**Microgreens in Urban Agriculture: Bridging Nutrition, Sustainability and Innovation**

**Abstract**

 Microgreens are young plants harvested just after the cotyledons have developed-have become known for their nutrient density, with studies showing they can have higher concentrations of vitamins, minerals and bioactive compounds than their mature counterparts.They are consumed for their dense content of up to 40 times nutrients including vitamin C, vitamin E and antioxidants. They are rich sources of vitamin C and vitamin E, calcium, iron and antioxidants. They hold potential for addressing micronutrient deficiencies and contributing to public health due to their better anti-oxidant and anti-inflammatory functions. Microgreens provide a variety of health benefits, such as protection from cardiovascular diseases, improved immune system function and a lower risk of chronic diseases. Research emphasizes the importance of microgreens for reducing LDL cholesterol levels, enhancing endothelial function and their anti-inflammatory and immunomodulatory effects, thus positioning them as a beneficial natural tool for cardiovascular health support and optimizing immunity. Microgreens are grown with either soil, hydroponic or aeroponic systems. Microgreens, despite their advantages, are challenged with low shelf-life (5-10 days), substantial initial investment on controlled-environment systems and limited consumer awareness in non-urban areas.

Urban agriculture incorporates microgreens to meet the growing food demand with a smaller carbon footprint, using less water and time. They grow quickly, making them well-suited to cities. However, the most challenged small-scale growers may benefit economically with high profitability given low startup costs, but high production costs impact economic viability and have limited expansion due to concise market. Microgreens have become increasingly popular in recent years owing to their high nutritional value, often offering a greater concentration of vitamins, minerals and antioxidants than their adult forms. As a result, there is growing interest and rising demand for microgreens in urban and health-focused markets. Cultivation methods, health benefits, and sustainable agriculture role are important to know & find a right market. This review paper discusses about nutritional, health, economical, environmental & cultivation & related aspects of microgreens.

 **Keywords**: Microgreens, urban agriculture, nutrient density, sustainable farming, Antioxidants.

1. **Introduction:**

Foods have a vital role in the development of the human body, promoting a healthy and balanced culture. Food provides essential nutrients for human development, including carbohydrates, fibre, protein and lipids. Sprouts and microgreens have been shown to drive curiosity in recent years through a variety of self-control mechanisms. Microgreens are small vegetable seedlings and natural herbs that grow in 7 to 14 days, making them an emerging superfood. They became well-known in high-end dining establishments as "vegetable confetti." The concept of microgreens is relatively novel in contemporary nutritional research. Microgreens are nutrient-dense and contribute to a healthy, balanced diet (Reddy et al., 2021). In the early 1980s, microgreens initially appeared on restaurant menus in San Francisco, California. Although microgreens have gained popularity since their introduction in high-end kitchens in the late 1990s, restaurant cooks remain the major target market. It was observed in 2018 that because microgreens are now readily available in supermarkets and gourmet retail outlets, their demand has skyrocketed. Many fruits, vegetables, grains and herbs from the Brassicaceae, Lamiaceae, Amaryllidaceae, Apiaceae, Amaranthaceous, Cucurbitaceae, Fabaceae and Asteraceae families have young and tender cotyledonary leaves, including hypocotyls, that can be environmentally friendly if appropriate (Choe et al., 2018a) (Kyriacou et al., 2016).



**Fig.1** Beetroot, Cabbage, Fenugreek and Radish Microgreens.

1. **Nutritional Profile of Microgreens:**

Microgreens have gained substantial interest in recent times because they offer nutritional value as well as health benefits. They bring both flavour and substantial amounts of vital elements and bioactive compounds that support human health. The evaluation of microgreens nutrition relies on research findings which reveal both their major and minor elements alongside their phytochemical counts, as shown in Table 1 (Bhaswant et al., 2023). Our rising incidence of chronic diseases because of unhealthy diets demands that nutritious food must remain accessible at all times. Microgreens hold outstanding nutritional worth because they pack 40 times more nutrients than full-size vegetables would (Lone et al., 2024). Microgreens are young vegetable greens harvested soon after the development of their cotyledon leaves. These products contain essential vitamins and minerals as well as antioxidants so they improve the dietary value of human nutrition (Xiao et al., 2012b). Research indicates that microgreens accumulate nutrient levels which exceed those found in mature vegetables so they serve as an effective remedy against micronutrient deficiencies .(Kyriacou et al., 2016c) Microgreens display a growth duration between 7 to 21 days and require little space which enables their installation in urban settings such as kitchens and rooftop gardens. Because of their dense nutrient content microgreens represent an optimal dietary remedy for those who need nutritional supplementation in cities. Cities that support microgreen cultivation locally will improve the sustainability and resilience of their food systems (Lone et al., 2024).

