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Microgreens: A Comprehensive Review Emphasizing Urban Agriculture

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Review Article

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ABSTRACT

In this comprehensive review, we delve into the multifaceted world of nutrient-rich microgreens, with a particular emphasis on their significance in urban agriculture. By exploring their nutritional composition, culinary applications and cultivation techniques, we aim to shed light on the transformative potential of microgreens in promoting sustainable urban food systems. Through an interdisciplinary lens encompassing agronomy, nutrition and urban planning, we uncover the myriad benefits of microgreens cultivation and highlight the critical role they play in shaping the future of urban agriculture.

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1. INTRODUCTION

Microgreens, also known as "vegetable confetti" (Treadwell *et al*., 2010) or "micro herbs" in the case of aromatic herbs (Di Gioia & Santamaria, 2015), are tiny plants harvested at an early stage of growth. As per Commission Regulation (EU) 752/2014, "baby leaf" refers to the tender leaves and petioles of various crops, harvested before reaching the 8 true leaf stage. The term "Microgreen" was coined by Botanist John Naar in the early 1980s. "microgreens" is a marketing term used to categorize a type of product that currently lacks a legal definition, as noted by Treadwell *et al*. (2010). Traditionally considered as a specialty in high-end restaurant kitchens as they are gaining popularity and finding broader applications as a food ingredient for people everywhere. Within the dynamic realm of culinary arts, microgreens have become the newest culinary trends, capturing the interest of both culinary experts and health-conscious consumers. These miniature wonders, renowned for their potent combination of flavour and nutrition, represent a paradigm shift in the way we approach food cultivation and consumption. Microgreens offer a unique blend of nutritional benefits and culinary versatility. These are tiny, but they're mighty in terms of nutrition, with concentrated amounts of vitamins, minerals and antioxidants that considerably overshadow those of their mature counterparts (Nath *et al*., 2015). In complement to their nutritional advantages, microgreens are a visual and flavourful treat, adding a vibrant kaleidoscope of colour and a burst of powerful, fresh flavour to food.

Against the backdrop of urbanization and environmental challenges, innovative agricultural techniques have become imperative for sustainable food production. Among these techniques, soil-less farming methods such as hydroponics have garnered attention for their ability to maximize resource efficiency and minimize environmental impact (Gebreegziher, 2023). By cultivating microgreens through hydroponics and other urban cropping methods, urban farmers can optimize space, conserve water and reduce reliance on conventional agricultural inputs (Jayachandran *et al*., 2022; Bindu, 2018). In contrast to the frequent fusion of cooking styles (Renna *et al*., 2021), this example highlights the adaptability and resilience of urban farming in solving modern food security problems by combining state-of-the-art technology with traditional agricultural practices.

Moreover, the versatility of microgreens extends beyond their nutritional and culinary attributes to encompass their role in urban greening and community engagement. As cities grapple with issues of food deserts and limited access to fresh produce, microgreens offer a viable solution for localized food production and urban revitalization (Kumar *et al*., 2018). Through rooftop gardens, vertical farms and community-supported agriculture initiatives, microgreens cultivation not only provides fresh and nutritious produce to urban dwellers but also fosters a sense of connection to the food system and promotes attention towards environment.

The global market for microgreens has witnessed a significant surge in demand, driven by their high nutritional value, diverse culinary applications and increasing consumer awareness of healthy eating habits (Singh *et al*., 2024). These young, edible greens are particularly favoured in fine dining and gourmet cooking, where they are used to enhance flavour, texture and visual appeal. Urban areas, in particular, are embracing microgreen production due to the rising popularity of indoor farming techniques such as vertical farming and hydroponics (Rajan *et al*., 2019). These methods not only optimize space but also cater to the growing demand for fresh, locally sourced, and pesticide-free produce. The trend aligns with the global push toward sustainable agriculture and urban self-reliance, making microgreens an attractive crop for urban farming initiatives. Moreover, organic farming concepts can be seamlessly integrated into urban cropping techniques, ensuring that microgreens are grown naturally and sustainably.

