than just garnishing, in recent years microgreens are also been extensively consumed in the form of juices, smoothies, shakes, and salads (Ghoora, Babu, & Srividya, 2020). Numerous experiments conducted by researchers have established the anti-inflammatory, anti-bacterial, anti-cancer, and anti-hyperglycemic properties of microgreens, as demonstrated in both in vitro and in vivo studies. As a result, microgreens are regarded as a novel functional food that may have significant health benefits for human consumption (Zhang et al., 2021).

Microgreens, as a new and developing agricultural product, hold vast potential for diversifying and sustaining the agriculture industry, while contributing to economic growth, demographic development, environmental preservation, and the improvement of human health (Weber, 2017). The microgreen market has improved rapidly in recent years, and near future, it is predicted that it will hold important shares in the global market up to a CAGR of 12–20%. Studies suggest that Consumer Purchasing Decisions (CPD), are one of the important factors that indicate an increase or decrease in the market value of products, CPD is significantly impacted by sensory attributes, understanding and analyzing the sensory information, perceptions, and purchasing scheme of customers regarding microgreens is essential (Dimita et al., 2022).

In the past decade, there has been a notable increase in research interest regarding microgreens. Fig. 1 (A) highlights the trend in publications from 2015 to 2024 using keywords like "microgreens" and "microgreens cultivation" with data sourced from 'Web of Science and Scopus.' The rise in the number of publications underscores the growing importance of this topic. Between 2015 and 2024, a total of 98 documents were published, comprising 61 articles, 23 conference papers, 10 review articles, 3 book chapters, and 1 book. Most publications were in the fields of Agriculture and Biological Sciences (39%), followed by Environmental Sciences (9%), as depicted in Fig. 1 (B). Country-wise, Italy led with 34 publications, followed by India with 13, and the United States with 9, as shown in Fig. 1 (C). Horticulture was the leading source with 12 publications during this period. To date, no review has specifically targeted research and strategic initiatives aimed at enhancing consumer understanding and improving cultivation methods to support market growth in the coming years.

There is a notable gap in comprehensive studies that examine the market dynamics and consumer perceptions of microgreens. Instead, the majority of research on microgreens concentrates on their nutritional benefits and possible health effects. This review is interesting since it takes a comprehensive approach, looking at the commercial possibilities and variables influencing consumer acceptance of microgreens in addition to their health benefits. This current comprehensive review article fills the gap in knowledge on how microgreens might be positioned as a valuable food source in the market by incorporating insights from market projections and current agricultural techniques. Apart from this, it also outlines solutions to improve market expansion and consumer education, it also draws attention to the problems associated with economic inequality and consumer awareness. This comprehensive perspective provides a foundation for future research and strategic initiatives to support the microgreens industry.

2. Emergence of microgreens

Microgreens are experiencing a surge in popularity due to their expanding use in high-end restaurants, as well as their increasing availability in supermarkets. The use of microgreens by chefs started in the early 1980s in San Francisco, California, according to early records of the local industry. In that period, only a limited variety of microgreens such as arugula, beets, basil, cilantro, and kale were available (Choe et al., 2018). The word "microgreens" was only coined in the year 1998 in the USA. Before that, they were referred to as greens, grasses, seedlings, or confetti. In addition to restaurants, they were also sold in local retail outlets across North America in the early 2000s and became prevalent in grocery stores by 2010 (Pinto et al., 2015). As a result of this popularity, researchers became interested in studying different aspects of microgreens Fig. 2. The very first research paper, which focused on seed treatment for improving the growth of microgreens, was published in the USA by Lee, Pill, Cobb, & Olszewski, 2004. in the year 2004. Subsequently, microgreens became a trending topic among researchers by 2010, with a majority of the studies focusing on cultivation practices and analyzing different growth parameters such as temperature, RH, irrigation, and especially the media used to grow microgreens. Further studies focused on assessing microgreens for bioactive compounds and the impact of various LED irradiation on the cultivation and formation of bioactive compounds in microgreens. The majority of studies were conducted by international researchers, while microgreens remained a relatively obscure research topic in India. Wadhawan, Tripathi, & Gautam, 2017. published the first research paper on microgreens in India, which investigated the in vitro functioning of enzymatic glucose secretion and absorption by mint leaf and extract fenugreek microgreens (Brazaityte et al., 2015). Recent studies are focusing on the implementation of advanced methodologies like the effect of blue vs red light emitting diode and detecting the shape avoidance response by a blue light on various microgreens, analyzing the biochemical and morpho-anatomical attributes on irradiated microgreens and immunomodulatory functional components of microgreens (Amitrano et al., 2023; Othman, Eliseeva, Santuryan, Molodkina, & Kadi, 2022).

Microgreens are stamped with captivating sensory attributes like sharp flavors, vivid colors, tender textures, and a rich source of phytonutrients. These qualities have made microgreens a popular ingredient among chefs for enhancing the visual appeal and taste of various cuisines. Moreover, microgreens have also earned a prominent place in "organic farming" stores due to their nutritional value and versatility. Moreover, a diverse range of plant species from various botanical families, like Amarillydaceae, Cucurbitaceae, Apiaceae, Amaranthaceae, Asteraceae, Brassicaceae, Fabaceae, Oxalidaceae, Lamiaceae, Polygonaceae, Poaceae, and Portulacaceae, are utilized for microgreen production based on their health and sensory attributes (Jones-Baumgardt, Llewellyn, Ying and Zheng, 2019).

3. Trends in microgreen cultivation and storage

Microgreen cultivation is economically feasible if producers can produce high-quality commodities, target the right customers, and manage their production and marketing processes successfully. Several variables play a role in microgreen growing economics, including market demand, production costs, distribution methods, and price (Enssle, 2020). The majority of the cost of producing microgreens goes towards seeds, growing substrates, trays or containers, lighting equipment, water, and utilities. Additional expenses including labor, pest management expenses, and packaging charges could arise (Gumble, 2015). Microgreens frequently possess greater revenue potential than traditional agricultural products due to their larger economic potential per unit area. Higher-end restaurants and specialty food stores generally charge extra for premium-quality microgreens, which is financially beneficial. Revenue margins vary based on regional conditions and specific operations. Their rapid revenue increase and regular harvesting are achieved by their rapid growth cycle. (Gentry, 2019).

Microgreen cultivation requires proper lighting for the seedlings, with an optimal temperature of 25–30 °C and relative humidity (RH) of 60–70% (Kyriacou et al., 2016). The initial phase of the germination process of microgreens requires a dark environment for a minimum of 3 days, after which, they are exposed to adequate light, with daily light exposure of 12–16 h, to promote growth (Kou et al., 2014; Negri, Bulgari, Santoro, & Ferrante, 2021). The RH during the cultivation and post-harvest periods greatly affects the quality of microgreens. Low humidity can cause dehydration and deteriorate the quality of microgreens, whereas high humidity can encourage microbial growth and negatively impact germination and growth. Therefore, the maintenance of optimal humidity range is crucial to preserve the quality of