**Table 1:** Performance of microgreens as compared to mature greens in various nutritional aspects.

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| --- |
| **Comparison of nutrient content of microgreens with mature vegetables or plants** |
| **NUTRIENT** | **MICROGREENS (100G)** | **MATURE GREENS (100G)** | **Refrences** |
| Vitamin C | Up to 40 mg | 5-15 mg | (Bhaswant et al., 2023) |
| Vitamin E | Up to 3 mg | 0.5-1 mg |
| Calcium | Up to 660 mg | 100-200 mg |
| Iron | Up to 15 mg | 1-3 mg |
| Antioxidants | High concentrations | Lower concentrations |

* 1. **Comparison of microgreens with mature greens**
		1. **Nutritional Content:**

Microgreens are often considered nutrient-dense foods, as they have a higher concentration of vitamins, minerals and antioxidants than mature produce. Research shows that microgreens of red cabbage, cilantro and garnet amaranth are far richer in vitamin C, vitamin E and beta-carotene than mature plants. Specifically, red cabbage microgreens contained 6× more vitamin C and 69× more vitamin K than mature red cabbage (Dubey et al., 2024). Likewise, broccoli, radish and mustard microgreens were found to contain higher concentrations of essential elements, including calcium, magnesium and iron, than their mature counterparts (Kyriacou et al., 2016). Microgreens are small and nutrient dense because they're growing fast and building metabolic activity in a young plant. Expanding on this, as plants grow older, their chemical concentration per unit weight generally declines due to dilution effects triggered by additional water-containing fractions as well as more recalcitrant components like cellulose and lignin. Due to this fact the overall nutrient yield per plant of mature vegetables is higher as compared to the immature ones due to the greater size and biomass mass accumulation of the mature vegetables (Tan et al., 2020).

* + 1. **Macronutrient Content:**

The nutritional elements in microgreens shift significantly based on the specific plant species together with cultivation methods. Microgreens contain a limited number of calories between 20 to 53 kilocalories in each 100-gram portion while their fat content remains between 0.15 to 0.66 grams per 100 grams (Kowitcharoen et al., 2021). The three main macronutrients found in microgreens consist of carbohydrates, proteins and dietary fibre. Lentil microgreens possess 6.47 g of protein per 100 g while mung bean microgreens have 7.16 g of carbohydrates in the same weight measurement ((Bhaswant et al., 2023; Kowitcharoen et al., 2021). The protein content present in Microgreen matches levels seen in matured plants which makes this nutrient composition stand out. Various culinary microgreens boast high protein content according to researchers so they function as excellent dietary protein supplements for people following low-protein diets. Some microgreens possess substantial fibre content levels since individual variants contain up to 2.46 g of dietary fibre within 100 g (G, 2022).



**Fig.2** Difference between Microgreens, Sprouts and Mature plants

* + 1. **Bioactive Compounds and Antioxidant Activity:**

Different bioactive chemicals found in microgreens include polyphenols glucosinolates and carotenoids that perform antioxidant and anti-inflammatory actions, as shown in Table 2. The glucosinolates and phenolic substances found in microgreens of broccoli and red cabbage exist at levels above those found in mature plants. The substances have proven benefits for reducing stress through oxidation while helping defend against diseases such as cancer and heart disease (Mir et al., 2017). Multiple scientific works show microgreens surpass the antioxidant power of mature plants while several studies confirm their better antioxidant capacity. The antioxidant activity in Microgreens of red cabbage, cilantro and garnet amaranth exceeds mature plants by 4-40 times (Dubey et al., 2024). Total phenolic content and antioxidant activity showed higher values for microgreens of kale and mustard when compared to mature (Choe et al., 2018). The high amount of bioactive chemicals developed through environmental stress response during early growth phases enables microgreens to demonstrate strong antioxidant properties. The chemical synthesis processes gradually decrease with plant aging so mature vegetables exhibit lower antioxidant activity (Tan et al., 2020).

Table 2: Bioactive compounds in various Microgreens

|  |  |  |
| --- | --- | --- |
| **Microgreen Species** | **Major Bioactive Compounds** | **Reference** |
| Broccoli *(Brassica oleracea var. italica)* | Glucosinolates, ascorbic acid, carotenoids, tocopherols | Bhaswant et al. 2023 |
| Kale (*Brassica oleracea var. sabellica*) | Glucosinolates, carotenoids, tocopherols, ascorbic acid |
| Red Amaranth (*Amaranthus cruentus*) | Anthocyanins, phenolic compounds, flavonoids |
| Radish (*Raphanus sativus*) | Anthocyanins, glucosinolates, ascorbic acid, phenolics | Gunjal et al. 2024 |
| Beetroot (*Beta vulgaris*) | Anthocyanins, betalains, phenolic acids |
| Flaxseed (*Linum usitatissimum*) | Chlorophylls, carotenoids, flavonoids |
| Lentil (Lens culinaris) | Carotenoids, chlorophylls, proteins | Kowitcharoen et al. 2021 |
| Buckwheat *(Fagopyrum esculentum*) | Phenolic compounds, flavonoids, antioxidants |

1. **Health Benefits:**

Microgreens is also a rich source of antioxidants that protect the heart, boost immunity system and minimize risk of chronic diseases. Microgreens derived from both broccoli and red cabbage have been shown through laboratory test results to reduce LDL cholesterol levels along with improved endothelial function for cardioprotective benefits. In vitro evaluation showed that mustard varieties and kale microgreens have anti-inflammatory and immunomodulatory properties which suggests their endless potential for boosting the immune system (Partap et al., 2023).