Space agencies are intrigued by microgreens for their potential to enhance astronaut's diets during space missions (Cahill & Hardiman, 2020). Additionally, cultivating microgreens holds promise for supporting the health of crew members during extended spaceflight missions. This review delves into the multifaceted world of microgreens, exploring their nutritional composition, culinary applications, and cultivation techniques. Through an interdisciplinary lens, we aim to uncover the transformative impact of microgreens on urban food systems.

Table 1. Nutritional Comparison between Microgreens and Sprouts

Nutrient	Microgreens	Sprouts
Antioxidants	High in carotenoids and chlorophylls	Moderate to high, depending on the type of sprout
Vitamins	Rich in vitamins C, K, and E	High in vitamins C, B complex, and folate
Minerals	Contains various minerals like calcium, iron, and magnesium	Rich in minerals like iron, zinc, and potassium
Protein	Moderate protein content	Moderate to high protein content, especially in legume sprouts
Fiber	Moderate fiber content	High fiber content, aiding digestion
Enzymes	Contains enzymes that aid in digestion	Sprouting process activates enzymes, enhancing nutrient absorption

Source: Ebert, 2022, Wojdyło et al., 2020

Microgreens vs sprouts: Microgreens and sprouts are both consumed in their early stages of growth, but they differ significantly. Sprouts are cultivated in damp, dark environments, whereas microgreens are grown in soil under light. This variance in cultivation methods results in microgreens having higher nutrient content and lower risk of microbial contamination compared to sprouts (Treadwell *et al*.,2010).

Powerhouses of flavour and nutrition: Microgreens are the miniature yet mighty members of the vegetable and herb kingdom. These tender greens are harvested from the seeds of various plants, typically just 7 to 14 days after germination (Lester *et al.,* 2013). They feature two fully developed cotyledon leaves and may sometimes exhibit the first signs of true leaves emerging (Choe *et al*., 2018). Despite their small size, microgreens pack a punch in both flavour and nutritional value.

Microgreens, known for their lower macronutrient content and higher concentrations of bioactive compounds, offer unique health benefits (Bhaswant *et al*, 2023). These bioactive compounds play a significant role in preventing chronic diseases like type-2 diabetes and heart disease. While their high moisture content and low carbohydrates and fats may indirectly support weight management, their primary contribution to health lies in their antioxidant, anti-inflammatory, and nutrient-dense profile (Westerterp-Plantenga *et al.,* 2009). Additionally, fiber present in microgreens is crucial for digestive health, lowering blood cholesterol and glucose levels, and promoting overall cardiovascular health (Anderson *et al*., 2009).

These miniature greens, measuring between 2.5 to 7.6 centimetres (1 to 3 inches) in height, offer an explosion of intense flavours, vibrant colours and tender textures. They provide a feast for the senses, enhancing the visual appeal, taste and mouthfeel of any dish they adorn.

Versatility is the name of the game when it comes to microgreens. Whether sprinkled atop salads, stirred into soups, or layered into sandwiches, these tiny greens elevate culinary creations to new heights. Their addition brings not only a burst of fresh flavour but also a pop of colour and a satisfying crunch (Milos Vukcevic, 2023).

A holistic approach to health and wellness: Microgreens, a plant-based functional food that consists of the seedlings of the edible plants harvested after 7–14 days of the germination process, are the stellar source of phytochemicals, such as essential minerals, polyphenols, carotenoids, chlorophyll, anthocyanins, glucosinolates, etc., which imparts high antioxidant, anti-inflammatory, anti-diabetic effects due to which it is considered as a practical food that might improve or attenuate chronic diseases (Zhang *et al*., 2021).