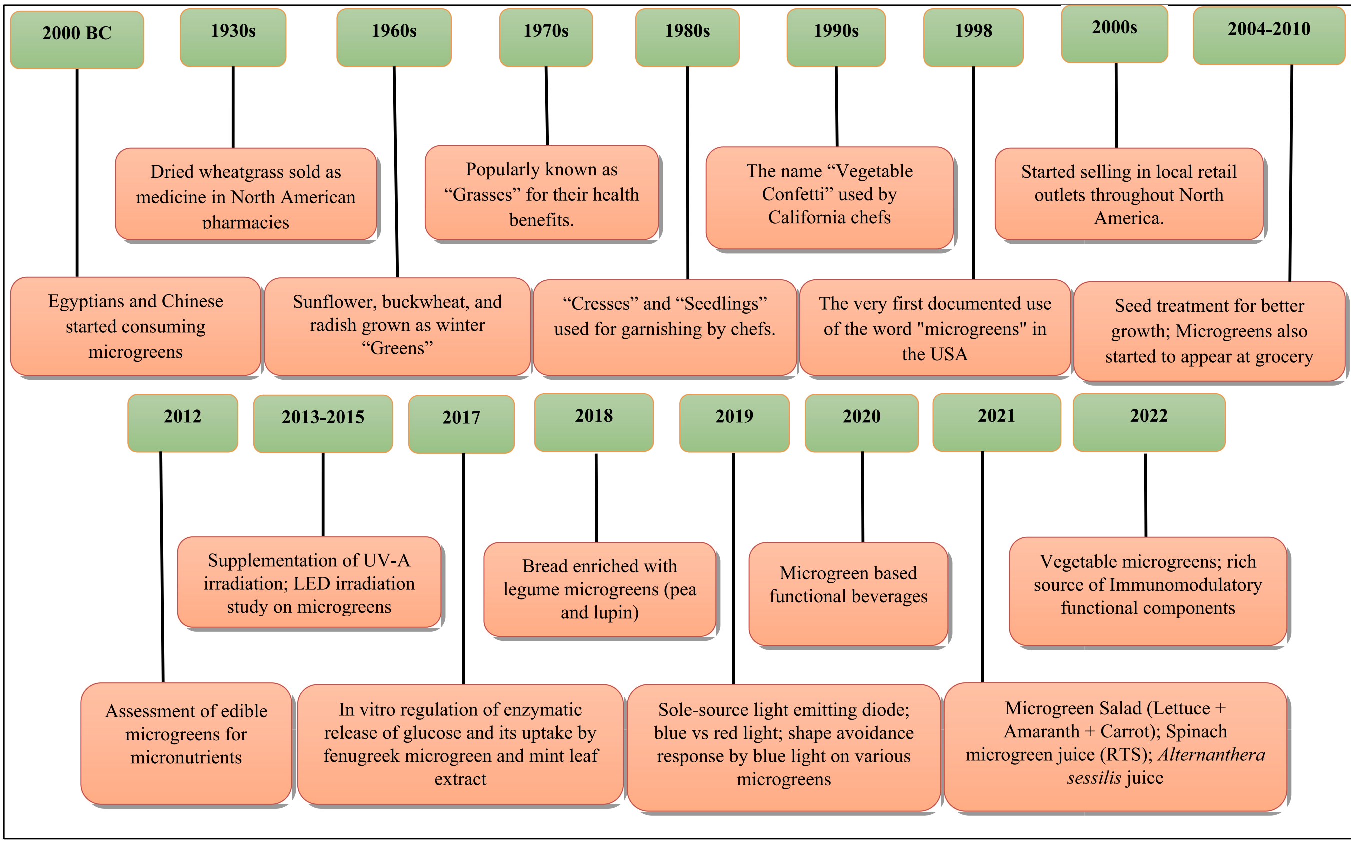

Fig. 2. History of microgreens.

microgreens (Warriner, Ibrahim, Dickinson, Wright, & Waites, 2003). The water is sprayed from the top by using a spray bottle to avoid water logging and the pH of the water being used for cultivation should be neutral to slightly acidic. Alternatively, wet paper towels can be used for the cultivation of microgreens. As this method of germination by using paper towels does not require media for growth like soil or cocopeat, the paper towel has to be watered with the nutrient solution to initiate the growth of microgreens (Ilahy et al., 2020).

Furthermore, to mitigate the risk of microbial contamination and to obtain a higher yield of microgreens, organic seeds are considered the most suitable option. To facilitate the germination process, microgreen seeds (arugula, pak choi, broccoli, and amaranthus) are soaked overnight, as soaking prevents surface contamination of the seeds (Mancini & Romanazzi, 2013). Before soaking, seeds are treated with some chemicals like 2% (*v*/v) sodium hypochlorite, 2% (*w*/*v*) calcium hypochlorite, and 5% (v/v) lactic acid for 10 min which further helps to decrease the risk of microbial contamination (Escamilla, Rosso, & Zhang, 2019). Kou et al. (2014) conducted a comparative experiment to analyze the potential benefits of calcium solution treatment (1, 10, 20 mM) on both seed (pre-harvest) and seedlings (post-harvest), the study concluded calcium application (10 mM) during preharvest increased the biomass up to 50% and enhanced the growth in comparison with the post-harvest application.

3.1. Soilless farming techniques of microgreens

Traditional farming systems produce relatively inadequate earnings while consuming enormous amounts of irrigation water and chemical fertilizers. To overcome the demerits, sustainable development tactics were developed and have gained popularity on a worldwide scale since the 1990s and the circular economy is both the most prevalent trend in ecological sustainability and the most efficient means of economic growth (Wei et al., 2019). Modern agriculture techniques like hydroponics, aeroponics, and aquaponics feed plants with nutrient-rich water instead of soil and require fewer resources such as water and space than the traditional systems of farming as the effectiveness of these techniques does not depend on the availability of fertile land. Another advantage of these technologies is the ability to practice vertical farming for cultivation, which raises the yield per square unit (AlShrouf, 2017). As of 2022, the global market size of vertical farming was valued at \$5.89 billion and will grow at a 20.1% CAGR rate from 2023 to 2030 (*Vertical Farming Market Size, Share, & Analysis Report, 2030,* n.d.). Aerated farming without soil is proven to produce crops with higher yields and better quality than traditional farming. This is because soilless farming offers a regulated environment that involves pH, light, CO_2, O_2, nutrients, temperature, and other elements (Treftz & Omaye, 2015).

3.1.1. Cocopeat cultivation

The cultivation medium highly influences the manufacturing process and has a significant impact on output and environmental sustainability (Bulgari, Negri, Santoro, & Ferrante, 2021). One of the best growth media for microgreens is cocopeat, which is a small and medium-length fiber obtained from the mesocarp of coconut (*Cocos nucifera* L.), that has various beneficial physical and chemical characteristics. It benefits the growth of microgreens and offers good moisture content for seed germination. When used by itself, it improves water retention and aeration and offers antifungal effects. There will be fewer naturally occurring air spaces around plant roots since coco peat has a denser volume (Dalal, Mainani, Thakker, & Solanki, 2022). Cocopeat possesses high cation exchange capacity with excellent drainage and aeration capabilities at a pH range of 5.5–7.0, 90–95% porosity, and 80–100 kg/ m^3 density. Cocopeat can also be combined with other soil to enhance better growth in a short period (Shukla, Mishra, & Sarkar, 2021). Gunjal et al. (2024) compared the effect of soil and cocopeat growing media on the morphological, nutritional, and antioxidant properties of selected microgreens. This study showed that the cocopeat growing medium was the most effective growing medium for the cultivation of microgreens to increase microgreens plant growth, yield, nutritional, biochemical composition, and antioxidant activity of microgreens. The cocopeat growing medium helps to enhance the fresh weight and dry weight of microgreens (Arya, Kutty, & Pradeepkumar, 2023).