The health benefits of matured vegetables may vary according their nutritional information and the distribution of bioactive phytochemicals. Broccoli at the mature stage is well known as a provider of the anti-cancer chemical sulforaphane with sulforaphane existing at lower levels than that found in broccoli microgreens. The mature broccoli has less sulforaphane than broccoli microgreens because microgreens are richer in glucoraphanin. The positive health impacts of microgreens can be attributed to their elevated nutritional content along with their bioactive chemical compounds which may act in concert to support human health (Partap et al., 2023)

1. **Environmental and Economic Considerations**:

These miniature vegetable plants deliver exceptional results over mature vegetables when it comes to sustainability both environmentally and economically. Microgreens utilize minimal land and water resources and cultivation period thus making them an environmentally sound choice for city-based agriculture and compact farm operations. The cultivation of microgreens requires only 90% of water and 50% of space that mature vegetables use which makes them an ideal choice for resource-scarce areas. A rapid production cycle of microgreens enables many cycles of harvest during a short timeframe. Furthermore, farmers can achieve greater income from their operations especially when fresh locally produced vegetables gain popularity in metropolitan regions. The growth requirement for mature vegetables extends beyond standard durations while needing additional resources resulting in economic constraints for certain production circumstances (Dubey et al., 2024).

5. **Cultivation ptactices of Microgreens**

* 1. **Soil-based Cultivation:**

 Soil-based cultivation stands as the conventional and standard technique used for microgreen plant cultivation. Seeds planted in a soil medium provide required nutrients together with water support and physical structure for the plants to grow. A preference exists for soil-based systems because they offer easy operation along with affordable beginnings and native soil nutrient resources. The outcome of microgreens development in terms of both their growth and nutritional profile heavily depends on the soil conditions with their texture and pH levels and their nutrient composition (Xiao et al., 2012).

* + 1. **Advantages of Soil-based Cultivation:**

 The main benefit of soil-based cultivation results from its extensive microbial environment that strengthens plant growth performance as well as mineral absorption. The broad microbial community present in soil contains beneficial fungi and bacteria which enhance essential nutrient quantities including N, P and K. The health of plant organisms improves through two key benefits of microorganisms in soil: they support root systemic growth and protect plants against pathogen attacks from the ground (Xiao et al., 2012). The buffering effect provided by soil-based systems protects microgreens against environmental changes that affect their growing environment particularly well for sensitive species. Soil functions as a water storage system which decreases irrigation needs and guarantees continuous moisture supply to plants (Di Gioia et al., 2017).

* + 1. **Impact on Nutritional Quality:**

Soil-grown microgreen nutritional content depends on what elements are present in the soil mix together with organic matter content. It was discovered that microgreens growing in soil demonstrate more significant mineral levels particularly calcium, magnesium and iron as compared to soilless cultivation (Xiao et al., 2012). Soil microorganisms boost nutrient accessibility in combination with soil mineral materials leading to this phenomenon.

The nutritional value of soil-grown microgreens may decrease because heavy metals along with pesticides accumulate within the growing soil. High-quality uncontaminated soil should be used for growing microgreens while chemical pesticides and fertilizers must be prevented. Despite the use of organic farming methods practitioners achieve two benefits: they sustain soil health while simultaneously decreasing contamination risks (Pinto et al., 2015).

* + 1. **Challenges of Soil-based Cultivation :**

The cultivation technique of using soil has several benefits yet it presents multiple operational hurdles. Soil-borne diseases together with pests present a main disadvantage that decreases microgreen yield quality and quantity. Soil usually contains two pathogens Fusarium and Pythium that cause root rot diseases which slow plant growth while reducing microgreen nutritional content (Di Gioia et al., 2017). Interactive pest management strategies should include plant selection of disease-resistant varieties together with biological control agents and soil sterilization measures for effective disease and pest control measures (Karlsson Green et al., 2020). Soil quality differences create challenges for consistent microgreen production because they result in irregular results. The growth and incorporation of nutrients gets negatively affected in soil that exhibits poor organic matter, drainage issues and unbalanced nutrient availability. The growers need to perform regular soil tests to determine proper amendment requirements by adding organic matter while also using lime and other soil conditioners (Zhou et al., 2024).

* 1. **Hydroponic Cultivation:**

 The method of hydroponic cultivation allows plant growers to cultivate plants without soil by providing them nutrients dissolved in water solutions. The method has become popular in microgreen farming because it offers exact control of nutrient delivery and water access along with environmental condition management. Hydroponic farmers utilize three major design options for their systems which are deep water culture and nutrient film technique and ebb and flow systems so they can select the configuration that suits their growing needs best (Di Gioia et al., 2017).

* + 1. **Advantages of Hydroponic Cultivation:**

 Hydroponic cultivation provides the main benefit of delivering optimized nutrient access right to plant roots. Through hydroponic systems plant roots receive their required essential elements because nutrients are dissolved in water before direct delivery to plant roots. Fast growth rates combined with elevated production outputs occur under hydroponic systems when compared with conventional soil cultivation according to (Di Gioia et al., 2017). Hydroponic systems enable users to control the pH and electrical conductivity (EC) of the nutrient solution precisely because the system adapts to various needs of specific microgreen species. Plants grown through hydroponics have a decreased likelihood of major soil-based diseases and pests since their growing substrate remains sterile. Hydroponic methods lower the requirement for chemicals in microgreen cultivation which produces safe and healthy microgreens free from detrimental substances. The water efficiency of hydroponic systems exceeds average because nutrients from the recirculated solution retain their value for further use thus minimizing water loss. (Benke & Tomkins, 2017).