Moreover, emerging research suggests that integrating microgreens into one's diet could potentially mitigate the risk factors associated with a variety of chronic ailments. Conditions like cardiovascular disease, chronic kidney disorders and diabetes may benefit from the nutrient-rich profile of microgreens, which can aid in maintaining healthy blood pressure, cholesterol levels and blood sugar regulation (Ma *et al*., 2022) (Huang *et al*., 2016) Additionally, microgreens' abundance of iron makes them particularly valuable in combating iron deficiencies, a prevalent concern globally (Xiao *et al*., 2016). Their low-calorie content and high nutrient density also position them as allies in the battle against obesity, offering satiety and

Table 2. Vegetables/Plants Used for Microgreens

Botanical Family	Common Vegetables/Plants Used for Microgreens
Brassicaceae	Cauliflower (*Brassica oleracea* var. *botrytis*), Broccoli (*Brassica oleracea* var. *italica*), Cabbage (*Brassica oleracea* var. *capitata*), Chinese Cabbage (*Brassica rapa* subsp. *pekinensis*), Kale (*Brassica oleracea* var. *acephala*), Savoy Cabbage (*Brassica oleracea* var. *sabauda*), Rappini or Brassica raab (*Brassica rapa*), Watercress (*Nasturtium officinale*), Mizuna (*Brassica rapa* var. *nipposinica*), Radish (*Raphanus sativus*), Arugula (*Eruca vesicaria*), Mustard (*Brassica juncea*), Tatsoi (*Brassica rapa* var. *rosularis*), Wild Radish (*Raphanus raphanistrum*), White Mustard (*Sinapis alba*), Mediterranean Mustard (*B. tournefortii*), Watercress (*Nasturtium officinale*), White wall rocket (*Diplotaxis erucoides*), wild rocket (*Diplotaxis tenufolia*), Ethiopian Mustard (*Brassica carinata*), Field Mustard (*Brassica rapa*), Sea Kale (*Crambe maritima*)
Asteraceae	Lettuce (*Lactuca sativa*), Endive (*Cichorium endivia*), Escarole (*Cichorium endivia* var. *latifolium*), Chicory (*Cichorium intybus*), Radicchio (*Cichorium intybus* var. *radicchio*), Sunflower (*Helianthus annuus*), Common Dandelion (*Taraxacum officinale*), Sea beet (*Beta vulgaris* subsp. m*aritima*), smooth golden fleece (*Urospermum dalechampii*), prickly golden fleece (Urospermum picroides), sea rocket (*Cakile edentula*), wild chicory (*Cichorium intybus*), common purslane (*Portulaca oleracea*), Goats beard (*Aruncus dioicus*), Mexican Tarragon (*Tagetes lucida*), Chrysanthemum (*Glebionis coronaria*), Blue Star (*Ageratum houstonianum*)
Apiaceae	Dill (*Anethum graveolens*), Carrot (*Daucus carota*), Fennel (*Foeniculum vulgare*), Celery (*Apium graveolens*), Wild Fennel (*Foeniculum vulgare*), Vietnamese Coriander (*Persicaria odorata*), Black Cumin (*Bunium persicum*)
Amaryllidaceae	Garlic (*Allium sativum*), Onion (*Allium cepa*), Leek (*Allium ampeloprasum* var. *porrum*), Sea Fennel (*Crithmum maritimum*)
Amaranthaceae	Amaranth (*Amaranthus* spp.), Red Orach (*Atriplex hortensis*), Swiss Chard (*Beta vulgaris* var. *cicla*), Beet (*Beta vulgaris*), Spinach (*Spinacia oleracea*), Quinoa (*Chenopodium quinoa*), Pigweed (*Amaranthus* spp.), *Salicornia*
Cucurbitaceae	Melon (*Cucumis melo*), cucumber (*Cucumis sativus*), squash (*Cucurbita pepo*)
Poaceae	Oat (*Avena sativa*), soft wheat (*Triticum aestivum*), durum wheat (*Triticum durum*), corn (*Zea mays*), barley (*Hordeum vulgare*), rice (*Oryza sativa*), Wheat Grass (*Triticum aestivum*), Bamboo Grass (*Bambusa* spp.), Japanese Forest Grass (*Hakonechloa macra*).
Fabaceae	Chickpea (*Cicer arietinum*), alfalfa (Medicago sativa), Green bean (*Phaseolus vulgaris*), Fenugreek (*Trigonella foenum-graecum*), Fava bean (*Vicia faba*), Lentil (Lens culinaris), pea (Pisum sativum), clover (*Trifolium repens*), Mung Bean (*Vigna radiata*), Red Clover (*Trifolium pratense*), Snow Pea (*Pisum sativum* var. *saccharatum*).
Linaceae	Flax (*Linum usitatissimum*)
Boraginaceae	Borage (*Borago officinalis*)
Polygonaceae	Buckwheat (*Fagopyrum esculentum*), Sorrel (*Rumex acetosa*)
Chenopodiaceae	Good King Henry (*Chenopodium bonus-henricus*), Tree Spinach (*Chenopodium giganteum*)
Malvaceae	Red Leaf Hibiscus (*Hibiscus acetosella*), Roselle (*Hibiscus sabdariffa*), Jute (*Corchorus olitorius*), Mallow (*Malva verticillata*)
Solanaceae	Ground Cherry (*Physalis pruinosa*), Pepino (*Solanum muricatum*), Tomato (*Solanum lycopersicum* var. *cerasiforme*), Sweet Pepper (*Capsicum annuum*)