3.1.2. Aquaponics

Aquaponics is the fusion of hydroponics and aquaculture and it uses a wide range of soilless systems, vegetation, and fishes in various combinations to produce crops (Love et al., 2015). Aquaponics has a better economic potential than conventional agriculture and less of a detrimental impact on the sustainability of groundwater (El-Essawy, Nasr, & Sewilam, 2019). According to recent market analytics data, the aquaponics market as of 2023 is $1560 million, which would reach $3415.5 million towards the end of 2033, expanding at a CAGR of 8% globally and 16% in India. (Aquaponics Market, 2023). In a comparative study, Kizak and Kapaligoz (2019) examined the effects of sump filter systems (SFS) and microgreen (arugula) aquaponics systems (APS) on water quality as well as the growth of goldfish. The results demonstrated a significant reduction in ammonium levels in the APS, but nitrification was more accomplished in the SFS. Both systems were similarly effective at controlling water quality and supporting goldfish growth. For the cultivation of leafy greens cabbage, lettuce, arugula, and sunflowers were compared to the effect of conventional, aquaponics, and hydroponic cultivation growing methods. The conventional growing method required more water for cultivation 8 and 66 times as compared to aquaponics, and hydroponic cultivation growing methods. Additionally, conventional cultivation requires double the nitrogen, which could be due to nitrogen loss in the runoff, resulting in eutrophication downstream (Van Ginkel, Igou, & Chen, 2017).

3.1.3. Hydroponics

Hydroponically - without the use of soil - crops are developed in specialized mediums or nutrient solutions. Water and nutrients are the only ingredients needed for hydroponic plant cultivation. Microgreens are usually cultivated using hydroponic or vertical farming methods instead of traditional agriculture, which uses less water and land. These methods allow for year-round cultivation, have the potential to be applied in urban areas, and reduce the environmental impact of transporting and storing items (Rajan, Lada, & MacDonald, 2019). Compared to traditional methods, hydroponic farming consumes only 10% of the irrigation resources, saves up to 5–20 times the water, provides complete nutrient control, and requires up to 75% less space (AlShrouf, 2017). The market for hydroponics systems and crops was valued at $12.1 billion and $37.7 billion, respectively, in 2022 and is anticipated to grow to $25.1 billion and $2027 by 2027, with respective CAGRs of 15.6% and 7.2% (*Hydroponics Market Size by System and Crop| Growth Trends Drivers & Opportunities | MarketsandMarkets™*, 2020). The hydroponic growing methods such as deep-water culture and nutrient film technique offer increased water efficiency but on the other hand, they require more cost for equipment, energy, and space. For the deep-water culture growing systems, seeds are planted on an inert medium that floats on a deep tank containing circulated water or nutrient solution, where the roots grow to absorb nutrients. These systems require continuous aeration of the reservoir (Teng et al., 2023). A recent study found that adequate aeration helps enhance the growth of lentil and wheat microgreens, while insufficient aeration led to root hypoxia and stunted growth (Grishin et al., 2021), and too much agitation and aeration were shown to damage roots and decrease yield in Swiss chard microgreens (Baiyin et al., 2021).

3.1.4. Aeroponics

Aeroponics, a subset of hydroponics systems is a technique of cultivating plants in the absence of growing media where nutrient-rich solution mist is sprayed on suspended plant roots regularly while maintaining a dark environment. Currently valued at $2.7 billion in 2023, the worldwide aeroponics market is anticipated to grow at a CAGR of 20.5% to reach $17.4 billion by 2033 (Aeroponics Market, 2023).

One of the key requirements of any hydroponic system is nutrients, which are supplied by a nutrient solution that contains a variety of macro- and micronutrients and controls plant growth (Kozai, 2018). Recently, the development of alternative nutrient sources, implementation of machine learning systems to analyze nutrient uptake, and Internet of Things (IoT)-based user-centered design and cultivation management systems for hydroponics have been studied (Evan, Anisa, Nurfitriyani, & Alexandra, 2022; Verma & Gawade, 2021). Balmadrid, Mallorca, Gerardo, and Medina (2022) developed an IoT-based system equipped with LED with different pulsed frequencies and analyzed the growth parameters of sunflower microgreens. Environmental parameters were controlled by sensors and dark and light periods were maintained for varying intervals which demonstrated that shorter dark period with lower frequency enhances stem elongation while an increase in frequency limits the stem length. Aydin et al. (2021) applied a novel technique to detoxify and disinfect wastewater using a reactor equipped with a photoelectrocatalytic membrane (PECM) and analyzed the effect of reused treated water on hydroponically grown lettuce to counteract the water loss caused by wastewater formation. The results depicted that PECM treatment reduced the water's toxicity by 75% hence treated water had no detrimental effect on lettuce while untreated water hindered the development of the lettuce plant.

The use of hydrogel, a highly effective adsorbent 3D crosslinked polymer matrix that enhances yield and has a high water retention capacity of up to 60% without requiring structural changes, is another advanced method to reduce excessive water and nutrient consumption when using soilless farming (Banitalebi, Mosaddeghi, & Shariatmadari, 2019; Verma et al., 2018). When red cabbage microgreens were grown in a hydrogel composite made of agarose with improved porosity, Teng et al. (2021, 2023) discovered that the yield increased by 44% and the microgreens survived for 12 days without watering.

Islam, Park, and Lee (2023) experimented on wheat and barley microgreens grown with organic soil and hydroponics cultivation techniques and observed that the cultivars from pre-soaking seeds in organic soil reached their optimum weight, height, and yield and had the highest chlorophyll content. These parameters of both microgreens declined when grown in hydroponics, whether from pre-soaked or non-soaked seeds whereas the maximum carotenoid concentration was produced in both species when grown via hydroponics from non-soaked seeds. Another study by Sinha and Thilakavathy (2021) reported that spinach microgreens cultivated in coco pith had the lowest nutritional value of all, whereas soil-grown fennel, mint, amaranth, and fenugreek microgreens contained the highest amounts of calcium, iron, vitamin C, and beta-carotene, respectively. Soil-grown microgreens contained higher nutritive value than coco pith and water when compared to the other two growing mediums.

Eswaranpillai, Murugesan, and Karuppiah (2023) examined the growth of six different microgreens, including fenugreek, wheat, cowpea, mung bean horse gram, and sorghum, in three distinct media: water, soil, and cocopeat to determine and compare the nutritional qualities of the chosen sprouts vs. microgreens. The results depicted that the best medium for growing microgreens is coco peat since it has a lengthy water retention time, is porous to allow for greater root aeration, and has a shorter harvest day. Soil performed best in terms of microgreens' nutritional value since it has the highest concentration of nutrients of any media.

3.2. Microgreen harvesting and storage

Planting and harvesting periods vary based on the species of microgreen. For example, radish microgreens can be harvested after 7 days, and red cabbage and arugula microgreens typically take 11 and 9 days to harvest (Dayarathna et al., 2023a, 2023b). The roots are not considered edible as they can be a source of contaminants. The delicate structure of microgreens poses a challenge to storage and preservation. The high respiration rate of microgreens makes them highly perishable after harvesting. Large surface area and high respiration rate can result in wilting of leaves, leading to early senescence. Thus, it is important to maintain a proper respiration rate and store it in a proper condition (Rajan et al., 2019). It is generally recommended to either deliver them while they are still planted on their trays or store them in sturdy plastic containers. The containers should be refrigerated at a temperature between 1 and 4 °C to prevent spoilage, this condition maintains freshness for at least 14 days by enhancing shelf life (Shukla et al., 2021).