* + 1. **Impact on Nutritional Quality:**

 Under optimal conditions which hydroponic systems provide growers can enhance microgreens nutritional quality by enabling precise nutrient delivery systems and reducing stress factors during cultivation. Scientific studies demonstrate that hydroponic cultivation raises the vitamin content of microgreens including vitamin C and vitamin E beyond levels detected in soil-based microgreens (Di Gioia et al., 2017). The accurate delivery control combined with pathogen-free conditions in hydroponics produce this effect on plant health. How microgreens develop through hydroponic cultivation depends largely upon what specific nutrients the growers feed to their plants. The precise monitoring of nutrient solution composition becomes vital because both deficiencies and toxicities in solution can cause nutritional problems in the growing microgreens. Regular checks and appropriate modifications of nutrient solution composition and pH and EC measurements should be performed by growers to maintain superior nutritional value (Renna & Paradiso, 2020a; Turner et al., 2020)

* + 1. **Challenges of Hydroponic Cultivation:**

 The benefits of hydroponic cultivation confront serious difficulties. The main difficulty in using hydroponic systems lies in their expensive initial setup requirements and technical complexity. Operating hydroponic systems demands specialized hardware including pumps and grow lights together with reservoirs that demand extensive knowledge to use and cost considerable money. Failed equipment components such as pumps together with power outages impact hydroponic systems more strongly because they create disruptions in nutrient delivery which results in damaged crops (Agarwal et al., 2302). Proper management stands as a critical challenge when operating the nutrient solution. The performance of plants and nutrient composition suffers when the nutrient solution becomes unbalanced due to either inadequate or harmful elements. The nutritional value of the hydroponic system depends on regular checks of nutrient solution composition and pH and EC measurements (Kumar et al., 2023).

* 1. **Aeroponic Cultivation:**

The aeroponic technique relies on mist-fed plants that have their root systems dangling in the air or mist environment. The plant roots receive both oxygen and nutrients through regular misting of water containing high nutrient content. The new method has demonstrated potential in microgreen production because it produces efficient results while generating high crop yields.

* + 1. **Advantages of Aeroponic Cultivation:**

 Roots in aeroponic cultivation receive optimized oxygen accessibility due to which their growth remains vigorous while they rapidly absorb nutrients from the environment. Hoogstraten allows roots to remain exposed to the atmosphere where maximum oxygen absorption takes place for root respiration and general plant health according to (Benke & Tomkins, 2017). Aeroponic cultivation enables better oxygen exposure to roots thus generating increased growth speed and higher harvest amounts in contrast to soil-based and hydroponic cultivation systems.

The sustainability of aeroponic cultivation improves through water conservation that exceeds traditional soil-based along with hydroponic cultivation methods. The nutrient solution delivers an efficient mist supply to plant roots by scheduled intervals which prevents water waste and supports efficient nutrient distribution. Because aeroponic systems occupy minimal space they represent an optimal solution for agriculture installations in urban areas that have restricted space (Lakhiar et al., 2018).

* + 1. **Impact on Nutritional Quality:**

 Higher metabolic activity occurs in plants because of increased oxygen levels within aeroponic systems which results in a better production of beneficial compounds. Aeroponic microgreen cultivation generates plants containing greater anti-oxidative elements such as polyphenols and flavonoids than plants grown using soil or hydroponic techniques (Benke & Tomkins, 2017). Plants acquire better nutrient uptake together with enhanced metabolic activity because of the aeroponic cultivation approach. The nutrition content of aeroponic microgreens depends on the mixture of misting solutions combined with misting cycles. When the nutrient solution contains irregular balances or misting routines do not follow proper schedules it results in bad growth outcomes alongside poor nutrient levels. The growers who want to achieve high nutritional value must maintain constant observation and modification of their nutrient solution composition and misting program (Lakhiar et al., 2018).

* + 1. **Challenges of Aeroponic Cultivation:**

 The benefits of aeroponic cultivation do not eliminate the difficulties which this system faces. Setting up an aeroponic system involves significant cost as well as technical complexity which represent the main drawback. Operating aeroponic systems presents cost and technical complexity because they need specialized equipment consisting of misting nozzles, pumps and timers. The susceptibility of aeroponic systems increase because equipment failures cause problems like misting nozzle clogging and power disruptions that prevent nutrient delivery which results in crop losses. The successful cultivation of mist-boosted vegetables requires constant optimization of both solution nutrients and watering schedule. A poor growth outcome and reduced nutrient composition emerges from both incorrect nutrient solution measurements along with inconsistent misting intervals. High nutritional quality depends on regular monitoring and adjustment of nutrient solution composition and misting schedule procedures (Lakhiar et al., 2018).