Source: Di Gioia et al. 2015 and Gunjal et al., 2024 nourishment without excess calories It has also been found to be effective in combating the common cold and treating skin infections, as demonstrated by research conducted by Hodges *et al*. (1969) and Heimer *et al*. (2009).

Furthermore, the presence of bioactive compounds in microgreens holds promise in combating carcinogenic processes and tumour growth. These compounds, including glucosinolates found in cruciferous microgreens like broccoli and kale, exhibit potential anti-cancer properties by interfering with tumour initiation, progression, and metastasis (Hayes *et al*., 2008). Incorporating microgreens into daily meals could thus serve as a proactive measure in promoting overall health and reducing the risk of various chronic diseases.

Commonly used species: Microgreen farming has proven successful with a variety of vegetables including white radish, pink radish, cabbage, red cabbage, leafy cabbage, mustard, broccoli, and bunching fenugreek. Additionally, plants such as peas, beans, mung beans, and cucumbers, known for their rich phytonutrient content, have been evaluated and cultivated with positive results (Rani *et al*., 2019).

Urban environment: Microgreens are a promising solution for urban agriculture, addressing the unique challenges of urban environments through their space efficiency, rapid growth, water efficiency and contribution to reducing transportation emissions (Bhaswanth *et al*., 2023). Their ability to thrive in compact spaces makes them an ideal choice for city dwellers with limited land, while their quick turnaround time allows for multiple harvests within a short period, maximizing productivity and ensuring a steady supply of fresh greens throughout the year (Franks and Richardson, 2009). Additionally, microgreens require significantly less water to thrive compared to traditional crops, making them a sustainable choice for urban agriculture that promotes water conservation and responsible resource management. In recent years, the adoption of modern high-tech growing methods, like indoor soilless cultivation, has led to enhanced water use efficiency (WUE) (Pignata *et al.,* 2017). Soilless agriculture involves growing plants without soil, where nutrients are supplied through irrigation water or a nutrient solution (NS) (Olympios, 1999). Presently, indoor soilless cultivation systems are a significant contributor to vegetable production in Europe, Canada, and the United States (O'Sullivan *et al.,* 2019). It's estimated that producing 1 kg of lettuce in an indoor soilless farm requires only 3% of the water needed for field-grown lettuce (O'Sullivan *et al*., 2019). Furthermore, the cultivation of microgreens in urban settings contributes to a reduction in transportation emissions, thereby mitigating the environmental impact associated with food production and distribution (Despommier, 2013). This localized approach not only reduces carbon emissions from transportation but also supports the development of resilient and self-sufficient food systems within urban communities. By adopting microgreens in urban agriculture, cities can create greener, healthier and more sustainable urban environments, aligning with global efforts to combat climate change and promote sustainability (Armanda *et al*., 2019)