According to Chandra, Kim, and Kim (2012), Chinese cabbage microgreens washed with chlorinated water and contained in sealed plastic bags at 5 °C, showed degradation of Chinese cabbage on the 5th day due to fungal contamination. However, microgreens treated with a solution of 0.5% citric acid, followed by 50% ethanol treatment, or with a combination of citric acid and ascorbic acid (0.25%), continued to maintain acceptable quality up to the 7th day. On sunflower microgreens, different chemical treatments (ethanol vapor [EV], citric acid [CA], ascorbic acid [AA], CA + ethanol [CA + E], and CA + AA) were used along with packaging in polystyrene trays at 10 ± 1 °C. Among these treatment, AA and CA + AA treatments were the most effective, preserving the highest levels of total chlorophylls, carotenoids, ascorbic acid, total phenols, and DPPH scavenging activity, while maintaining the lowest microbial load (Dalal, Siddiqui, & Phogat, 2020). These findings suggest that various pre-storage treatments can have a remarkable shelf life for microgreens and should be taken into consideration when storing and preserving microgreens. A general rule of thumb in food preservation is that the rate of deterioration of perishable items accelerates threefold with a temperature of every 10 °C, which implies that higher temperature results in a faster rate of spoilage and can significantly reduce the shelf life of perishable items, including microgreens. Therefore, microgreens must be stored at low temperatures to slow down the rate of deterioration (Tracey, Kryuchkova, Bhatt, Krivoshapkin, & Krivoshapkina, 2023). Berba and Uchanski (2012) analyzed the shelf life of three varieties of microgreens to assess the effect of storage temperature. It was observed that on increasing the storage temperature from 4 to 10 °C, the shelf life of radish microgreens decreased from 21 days to 14 days. Moreover, the shelf life of red cabbage and arugula microgreens was also reduced from 14 days to 7 days. Appropriate storage conditions, particularly low temperatures, are crucial in sustaining the quality and extending the shelf life of these delicate plants. According to Xiao et al. (2014), a 1 °C storage temperature was more effective than 5 °C in preserving the sensory attributes and bioactive compounds of radish microgreens.

Mustard microgreens stored at 5 °C in polyethylene bags (150 μm) maintained high postharvest quality parameters (antioxidant activity and sensory attributes) for up to 14 days. Storage at higher temperatures (10–25 °C) significantly affected the quality and shelf life, with mustard microgreens deteriorating beyond consumption within one day at 20 and 25 °C (Dayarathna et al., 2023a, 2023b). The effect of PET clamshell (PET–CS) and LDPE self-seal bag (LDPE–SSB), on radish (RaS) and roselle (HbS) microgreens stored at 5 °C and compared pre-harvest *Aloe vera* gel spray treatment (AGSC) with postharvest dip coating (AGDC) for microgreens. PET–CS packaging resulted in better postharvest quality indicators, and AG-coated microgreens showed significantly fewer deteriorative changes and higher ascorbic acid content. AGSC was particularly effective in maintaining overall acceptability and quality, especially for HbS microgreens, suggesting it as a promising pre-harvest treatment combined with PET–CS packaging (Ghoora & Srividya, 2020).

Future research should focus on optimizing pre-harvest treatments (natural bio-stimulants and innovative cultivation practices) that help enhance the nutritional quality and shelf life of microgreens. Apart from these investigations into advanced packaging technologies such as biodegradable and compostable materials, could provide sustainable solutions while maintaining the quality and storage period of microgreens. Detailed studies is required on the impact of varying storage temperatures and humidity levels on different microgreen species could help develop species-specific storage conditions. Additionally, further research into the microbial safety of microgreens and retentions of bioactive compounds, including the efficacy of natural antimicrobial treatments and understanding microbial dynamics during storage, is crucial.

4. Microgreens nutrients and their health benefits

Despite the compact size of microgreens, they are an outstanding source of various phytochemicals that are required for the regulation of our body. They are abundant in minerals such as manganese, calcium, and zinc, as well as in bioactive compounds such as phylloquinone ascorbic acid, β-carotene, and α-tocopherol (Bakshi, Wadhwa, & Makkar, 2018; Guo et al., 2020). These nutritional constituents are known to offer various health benefits and are essential for maintaining overall well-being (Kyriacou et al., 2019). Phytonutrient content varies from one microgreen variety to another. According to Weber (2017), broccoli microgreens grown in compost contained 1.15 to 2.32 times greater mineral levels (Mg, P, Fe, K, Zn, Mn, Cu, Na, and Ca) than their mature versions. Microgreens are known for their highly concentrated nutrient content, with levels up to 30–40 times greater than those found in mature fruits and vegetables. This nutrient density, along with the presence of plant secondary metabolites, has earned microgreens a reputation as a "superfood" (Kyriacou et al., 2020). According to Wani, Farooq, and Thakur (2022), red cabbage, cilantro, green radish, and garnet amaranth microgreens contain particularly high concentrations of phytochemicals like ascorbic acid, carotenoids, tocopherols, and phylloquinone. All these varieties of microgreens also contain a significant amount of both macrominerals and microminerals, such as iron, calcium, magnesium, manganese, zinc, molybdenum, and selenium. The consumption of microgreens has been linked to the prevention of various health issues, including deficiency disorders, osteoporosis, inflammation, indigestion, and obesity, owing to their functional and nutritional properties (El-Nakhel et al., 2020; Xiao et al., 2015). Similarly, Choe et al. (2018) discussed the potential of microgreens as functional foods for the prevention of diet-related diseases. It is particularly beneficial for patients with conditions such as obesity, juvenile and adult-onset diabetes, cancer, and several cardiovascular diseases Table 1.

According to Huang et al. (2016), microgreens are an excellent source of flavonoids including kaempferol, apigenin, quercetin puerarin, and catechin, which have the potential to control the gut microbiome. Moreover, the bioefficacies of microgreens can be improved by the microbiome's metabolism of the bioactive compounds present in microgreens (Choe et al., 2018). Microgreens of barley and fenugreek have the potential to control diabetes as they contain high levels of antioxidants that decrease glucose-induced stress on cells and increase cellular glucose uptake by 25–44% (Mohamed, Abdel-Rahim, Aly, Naguib, & Khattab, 2021). Another study investigated the metabolomic profile of fenugreek microgreens and their significant bioactive potential such as antioxidant, antibacterial, and antibiofilm properties. Phytochemical analysis revealed high phenolic content in ethanol extracts and elevated flavonoid and tannin levels in methanol extracts. The methanol extract demonstrated strong antioxidant capacity, while the ethyl acetate extract showed effective antibacterial activity (*Aeromonas hydrophila, Pseudomonas aeruginosa,* and *Staphylococcus aureus*) and significant antibiofilm properties against various pathogens (Jayaraman & Ramasamy, 2024). Polyphenols can lower low-density lipoprotein (LDL) levels and help mitigate the risk of certain heart diseases like atherosclerosis and stroke, as well as decrease the risk of obesity (Zhou et al., 2016). Huang et al., 2016) experimented to assess the impact of red cabbage microgreens as a dietary supplement in mice that were previously fed a diet that had different varieties of food containing high amounts of fat. Throughout the experiment, it was observed that the

Table 1
Microgreens types and their associated health benefits.