1. **Role of Microgreens in Sustainable and Urban Agriculture:**

Urban agriculture functions as an essential feature of sustainable food systems because it provides the solution for issues such as food security while improving nutrition and environmental problems. The manufacturing and distribution of plant-based food items create considerable greenhouse gas (GHG) pollution levels particularly throughout city environments. The proximity of food production sites near urban centres leads to reduces carbon footprints. UA represents the broad system for cultivating food directly inside city facilities while using fewer transportation systems in both urban settings and nearby rural areas. The indoor vertical farm (IVF) provides a urban agriculture system that stacks farming properties for soilless plant cultivation (Parkes et al., 2023). Microgreens represent a modern vegetable type that shares its existence with both sprouts and baby leaf greens. Microgreens offer superior taste together with various leaf or cotyledon colour patterns plus nutritional advantages as "superfoods." These vegetables possess brief cultivation times and shallow root systems that make hydroponic culture among controlled indoor conditions work well. Protected-environment farming systems require intense monitoring of light conditions together with temperature levels and water quality as well as pH balance and CO2 concentration and fertilizer solution composition to ensure optimal plant growth (Budavári et al., 2024).

* 1. **Importance of Urban Agriculture:**

 The practice of growing food through crop farming and raising animals takes place both inside and around urban centres. Urban agriculture serves as a vital element for food security by offering fresh produce to city dwellers while it cuts down on distant food transport routes and lowers environmental influences of food shipment systems. Overall urban agriculture satisfies nutritional needs because it expands the availability of fresh vitamins and minerals to food-deprived neighbourhoods. Urban agriculture uses microgreens as a sustainable remedy for handling supply chain difficulties (Poulsen et al., 2015).

* 1. **Integration into Urban Spaces:**

Urban gardens and vertical spaces combined with hydroponic methods provide proper containers for microgreen cultivation because of their compact growth requirements. Microgreens find perfect cultivation grounds on rooftops which convert empty areas into nutrient-producing spaces (Orsini et al., 2013).The gardens both enhance food production together with providing recreational spaces that boost community wellness and interpersonal connections The capability to grow microgreens under controlled indoor conditions gives urban residents the opportunity to produce fresh vegetables throughout the entire year irrespective of unfavourable outdoor conditions (Guitart et al., 2012).

* 1. **Economic and Recreational Benefits:**

 Microgreens create profitable prospects for those living in urban settings. Home growers and small-scale microgreen business owners can serve towns with their self-established enterprises. The farming process generates passive earnings from marketplace sales together with offering fresh vegetables to the community. These plant species provide passive income because they maintain high value in the market yet require minimal production costs. The selling of microgreens by urban farmers toward local markets together with restaurants and consumers enables them to build a sustainable financial basis. The practice of producing microgreens has multiple levels of enjoyment because it delivers both mental satisfaction with growing plants and peaceful relaxation. The environmentally responsible growing of microgreens demands minimal water use along with no need for pesticide application so they represent sustainable farming practices (Renna & Paradiso, 2020b). These plants show an ability to thrive because of their suitability for situations where traditional agriculture cannot work (Lone et al., 2024).

1. **Challenges and Limitations in Microgreen Production**
	1. **Perishability and Post-Harvest Losses:**

Perishability is always a major concern during microgreen cultivation. The shelf life of microgreens extends from 5 to 10 days when they are stored under optimal conditions (Xiao et al., 2012b). The combination of their fragile anatomy and moisture-rich composition makes microgreens highly vulnerable to bacterial growth alongside wilting and nutrient damage which generates increased susceptibility to spoilage patterns. Growing post-harvest losses in developing countries become worse because these countries possess sub-standard storage facilities and display inefficient handling processes (Di Gioia et al., 2017). These product's short shelf life requires well-organized distribution systems and storage solutions that may present difficulties for small farm operations to handle. Cold chain management across with innovative packaging solutions specifically modified atmosphere packaging acts as vital methods to extend shelf life and minimize product loss (Kou et al., 2015). (Kou et al., 2015).

* 1. **Lack of Education and Technical Knowledge:**

Farmer and producer success is limited by their insufficient education levels and technical proficiency. Successful microgreen cultivation depends on using precise control of environmental factors which includes light intensity alongside temperature and humidity alongside nutrient levels. Insufficient training services as well as limited resources among small-scale farmers creates unfavourable growing environments which results in decreased agricultural yields. Currently consumers show limited awareness regarding microgreen nutrition values and kitchen applications thus limiting their market demand. The practices needed to create microgreens successfully along with their nutritional advantages remain unknown to several city dwellers. Educational programs alongside outreach activities need to create this awareness gap because they allow people to learn sustainable microgreen cultivation methods (Rani et al., 2019).