Microgreens Vs mature plants: Microgreens contain better nutrient composition compared to the mature plants but this is not always true . Microgreens have a lower NO_{3-} concentration than mature lettuces and a greater amount of most minerals (Ca, Mg, Fe, Mn, Zn, Se, and Mo), according to Pinto *et al.* (2015). Microgreens of celery were found to contain higher amounts of macro elements (e.g., calcium and potassium) and microelements (e.g., iron and zinc), suggesting their potential to contribute significantly to fulfilling daily nutrient requirements and emphasizing the importance of identifying and developing celery cultivars with enhanced nutritional profiles (Singh *et al*., 2023). Based on the dry weight analysis, microgreens were found to contain higher concentrations of minerals compared to other developmental stages of kale, but based on fresh weight the mature stages are better (Waterland *et al*., 2017). In a study, the USDA-ARS researchers from the Food Quality Laboratory and Crop Systems and Global Change Laboratory examined the concentrations of microelements (copper, iron, manganese, and zinc) and macro elements (calcium, magnesium, phosphorus, sodium, and potassium) in 30 species of microgreens from 10 genera. The findings showed that microgreens of the Brassicaceae family are an excellent source of both macro and microelements, including potassium and calcium (e.g., iron and zinc). It appears that this study (Xiao *et al*., 2016) is the first to record the mineral content of microgreens of the Brassicaceae family that are sold commercially.

Whereas, Yadav *et al*. (2019) conducted the first study comparing antioxidants and mineral profiles of summer leafy vegetables at both microgreen and mature stages. They found that mature stages had higher antioxidant content and activity compared to microgreen stages. However, microgreens were identified as richer sources of potassium (K) and zinc (Zn). No specific trend was observed for copper (Cu), iron (Fe) and manganese (Mn) content. Consequently, the experiment concluded that for dietary antioxidants, leafy vegetables at mature stages should be consumed for better health, while microgreens should be preferred for mineral intake.

So not all studies agree on the extent of the difference in nutrient content. Some research suggests that mature crops may sometimes contain similar or even higher levels of certain nutrients Microgreens often have a stronger flavour compared to mature plants, which can be a positive or negative aspect depending on individual preferences.

Balancing organoleptic and nutritional factors: Harvesting microgreens requires a keen eye and attention to detail, as there isn't a specific stage akin to traditional crop harvesting (Franks and Richardson, 2009.). Instead, the decision to harvest microgreens hinges on assessing both organoleptic (sensory) and nutritional components, along with key physical maturity indices, to pinpoint the optimal stage.

Organoleptic factors such as colour, flavour, aroma and texture play a crucial role in determining readiness for harvest (Adewoyin, 2023). Microgreens should exhibit vibrant hues indicative of their specific plant variety, along with a fresh and appealing aroma (Partap *et al*., 2023). The leaves should be tender yet crisp, providing a satisfying texture when consumed.

Physical maturity indices serve as crucial benchmarks, with the emergence of true leaves being a primary indicator occurring between 3-7 days after planting, varying by species. Fast-growing varieties like radish and mustard develop true leaves as early as 3-4 days, while slower-growing herbs such as basil and cilantro take 5-7 days. Height is another critical indicator, with most microgreens reaching optimal harvest height between 1.5-3 inches, though some varieties like wheatgrass and pea shoots can extend to 4-7 inches. The total days to harvest varies significantly among species: quick-growing varieties like radish and mustard mature in 5-7 days, medium-speed growers such as sunflower and broccoli require 7-12 days, and slower varieties like basil and cilantro need 14-21 days for optimal development. Visual indicators complement these metrics, including fully expanded cotyledons, strong stem development, and proper leaf coloration characteristic of each variety. For optimal quality, harvest should occur when plants display these maturity indices but before they become overly mature, as this can affect both flavour and nutritional value.

Nutritional considerations are equally important. Microgreens reach their peak nutritional potency at different stages of growth, depending on the plant variety. The ontogenetic stages for harvesting microgreens range from the cotyledonary stage to the emergence of the second true leaf (Kyriacou *et al*., 2021). Typically, microgreens are harvested when they have developed their first true leaves, which are the second set of leaves to emerge after the cotyledons (Wikipedia,2024). At this stage, they typically contain higher concentrations of vitamins, minerals and phytochemicals, making them nutritionally dense (Paradiso and Renna, 2021)

Harvesting at the optimal stage ensures the microgreens offer the best combination of flavour and nutritional value (Hendriks, 2021) It's a delicate balance that requires careful observation and timing to achieve the desired outcome.