Microgreen variety	Family	Flavor	Color	Nutritional constituents	Health Benefits	Reference
Asparagus	Asparagaceae	Spicy, peppery taste	Dark green leaves with a yellow stem	Vitamin A, C, potassium, magnesium, iron	Anti-cancer, anti-tumor, antioxidant, immunomodulatory, hypoglycemic, anti-hypertensive, and anti-epileptic effects	Guo et al. (2020); Negri et al. (2021)
Barley	Graminae	Mild, earthy, grassy taste	Green leaves with white stem	Protein, dietary fiber, vitamin E, β-carotene, and minerals like molybdenum, selenium, manganese	Improve digestion, antidiabetic, anticancerous, prevents CVD	Guo et al. (2020)
Broccoli	Brassicaceae	Mild, crunchy, slightly bitter	Bright green leaves with slight pinkish stem	Vitamin A, C, K, protein, calcium	Prevent lung and colon cancers, bone health, improve digestion, antimicrobial properties	Weber (2017); Turner et al. (2020)
Celery	Apiaceae	Sharp, distinctive flavor	Green leaves with pale green stem	Potassium, dietary fiber, vitamins A, B, C, and E, iron, magnesium, phosphorus, calcium	Improves digestion, sleep, and bone density, and helps to maintain weight,	Ghoora et al. (2020)
Cilantro	Apiaceae	Strong citrusy-celery-like taste	Greenish-red leaves	Vitamin A, C, K, calcium, iron, phosphorus, lutein, zeaxanthin	Enhance bone health, vision, and nervous system	Xiao et al. (2012)
Fenugreek	Fabaceae	Mild spicy, bitter, and nutty	Dark green leaves with light green stem	Vitamin C, protein, fibers, anthocyanins, potassium, iron, flavonoids	Controls diabetes, improves heart health and digestion, prevents prostate cancer	Kim and Milner (2005); Huang, Jiang, et al. (2016)
Flaxseeds	Linaceae	Nutty, mild spicy	Vibrant Green leaves with greenish/ pinkish stem	Protein, crude fiber, calcium, phosphorus, zinc, copper	Promote body development, bone health, improve digestion	Berry et al. (2012)
Garnet amaranth	Amaranthaceae	Beet-like, earthy taste	Deep red leaves with vibrant reddish pink stem	Vitamin C, K, phytosterols	Prevents CVD and cancer	Argumedo-Macias et al., 2021Ebert et al. (2017)
Kale	Brassicaceae	Mild grassy flavor	Dark green leaves	Vitamin C, K, protein	Good for skin, anti-cancer properties	Yanes-Molina et al. (2019)
Lemon Balm	Rutaceae	Strong citrus-lemony aroma and taste	Green leaves	Vitamin C, E, K, carotenoids, magnesium, potassium	Improves sleep, focus, DNA integrity, antimicrobial and anti-inflammatory	Wani et al. (2022); Turner et al. (2020)
Lettuce	Asteraceae	Slightly sweet	Bright green leaves with pale green stem	Vitamin C, E, K_1, minerals like potassium, sulfur, phosphorus, calcium, magnesium	Prevent inflammation, anti-cancer, eye health, heart health	Pinto et al. (2015); Yanes-Molina et al. (2019)
Melon	Cucurbitaceae	Cantaloupe flavor	Deep green leaves	Antioxidants, vitamin C, β-carotene, dietary fibers, potassium, zinc, cucurbitacin-B, folic acid	Anticancer, Anti-depressant, anti-dandruff, prevents ulcers and improves immunity	Yanes-Molina et al. (2019); Silva, Albuquerque, Alves, Oliveira, and Costa (2020)
Mint	Lamiaceae	Strong minty flavor	Light green leaves	High menthol content, contains menthone and methyl esters, dietary fiber, vitamin C, calcium, phosphorous, potassium	Helps with digestion, and weight loss, has antiseptic and antibacterial properties, boosts immunity	Berry et al. (2012); Huang, Chen, et al. (2016)
Pea tendrils	Fabaceae	Mild, sweet, nutty pea-like flavor	Yellowish green color leaves with pale green stem	High vitamins A, and C, protein, folate, and fiber	Boost immune system, improves eye health, control blood sugar, prevent breast cancer	Kim and Milner (2005)
Peppercress	Brassicaceae	Peppery, tangy taste	Dark green leaves with yellowish white stem	Vitamin A, C, K, isothiocyanates, glucotropaeolin	Improves heart, and eye health, prevents breast and prostate cancer, good for teeth	Kim and Milner (2005)
Radish	Brassicaceae	Mild earthy taste	Dark pink leaves with pale green stem	Tocopherol, high in vitamins A, C, E, and K, β-carotene, lutein/ zeaxanthin, violaxanthin, isothiocyanates	Promote eye health, reduce the risk of heart diseases, and prevent lung and breast cancers	Gao et al. (2021)
Red beet	Chenopodiaceae	Earthy, nutty flavor	Vibrant red leaves with white stem	Vitamin B_1, B_2, B_6, and C, β-carotene, folate, and minerals like copper, iron, magnesium, manganese, potassium, zinc	Helps to prevent osteoporosis and cancer	Choe et al. (2018)
Red cabbage	Brassicaceae	Mild, sweet, earthy taste	Purplish leaves with green stem	Vitamin A, C, E, β-carotene, anthocyanin potassium	Improves eyesight, digestion, and sleep	Xiao et al. (2012); Negri et al. (2021)
Sunflower	Asteraceae	Slightly sweet and nutty taste	Pale green leaves with white stem	Protein, calcium, and iron, essential amino acids, vitamins A, B, C, D, K, folic acid, and various trace minerals.	Lowers cholesterol, regulates hormones, improves bone, teeth, and heart health	Tangney and Rasmussen (2013)
Wheatgrass	Poaceae	Slightly bitter and grassy, taste	Vibrant green leaves with stem	Vitamin A, C, and B complex, essential amino acids, minerals like calcium and iron	Prevents leukemia, lowers blood cholesterol, improves digestion, anti-aging, cleanses the liver (detoxify)	Tangney and Rasmussen (2013)

inclusion of red cabbage microgreens in the diet had significant health-promoting effects on the mice. Fenugreek microgreen extract (2 mg/mL) inhibited α-amylase by 70% in HepG2 cells and enhanced glucose uptake in L6 cells by 44% in the presence of insulin, likely due to their phenolic content, flavonoids, and antioxidants (Wadhawan et al., 2017). Additionally, lyophilized broccoli microgreen powder (2 g/kg body weight) exhibits the hypoglycemic effect in mice on a high-fat diet and/or treated with streptozotocin, while barley microgreens improved glucose metabolism and reduced sperm morphological defects and chromosomal aberrations in diabetic rats (Ma et al., 2022). In another study Li et al. (2021) studied the anti-obesity effects of broccoli microgreen juice in C57BL/6 J mice on a high-fat diet. The juice significantly reduced body weight, white adipose tissue mass, and adipocyte size while improving insulin sensitivity and glucose tolerance. This study concluded that broccoli microgreen juice may prevent diet-induced obesity by modulating gut microbiota and enhancing liver antioxidant capacity, supporting its potential as a functional food for obesity management.