* 1. **Concise Market and Limited Consumer Base:**

Restaurants with high prices along with health-conscious individuals and urban residents compose the main customer groups within the market sector for microgreens. The narrow market for microgreens hinders widespread production developments thus making it unprofitable for small-scale farmers. Small-city producers along with rural market participants face market accessibility problems caused by limited industry reach. Many growers struggle to build long-lasting business operations since they lack sufficient local customers (Renna & Paradiso, 2020a). The microgreen market mostly operates in tier-1 cities which serve consumers with elevated income and advanced knowledge of health-driven dining practices. The accessibility of the market to tier-2 and tier-3 cities faces difficulties because of minimal customer interest and transportation limitations (Choe et al., 2018b). Urban farmers depend on selling goods directly to restaurants along with farmers' markets and health food stores yet these establishments are mainly located within major metropolitan areas (PMC, 2024). The search for willing premium buyers becomes difficult for small-town producers who want to sell fresh microgreens because few customers in these areas accept high prices. Microgreen businesses face constraints for growth because poor infrastructure and weak distribution networks exist between main urban areas (Berba & Uchanski, 2012).

* 1. **High Initial Investment and Operational Costs:**

Starting microgreen production demands significant capital investment for controlled environment agriculture (CEA) systems together with hydroponic or aeroponic setups as well as specialized lighting equipment. The expenses associated with microgreen farming prove to be difficult for small farmers and especially those located in developing nations. Financial costs associated with electricity along with seeds and nutrients for operations make it more challenging for profitability. Limited by substantial financial costs of entry microgreens cannot be easily used by farmers who lack resources (Kyriacou et al., 2016c).

1. **CONCLUSION**

Microgreens have been gaining attention for packing substantially higher levels of vitamins, minerals and bioactive compounds than mature plants. Studies (Xiao et al., 2012; Kyriacou et al., 2016) show that microgreens can have 40 times the nutrients of mature greens, with higher concentration of vitamin C, vitamin E, calcium and iron, indicating they are perfect for health-conscious consumers. They are rich in antioxidants, including polyphenols, glucosinolates and carotenoids, which impart protective properties against oxidative stress, inflammation and chronic diseases (cardiovascular diseases and cancers) (Huang et al., 2016; Partap et al., 2023).

There are actually three methods of growing microgreens-soil-based, hydroponic and aeroponic-each with its own benefits and challenges. Soil-based systems utilize native microbial ecosystems to help uptake nutrients, but are susceptible to soil-borne pathogens. Although hydroponic and aeroponic systems are more resource-efficient and allow for precise control of nutrients, they are more capital- and expertise-intensive (Di Gioia et al, 2017; Lakhiar et al, 2018). Despite these difficulties, the very short cycle of 7-21 days for growth, their use of small amounts of space and low water consumption also make microgreens well-suited for urban agriculture, which includes rooftop gardens, for instance, as well as vertical farms (Orsini et al., 2013; Budavári et al., 2024).

Nevertheless, microgreen production encounters challenges characterized by perishability (5-10-day shelf life), low consumer awareness and a high operational cost for controlled-environment systems (Turner et al., 2020; Renna & Paradiso, 2020a). Better post-harvest technologies, improved education and expanded market access are also key to broader adoption.

Microgreens are, therefore, both a sustainable and nutrient-dense answer to these modern dietary and agricultural issues. This contribution to urban lives can increase food security, lower ecological footprint and provide income sources. Future research should be directed toward optimizing cultivation methods, extending shelf-life and informing the public on maximizing their potential as a global superfood.