Culinary applications of microgreens in Indian cuisine: In India, microgreens have gained significant attention for their diverse culinary applications, reflecting both traditional and contemporary food practices. These tiny, nutrient-dense greens, such as mustard, fenugreek, coriander, and radish, are commonly used to enhance the flavour and visual appeal of various dishes. In Indian cuisine, they are often incorporated into salads, chaats, and raita, providing a fresh, crunchy texture and a burst of flavour. Microgreens are also used as garnishes in soups, curries, and even street food, adding vibrant colour and enhancing the dish's aesthetic. Additionally, they are blended into smoothies, juices, and chutneys, offering a healthy, flavourful punch. The growing interest in health-conscious eating has led to their inclusion in contemporary Indian fusion dishes, such as wraps, sandwiches, and even dosa fillings (Cooking with shy, 2024). Their versatility, combined with their rich nutrient profile, makes them a valuable addition to Indian kitchens, offering both taste and health benefits.

Commercial microgreen farming: The rich flavour and nutrient density of these miniature plants have propelled their popularity, becoming sought-after additions to salads, sandwiches and garnishes in upscale restaurants and health-conscious markets (Ebert *et al.,* 2022). This demand has created a substantial market for growers, particularly in tier-1 cities, where the trend toward healthier eating and gourmet culinary experiences is most pronounced (Paraschivu, 2022)

In developing countries like India, where the majority of microgreens are imported, they often come at a higher price and incur a significant 40% loss when supplied to hotels. However, an article from the Economic Times highlights how First Agro, a Bangalore-based company, has addressed this challenge. They have ventured into producing exotic greens and have successfully established partnerships with prestigious hotels such as Ritz Carlton, JW Marriott, Hyatt, Oberoi, and Taj.

Recognizing the increasing demand for fresh produce in the hospitality sector, First Agro launched Chef Garden, a dedicated business unit targeting large hotel chains. By locally sourcing their produce, they not only ensure freshness but also gain better control over wastage. This strategic approach is in line with the trend among five-star hotels to either cultivate their own vegetables or procure them from local growers as a cost-saving measure.

Cultivation: In urban environments where resources are limited, special attention is given to cost-effective methods for producing microgreens.

Selection of Crops: All Crops are not economical for commercial microgreen production due to longer growth times, lower yields and limited market demand. Some commercial microgreens are Arugula, Radish, Cilantro, Peas, Broccoli, Basil etc. which are commonly used by chefs (EUTM Organics).

Growing Environment Microgreens are commonly cultivated for commercial purposes using soil-less farming systems or mist chambers in trays (Bhaswanth *et al*., 2023). Commercial microgreen farming in soil-less systems involves selecting a suitable growing method like hydroponics or aeroponics, setting up a growing area with appropriate lighting and racks, and choosing inert mediums such as coco coir or rockwool. Hydroponics, in particular, is an ideal method for growing microgreens due to its ability to provide optimal growing conditions and promote rapid growth. This soilless technique involves growing microgreens in a nutrient-rich water solution, ensuring precise control over nutrients, water, and environmental conditions. Plants like arugula, radish, cilantro, and mustard, which are typically harvested at an early stage, thrive in these systems due to their shallow root systems and short growth cycles. Nutrient solutions are prepared and delivered to the plants, ensuring optimal growth conditions while eliminating the need for soil, reducing the risk of pests, diseases, and weeds. Germination, seeding, and maintenance are closely monitored to promote healthy growth and prevent nutrient imbalances (Ampim *et al.,* 2022). This method not only enhances the flavor, color, and nutritional content of microgreens but also allows for year-round production, particularly in urban settings or regions with limited agricultural space. Harvested microgreens are packaged and distributed to various markets. As demand increases, growers can scale up their operations by investing in additional equipment and space. This approach allows for efficient, year-round production of high-quality microgreens while minimizing resource use and environmental impact.

Growing microgreens in trays within a mist chamber cooled with a fan and pad system, with trays arranged in racks, is a sophisticated method that optimizes growing conditions (Robert and Elsa) The mist chamber maintains high humidity levels essential for germination and growth, while the fan and pad system regulate temperature, creating an ideal microclimate (Shamsheri, 2007). Trays are organized in racks, maximizing space utilization and facilitating efficient airflow around the plants. This setup ensures consistent moisture levels, proper airflow and temperature control, promoting healthy and uniform growth of microgreens.