In addition to this, microgreens from plants such as garlic, cabbage, soybeans, and ginger are the richest source of antioxidants and polyphenolic compounds which might be effective against the rise of cancer and Alzheimer's disease. Supplementation with microgreens has been shown to prevent or reduce excess body fat, and cholesterol levels, and reduce hepatic cholesterol ester, triglyceride, and inflammatory cytokine levels. Moreover, microgreens from families such as Brassicaceae and Lamiaceae contain compounds like indole-3-carbinol, retinoic acid, and a metabolite of β-carotene help to regulate weight by suppressing adipogenesis (Berry, DeSantis, Soltanian, Croniger, & Noy, 2012; Choi, Um, & Park, 2012). Microgreens have been identified as a potential means of preventing cancer through their impact on inflammatory pathways. Research has found that the compounds indole-3-carbinol, as well as diindolylmethane, found in microgreens, are capable of activating enzymes involved in xenobiotic metabolism (Dashwood, Arbogast, Fong, Hendricks, & Bailey, 1988). This process helps cells more effectively defend against and eliminate carcinogenic substances from the body (Kim & Milner, 2005). Microgreens derived from Brassica vegetables contain high levels of indole precursors and other inducers of xenobiotic metabolism, which stimulate the activity of Phase I and II enzymes involved in the metabolism of xenobiotics. These enzymes play a critical role in suppressing cancer-initiating cells (Bradfield & Bjeldanes, 1987.

5. Market trends of microgreens

The demand for the availability of microgreens is tremendously increasing, because of the associated health benefits with their regular inclusion in the diet. The market for microgreens is predominantly targeted towards upscale grocery stores and restaurant chefs, along with the cosmetic industry, which utilizes microgreens for the production of oils and certain other ingredients in skincare and shampoo products. Due to this, the microgreens market is predicted to expand vastly in the upcoming years, primarily driven by advancements in indoor growing technologies (Paraschivu et al., 2021). Microgreens are utilized globally by chefs as both flavorful additions and garnishes across various cuisines, providing significant nutritional benefits to human diets (Treadwell, Hochmuth, Landrum, & Laughlin, 2020). Microgreens impart unique flavors ranging from spicy to sweet and spruce it up with vibrant hues and flavors, thus elevating the aesthetic character of a dish. They are generally served along with salads, sandwiches, and soups, and are also extensively used for garnishing and toppings on pizza, curries, omelets, etc. (Murphy, Lort, & Pill, 2010).

Microgreens businesses typically require minimal upfront investment and utilize limited resources and workspace. They also have a quick turnover rate and can be cultivated year-round using various methods, making them highly profitable. Many growers opt for the seeding mat production system, which is popular due to its ability to facilitate faster harvesting and be sold directly to chefs for on-demand harvesting. This method allows for more efficient and profitable cultivation of microgreens (Hochmuth & Cantliffe, 2012).

Although the majority of microgreens are now produced domestically the globalized nature of the food supply chain has made food production and commerce an increasingly important topic in domestic policy and international relations. Wholesale to high-end, mid-range restaurants, and supermarkets, as well as direct-to-consumer sales through local farmers' markets, field stands, and online purchasing the main distribution route for microgreen suppliers. Many farmers have created online or in-person business-to-consumer platforms in addition to direct distribution to consumers at farmer's markets. High-cuisine restaurants relate to the microgreens market niche both domestically and internationally (Yanes-Molina, Jaime-Meuly, Andrade-Bustamante, & Lucero-Flores, 2019). The market sectors in industrialized nations have extended to include organic supermarkets and general stores (farmers' markets), where people are willing to spend a higher cost to receive high-quality, organic, locally produced, and nutrient-dense goods.

Microgreens have been in use since the 1980s, yet, to date, no commercial microgreen-based product is available in the market. The popularity of microgreens has just recently increased, and microgreen research is still in its infancy. Limited research has been done on the optimization of microgreen-based products and their analysis of possible bioactive compounds Fig. 3. Some of the optimized products include Amaranth microgreens salads, ready-to-serve and fruit-based microgreen beverages with spinach and fenugreek microgreens, bread enriched with pea and lupin microgreens and fresh microgreen *Alternanthera sessilis* microgreens juice. These products were analyzed for several phytochemicals and were proved to be an excellent source of bioactive compounds like Quercetin, kaempferol, chrysoberyl, ascorbic acid, tocopherol, genistein, carotenoids, saponins, tannins, terpenoids, steroids flavonoids, chlorophyll and some minerals like selenium, molybdenum, calcium, iron. All these products have excellent health benefits like as anti-diabetic, anti-ulcer, antibacterial, anti-inflammatory, antioxidative, anti-cancer, and anti-proliferative activity that can help in the prevention of cardiovascular diseases, lowering blood pressure, and improving bone health and eyesight. The quick quality degradation that happens shortly after harvesting, which results in high prices and confines trade to local retailers, is one of the key factors limiting the expansion of the microgreen sector (Turner et al., 2020).

Microgreens are still relatively new to the majority of customers. The findings of a recent survey conducted in Nepal by Van Rooyen et al., 2021) indicate that 89% of microgreens sales are negatively impacted by a lack of consumer awareness, the survey concluded only 50% of survey participants were found to be aware of microgreens. India has seen a notable increase in both awareness and research regarding microgreens in recent years in comparison with Nepal. The growth of the microgreens market in India can be attributed to the widespread adoption of hydroponic farming practices in the agricultural sector. Hydroponic cultures are favored for their ability to produce nutrient-dense and delicious vegetables, particularly in the hotel industry. This method is highly efficient in terms of cost, eliminates the need for pesticides, optimizes land usage, and increases yield.

In the year 2019, the estimated net worth of the global microgreens market was around $1.3 billion, which was forecasted to rise to $2.2 billion by the end of 2028, growing at a CAGR (Compound annual growth rate) of 11.1% from 2021 to 2028, Fig. 4. In the year 2022, the market value of microgreens was estimated to be $1.7 billion, which has been forecasted to reach $2.61 billion by the end of 2029 (*Allied Market Research*, 2022). The United States is the largest growing sector of the global microgreens market, closely followed by Mexico and Canada. North America held a total sales of 50% market share for microgreens in 2019 and is expected to maintain its dominance globally in the microgreens market till the forecast period from 2019 to 2028. According to a 2019 report by Straits Research, the North American and European