**Disclaimer (Artificial intelligence)**

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

**References**

1. Agarwal, S., Dubey, H., & Jain, C. L. (2302). *A STUDY ON HYDROPONIC FARMING* (Vol. 5, Issue 2). www.ijfmr.com
2. Benke, K., & Tomkins, B. (2017). Future food-production systems: vertical farming and controlled-environment agriculture. *Sustainability: Science, Practice and Policy*, *13*(1), 13–26. https://doi.org/10.1080/15487733.2017.1394054
3. Berba, K. J., & Uchanski, M. E. (2012). *Post-harvest physiology of microgreens* (Vol. 24).
4. Bhaswant, M., Shanmugam, D. K., Miyazawa, T., Abe, C., & Miyazawa, T. (2023). Microgreens—A Comprehensive Review of Bioactive Molecules and Health Benefits. In *Molecules* (Vol. 28, Issue 2). MDPI. https://doi.org/10.3390/molecules28020867
5. Budavári, N., Pék, Z., Helyes, L., Takács, S., & Nemeskéri, E. (2024). An Overview on the Use of Artificial Lighting for Sustainable Lettuce and Microgreens Production in an Indoor Vertical Farming System. *Horticulturae*, *10*(9), 938. https://doi.org/10.3390/horticulturae10090938
6. Choe, U., Yu, L. L., & Wang, T. T. Y. (2018a). The Science behind Microgreens as an Exciting New Food for the 21st Century. *Journal of Agricultural and Food Chemistry*, *66*(44), 11519–11530. https://doi.org/10.1021/acs.jafc.8b03096
7. Choe, U., Yu, L. L., & Wang, T. T. Y. (2018b). The Science behind Microgreens as an Exciting New Food for the 21st Century. *Journal of Agricultural and Food Chemistry*, *66*(44), 11519–11530. https://doi.org/10.1021/acs.jafc.8b03096
8. Di Gioia, F., Petropoulos, S. A., Ozores-Hampton, M., Morgan, K., & Rosskopf, E. N. (2019). Zinc and iron agronomic biofortification of Brassicaceae microgreens. *Agronomy*, *9*(11). https://doi.org/10.3390/agronomy9110677
9. Di Gioia, F., Renna, M., & Santamaria, P. (2017). Sprouts, Microgreens and “Baby Leaf” Vegetables. In *Food Engineering Series* (pp. 403–432). Springer. https://doi.org/10.1007/978-1-4939-7018-6\_11
10. Du, M., Xiao, Z., & Luo, Y. (2022). Advances and emerging trends in cultivation substrates for growing sprouts and microgreens toward safe and sustainable agriculture. *Current Opinion in Food Science*, *46*, 100863. https://doi.org/10.1016/J.COFS.2022.100863
11. Dubey, S., Harbourne, N., Harty, M., Hurley, D., & Elliott-Kingston, C. (2024). Microgreens Production: Exploiting Environmental and Cultural Factors for Enhanced Agronomical Benefits. In *Plants* (Vol. 13, Issue 18). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/plants13182631
12. G, K. P. (2022). A Short Literature on Microgreens: Understanding their nature and Current Research. In *International Journal of Multidisciplinary Research in Arts* (Vol. 2, Issue 1). http://www.sdnbvc.edu.in/ijmrasc
13. Guitart, D., Pickering, C., & Byrne, J. (2012). Past results and future directions in urban community gardens research. In *Urban Forestry and Urban Greening* (Vol. 11, Issue 4, pp. 364–373). https://doi.org/10.1016/j.ufug.2012.06.007
14. Gunjal, M., Singh, J., Kaur, S., Nanda, V., Ullah, R., Iqbal, Z., Ercisli, S., & Rasane, P. (2024). Assessment of bioactive compounds, antioxidant properties and morphological parameters in selected microgreens cultivated in soilless media. *Scientific Reports*, *14*(1), 23605. https://doi.org/10.1038/s41598-024-73973-w
15. Huang, H., Jiang, X., Xiao, Z., Yu, L., Pham, Q., Sun, J., Chen, P., Yokoyama, W., Yu, L. L., Luo, Y. S., & Wang, T. T. Y. (2016). Red Cabbage Microgreens Lower Circulating Low-Density Lipoprotein (LDL), Liver Cholesterol and Inflammatory Cytokines in Mice Fed a High-Fat Diet. *Journal of Agricultural and Food Chemistry*, *64*(48), 9161–9171. https://doi.org/10.1021/acs.jafc.6b03805
16. Karlsson Green, K., Stenberg, J. A., & Lankinen, Å. (2020). Making sense of Integrated Pest Management (IPM) in the light of evolution. *Evolutionary Applications*, *13*(8), 1791–1805. https://doi.org/10.1111/eva.13067
17. Kou, L., Yang, T., Liu, X., & Luo, Y. (2015). Effects of Pre-and Postharvest Calcium Treatments on Shelf Life and Postharvest Quality of Broccoli Microgreens. In *HORTSCIENCE* (Vol. 50, Issue 12).
18. Kowitcharoen, L., Phornvillay, S., Lekkham, P., Pongprasert, N., & Srilaong, V. (2021). Bioactive composition and nutritional profile of microgreens cultivated in Thailand. *Applied Sciences (Switzerland)*, *11*(17). https://doi.org/10.3390/app11177981
19. Kumar, S., Kumar, S., & Lal, J. (2023). Assessing Opportunities and Difficulties in Hydroponic Farming. *Bhartiya Krishi Anusandhan Patrika*, *Of*. https://doi.org/10.18805/bkap556
20. Kyriacou, M. C., Rouphael, Y., Di Gioia, F., Kyratzis, A., Serio, F., Renna, M., De Pascale, S., & Santamaria, P. (2016a). Micro-scale vegetable production and the rise of microgreens. In *Trends in Food Science and Technology* (Vol. 57, pp. 103–115). Elsevier Ltd. https://doi.org/10.1016/j.tifs.2016.09.005
21. Kyriacou, M. C., Rouphael, Y., Di Gioia, F., Kyratzis, A., Serio, F., Renna, M., De Pascale, S., & Santamaria, P. (2016b). Micro-scale vegetable production and the rise of microgreens. In *Trends in Food Science and Technology* (Vol. 57, pp. 103–115). Elsevier Ltd. https://doi.org/10.1016/j.tifs.2016.09.005