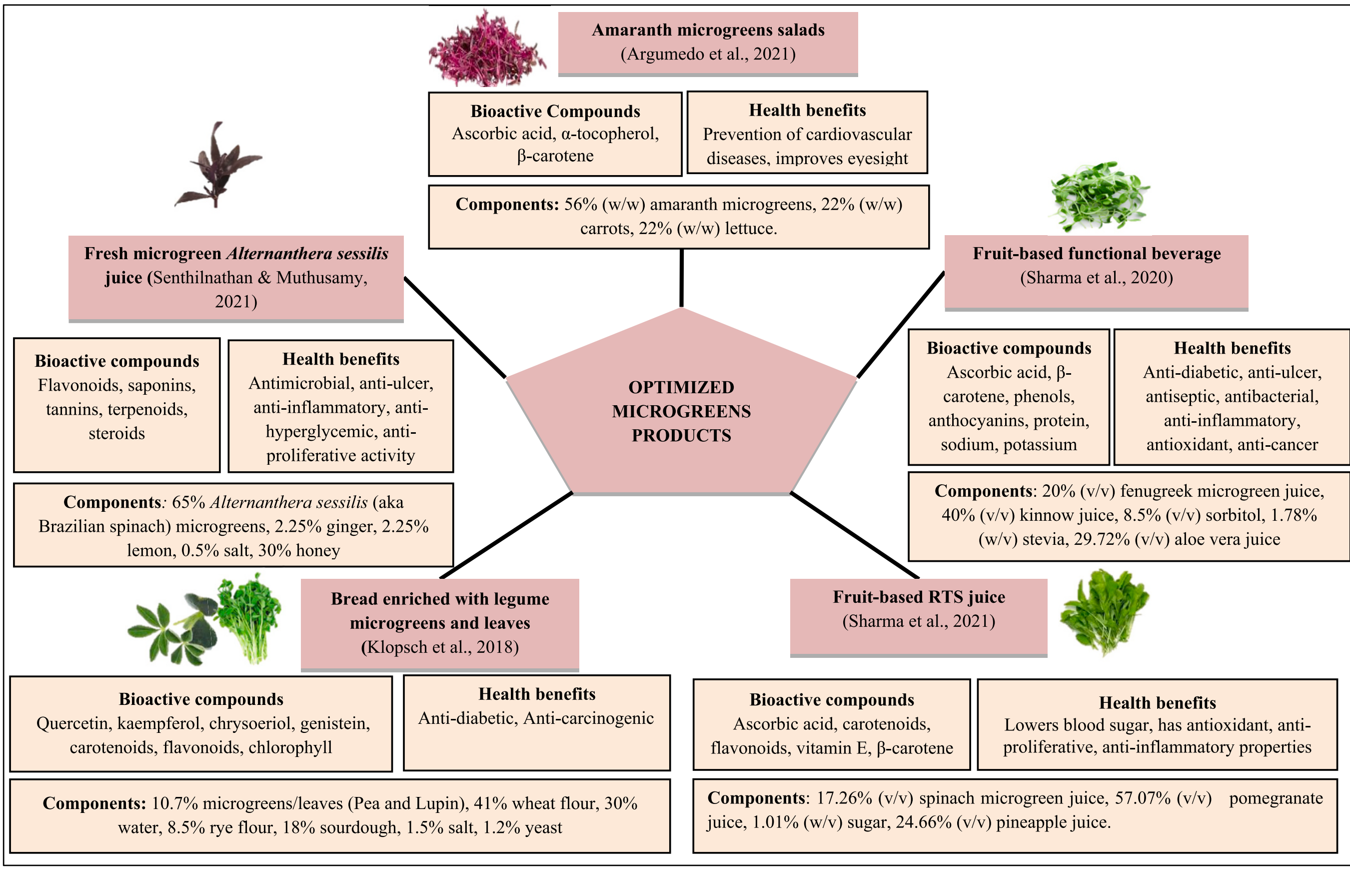

Fig. 3. The optimized microgreens based value added products.

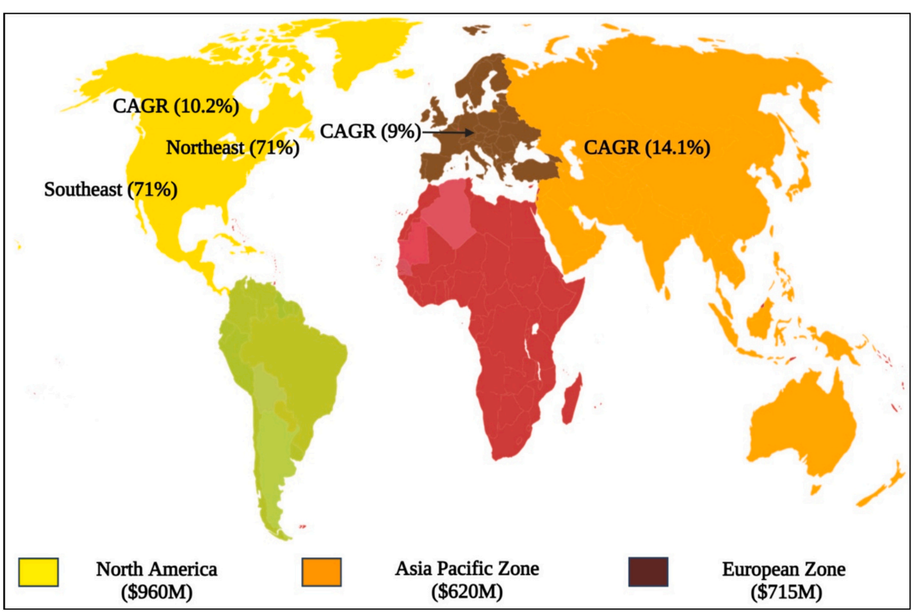

Fig. 4. The worldwide microgreens market CAGR forecast (2019–2030).

markets for microgreens were estimated to reach $960 million and $715 million respectively by 2030, with a CAGR of 10.2% and 9.7%. According to the Comprehensive Research Report by Market Research Future (MRFR), the microgreens market is estimated to reach nearly $2500 million by the end of 2030, with a CAGR of approximately 13.5% from 2020 to 2030. Moreover, NASA and the European Space Agency have identified microgreens as a potential source of fresh food and essential nutrients in space stations. Recent studies have shown that as part of parabolic flight tests, the Kennedy team developed growing boxes to test their efficacy by implementing a variety of harvesting and bagging practices. The plane's trajectory during a parabolic flight was made up of several sets of parabolas, where every set provided 20 s of weightlessness and 20 s of high gravity. Typically, research flights follow a trajectory made up of six distinct sets of five parabolas. The initial group of parabolas used in the Kennedy team's microgreen test flights produced Martian (3/8 g) and Lunar (1/6 g) gravitational levels rather than weightlessness and included three different methods of harvesting (traditional, sliding blades, and counter-rotating plates) along with manual and mesh bag (attached to chamber) bagging methods. The experiment concluded that harvesting within a glovebox was preferred to avoid any microgreens and debris dispersion in the aircraft due to antigravity (Braatz, Massa, Johnson, Poulet, & Boles, 2022.

According to Du, Xiao, and Luo (2022), lettuce, broccoli, arugula, and basil are among the major microgreens grown using hydroponics and vertical farming techniques in various locations. The market for these microgreens is driven by the widespread farming and consumption of microgreens in the USA, with restaurants being the largest consumers. A survey conducted in Mexico by Yanes-Molina et al. (2019) revealed that 61.54% of the surveyed restaurants were aware of microgreens, whereas the remaining 38.46% were unaware.

The fastest-growing microgreens market is currently the Asia-Pacific region, which is projected to reach a value of $620 million by the end of 2030 with a CAGR of 14.1% (Straits Research, 2022). The Food and Agriculture Organization reported that the top producers of broccoli microgreens were China as well as India, accounting for the global production of a total of 73% in 2017, with sales of 10.4 million and 8.6 million metric tonnes, respectively. In India, there are great business-to-business opportunities (B2B) opportunities for entrepreneurs and farmers in the microgreens cultivation sector, due to the growth of the consumer-driven economy. An increase in the hospitality and travel industries leads to the establishment of more hotels and restaurants, which are the largest consumers of microgreens. The rising literacy rate and awareness among people, along with changes in lifestyle and food choices, provide favorable business-to-consumer trends for the microgreens market. Microgreens in India are highly valuable and 100 g of microgreens can be sold for a profitable price of approximately Rs. 150 (Gupta et al., 2023).

Xiao et al. (2019) found that Brassicaceae microgreens, such as broccoli and cauliflower have a surplus amount of phylloquinone, ascorbic acid, tocopherols, polyphenols, carotenoids, and glucosinolates. According to various studies, leafy greens belonging to the Brassica family contain phytochemicals that have anticancerous properties. Microgreens belonging to the Brassicaceae family contain a class of natural compounds called Sulforaphane (isothiocyanate), a redox-active natural substance. The highest content of Isothiocyanates is present in broccoli microgreens. It also contains Glucosinolates, (sulfur-rich thioglucosides), which is a precursor of Sulforaphane, that inhibit the proliferation of cancerous cells helps with detoxification, hormone imbalance, estrogen metabolism, and improve symptoms of autism spectrum disorder (Gao et al., 2021). In a study by Xiao et al. (2016), 30 different varieties of Brassicaceae microgreens were examined, and it was found that these microgreens are rich sources of macro and micro elements like calcium, potassium, iron, and zinc. In addition to this, the results also revealed that the carotenoid content in cauliflower and broccoli microgreens was more than that of their fully mature florets. Because of their exceptional qualities, Brassica microgreens, particularly broccoli microgreens, are the most widely used, with Arugula microgreens being the second most popular· The estimated market value for broccoli and arugula microgreens is expected to grow to $560 million and $330 million respectively by 2030, at a CAGR of 10% and 9.4% (*Allied Market Research*, 2022).

Among all these species, Brassicaceae, particularly broccoli, is the most widely cultivated due to its nutritional value and ease of growth. A study by Renna and Paradiso (2020) compared six microgreen varieties for potassium, magnesium, total antioxidant capacity, iron, total soluble polyphenols, ascorbic acid, total anthocyanins, calcium, total carotenoids, zinc, and total isothiocyanates content. After the evaluation, the results of the experiment revealed that cauliflower microgreens had the highest yield, with higher levels of magnesium and tocopherol in comparison with other genotypes. Meanwhile, broccoli raab had the fastest growth rate among the six varieties.

6. Consumer acceptance of microgreens

The growth of the microgreens market is dependent on the restaurant's growth rate. The sensory properties, chemical properties, acceptability, customer perception, and socioeconomic status are crucial factors in determining the market's growth of microgreens. In a comparative study conducted by Caracciolo et al. (2020) on the sensory analysis and acceptability of 12 microgreens varieties including amaranth, cress, komatsuna, green basil, coriander, mizuna, mibuna, pak choi, purple basil, tatsoi, swiss chard, and purslane; it was observed that the overall consumer acceptance of the selected microgreens by 54 individuals was mainly determined by flavors like lower astringency, sourness, bitterness, and better texture, despite their appreciable appearance. Among the evaluated microgreens, cress and mibuna were the least preferred varieties, while coriander and Swiss chard accepted the highest ratings by the consumers.

Michell et al. (2020) surveyed six popular microgreen species—broccoli, bull's blood beet, arugula, red garnet amaranth, pea, and red cabbage, which were tested for consumer approval. Based on their sensory qualities, all six microgreen crops could be employed to improve the aesthetic appeal of dishes because they all obtained high scores in terms of appearance. Broccoli, pea, and red cabbage obtained the highest overall approval score out of the six microgreen crops tested, with comparable tendencies for flavor and texture.

Xiao et al. (2015) conducted a study on the acceptability of six different varieties of microgreens including mustard, pepper cress, basil, china rose, blood beet, and red amaranth. Results showed that all the species of microgreens were well accepted and received “good” to “outstanding” consumer approval ratings. Among these species, bull's blood beet received the highest acceptability rating due to its favorable characteristics and overall sensory attributes, while pepper cress received the lowest rating.

In South Asia, the consumption of mung beans is primarily in the form of porridge or dhal, as reported by Ebert, Chang, Yan, and Yang (2017). However, the consumption of mungbean microgreens is being promoted as a more nutritionally superior alternative, particularly in the high-altitude and plain regions of Ladakh, due to their fast cultivation period, low workspace requirements, and high economic yield (Mishra et al., 2022). Ghoora et al. (2020) conducted a consumer acceptance study in India to assess the acceptability of 10 different microgreens including fenugreek, carrot, radish, red roselle, mustard, spinach, onion, fennel, sunflower, and French basil. Results showed that all 10 microgreens received very good to excellent ratings for organoleptic properties. Consumer acceptability and trends can significantly impact the growth of the microgreens market. Studies have shown that microgreens receive favorable ratings for appearance, flavor, and texture, and consumption is constantly growing and gaining popularity in various regions including South Asia (Caracciolo et al., 2020; Renna & Paradiso, 2020).

7. Future scope

Microgreens, being a highly nutritious and rapidly growing plant variety, have gained the attention of researchers in NASA to combat the limited resources of food and psychological requirements of crew members on orbital flights. (Kyriacou et al., 2016). Cultivating microgreens in space still requires extensive research to fully overcome the challenges of sanitation, water resources, excessive use of seeds, enhancing the shelf life of microgreens, etc. Microgreens have a comparatively shorter shelf life and can be easily grown. To increase their shelf life and preserve the nutritional content of microgreens, they can be dehydrated and powdered to improve their shelf stability. Generating and analyzing in-depth experimentation data on the effects of different drying temperatures on microgreens could prove to be beneficial could analyze the loss/gain of bioactive compounds, and activation energy and help to develop sustainable methods to improve the economics of the microgreens production and its marketability.

Microgreens possess diverse health benefits but challenges in production, storage, and consumption need addressing, including optimizing the growth rate and yield of microgreens. Further research is needed to understand the microbial load and develop techniques to prevent food-borne diseases. Exploring the metabolic profiles of various microgreen species is crucial to map their activity. Additionally, improving production technology, pre- and post-harvest techniques, packaging, and shelf-life maintenance are essential. Increasing awareness of the nutritional value, preparation methods, sensory characteristics, and palatability of microgreens will help enhance health outcomes.

8. Conclusion

The microgreens market is certainly gaining popularity and can surely be enhanced by addressing quite a few challenges. Analysis of the factors that influence consumers' food purchasing intentions can provide substantial benefits to sellers and food producers by enabling them to approach their audience more effectively and maintain their competitiveness in the food market. Cultivation, harvesting, packaging, and storage parameters are critical factors that can significantly impact the sensory aspects of microgreens, thereby influencing consumers' sensory analysis, perception, and acceptability. According to the above review, the United States microgreens market holds the largest share while the fastest growing sector is the Asia-Pacific. The limited awareness of microgreens in India is due to a lack of interest in trying new things among those who follow traditional and cultural beliefs. To raise awareness about the health-promoting benefits of microgreens, it is essential to increase advertising efforts. Further research is needed to develop and analyze microgreen-based products to address the challenges of quick degradation in quality after harvest. Addressing these challenges could potentially expand the microgreen industry and make microgreen products more accessible to consumers.

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Aishvina Singh: Writing – original draft. **Jyoti Singh:** Visualization, Supervision. **Sawinder Kaur:** Supervision. **Mahendra Gunjal:** Validation, Software. **Jaspreet Kaur:** Visualization, Supervision. **Vikas Nanda:** Writing – review & editing, Supervision. **Riaz Ullah:** Supervision, Funding acquisition. **Sezai Ercisli:** Validation, Resources. **Prasad Rasane:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors declare that there is no conflict of interest.

Data availability

Data will be made available on request.

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