22. Kyriacou, M. C., Rouphael, Y., Di Gioia, F., Kyratzis, A., Serio, F., Renna, M., De Pascale, S., & Santamaria, P. (2016c). Micro-scale vegetable production and the rise of microgreens. In *Trends in Food Science and Technology* (Vol. 57, pp. 103–115). Elsevier Ltd. https://doi.org/10.1016/j.tifs.2016.09.005
23. Lakhiar, I. A., Gao, J., Syed, T. N., Chandio, F. A., & Buttar, N. A. (2018). Modern plant cultivation technologies in agriculture under controlled environment: A review on aeroponics. *Journal of Plant Interactions*, *13*(1), 338–352. https://doi.org/10.1080/17429145.2018.1472308
24. Lone, J. K., Pandey, R., & Gayacharan. (2024). Microgreens on the rise: Expanding our horizons from farm to fork. In *Heliyon* (Vol. 10, Issue 4). Elsevier Ltd. https://doi.org/10.1016/j.heliyon.2024.e25870
25. Mir, S. A., Shah, M. A., & Mir, M. M. (2017). Microgreens: Production, shelf life and bioactive components. In *Critical Reviews in Food Science and Nutrition* (Vol. 57, Issue 12, pp. 2730–2736). Taylor and Francis Inc. https://doi.org/10.1080/10408398.2016.1144557
26. Orsini, F., Kahane, R., Nono-Womdim, R., & Gianquinto, G. (2013). Urban agriculture in the developing world: A review. In *Agronomy for Sustainable Development* (Vol. 33, Issue 4, pp. 695–720). https://doi.org/10.1007/s13593-013-0143-z
27. Parkes, M. G., Azevedo, D. L., Cavallo, A. C., Domingos, T., & Teixeira, R. F. M. (2023). Life cycle assessment of microgreen production: effects of indoor vertical farm management on yield and environmental performance. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-023-38325-0
28. Partap, M., Sharma, D., HN, D., Thakur, M., Verma, V., Ujala, & Bhargava, B. (2023). Microgreen: A tiny plant with superfood potential. In *Journal of Functional Foods* (Vol. 107). Elsevier Ltd. https://doi.org/10.1016/j.jff.2023.105697
29. Pinto, E., Almeida, A. A., Aguiar, A. A., & Ferreira, I. M. P. L. V. O. (2015). Comparison between the mineral profile and nitrate content of microgreens and mature lettuces. *Journal of Food Composition and Analysis*, *37*, 38–43. https://doi.org/10.1016/j.jfca.2014.06.018
30. Poulsen, M. N., McNab, P. R., Clayton, M. L., & Neff, R. A. (2015). A systematic review of urban agriculture and food security impacts in low-income countries. In *Food Policy* (Vol. 55, pp. 131–146). Elsevier Ltd. https://doi.org/10.1016/j.foodpol.2015.07.002
31. Rani, S., Singh, N., Maurya, S. B., & Phour, M. (2019). *Microgreen farming A new approach for nutrient rich greenfood for remote locations*.
32. Reddy, M., Vadlamudi, K., & Ganesh, B. (2021). *ROLE OF MICROGREENS AND THEIR POTENTIAL HEALTH BENEFITS: A REVIEW* (Vol. 8). JETIR. www.jetir.org
33. Renna, M., & Paradiso, V. M. (2020a). Ongoing research on microgreens: Nutritional properties, shelf-life, sustainable production, innovative growing and processing approaches. In *Foods* (Vol. 9, Issue 6). MDPI Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/foods9060826
34. Renna, M., & Paradiso, V. M. (2020b). Ongoing research on microgreens: Nutritional properties, shelf-life, sustainable production, innovative growing and processing approaches. In *Foods* (Vol. 9, Issue 6). MDPI Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/foods9060826
35. Selma, M. V., Luna, M. C., Martínez-Sánchez, A., Tudela, J. A., Beltrán, D., Baixauli, C., & Gil, M. I. (2012). Sensory quality, bioactive constituents and microbiological quality of green and red fresh-cut lettuces (Lactuca sativa L.) are influenced by soil and soilless agricultural production systems. *Postharvest Biology and Technology*, *63*(1), 16–24. https://doi.org/10.1016/j.postharvbio.2011.08.002
36. Tan, L., Nuffer, H., Feng, J., Kwan, S. H., Chen, H., Tong, X., & Kong, L. (2020). Antioxidant properties and sensory evaluation of microgreens from commercial and local farms. *Food Science and Human Wellness*, *9*(1), 45–51. https://doi.org/10.1016/j.fshw.2019.12.002
37. Turner, E. R., Luo, Y., & Buchanan, R. L. (2020). Microgreen nutrition, food safety and shelf life: A review. In *Journal of Food Science* (Vol. 85, Issue 4, pp. 870–882). Blackwell Publishing Inc. https://doi.org/10.1111/1750-3841.15049
38. Weber, C. F. (2017). Broccoli Microgreens: A Mineral-Rich Crop That Can Diversify Food Systems. *Frontiers in Nutrition*, *4*. https://doi.org/10.3389/fnut.2017.00007
39. Xiao, Z., Lester, G. E., Luo, Y., & Wang, Q. (2012a). Assessment of vitamin and carotenoid concentrations of emerging food products: Edible microgreens. *Journal of Agricultural and Food Chemistry*, *60*(31), 7644–7651. https://doi.org/10.1021/jf300459b
40. Xiao, Z., Lester, G. E., Luo, Y., & Wang, Q. (2012b). Assessment of vitamin and carotenoid concentrations of emerging food products: Edible microgreens. *Journal of Agricultural and Food Chemistry*, *60*(31), 7644–7651. https://doi.org/10.1021/jf300459b
41. Zhou, W., Arcot, Y., Medina, R. F., Bernal, J., Cisneros-Zevallos, L., & Akbulut, M. E. S. (2024). Integrated Pest Management: An Update on the Sustainability Approach to Crop Protection. In *ACS Omega*. American Chemical Society. https://doi.org/10.1021/acsomega.4c06628