In this setup, inert growing media like coco coir, rockwool, or peat moss are commonly used. These media offer a stable base for the roots of microgreens and facilitate efficient nutrient absorption. Moreover, they have excellent moisture retention properties, ensuring consistent hydration for the growing plants. Additionally, these media are sterile and devoid of pests and diseases, promoting a clean and healthy growth environment.

However, according to Arif Sadik *et al*. (2019), the optimal medium for microgreen farming in trays or beds is a mixture of cow dung and soil. This combination offers advantages such as high-water retention capacity, improved root penetration and increased nutrient availability.

Vertical STACKING: Many microgreen farmers enhance space efficiency by stacking trays vertically. Typically, microgreen trays are arranged on 4 to 6-shelf racks made of metal or plastic, with lighting strips mounted under each shelf (Rani *et al*., 2019). Vertical stacking can be utilized in both soil-based and soilless growing systems, optimizing the use of available space. However, it is crucial to evaluate the growing environment to ensure it is practical and safe for farmers to access higher shelves multiple times throughout the day.

Deep water culture: An alternative to vertical stacking is the deep-water culture (DWC) method, suitable for both hydroponic and aquaponic systems. In this approach, small net pots or trays containing the growing medium and seeds are placed directly into a large tank, giving plants direct access to a water source. This method is often more cost-effective due to its simplicity, requiring minimal maintenance once established and involving fewer components. However, regulating water temperature and pH levels can be challenging, potentially affecting plant growth.

Advanced lighting technologies for optimized microgreen production: Lighting technologies are a cornerstone of microgreen production, enabling precise control over growth conditions and enhancing yield quality. Among the available options, **Light-Emitting Diode (LED)** systems stand out for their energy efficiency, consuming 40-50% less energy than fluorescent lights, while providing low heat emission, customizable light spectra, and long lifespans exceeding 50,000 hours. Full-spectrum LEDs deliver optimized Photosynthetically Active Radiation (PAR) with a typical ratio of 80% red (660nm) and 20% blue (450nm) for balanced growth, while targeted-spectrum LEDs focus on specific wavelengths like red for germination and stem elongation, blue for chlorophyll synthesis, far-red for morphology modulation, and UV-A for boosting nutritional content. Fluorescent lighting, including T_5 high-output lamps and compact fluorescent lamps (CFLs), is still favored by small-scale and budget-conscious growers, though these options have limited spectral control and shorter lifespans (Flores *et al*., 2024). For large-scale operations, **High-Intensity Discharge (HID) lamps**, such as Metal Halide (MH) and High-Pressure Sodium (HPS), offer intense light outputs but come with higher energy costs and significant heat production.

Hybrid systems, combining LEDs with natural light or fluorescent lamps, are increasingly popular for their energy efficiency and flexibility. Key parameters like Photosynthetic Photon Flux Density (PPFD) of 200-400 μmol/m²/s, Daily Light Integral (DLI) of 12-16 mol/m²/day, and a photoperiod of 16-18 hours are critical for optimizing growth. Advanced control systems, including automated timers, light intensity sensors, and spectrum analyzers, allow for precise environmental management, while proper light placement—typically 12-24 inches above the canopy—and heat dissipation systems ensure uniform coverage and temperature stability.

Economic considerations play a significant role, with LED systems requiring a higher initial investment but offering lower operating costs compared to fluorescent or HID systems. Future trends in microgreen lighting include IoT-enabled smart systems, artificial intelligence-driven spectrum optimization, and enhanced energy-efficient technologies. Best practices involve regular monitoring of light intensity, spectrum adjustments tailored to growth stages, scheduled maintenance, and energy use optimization. By integrating advanced lighting technologies and management strategies, growers can achieve consistent, high-quality microgreen production while minimizing environmental and economic impacts.

Irrigation: In commercial Farming instead of direct watering Misting is done to the trays with 50 ml water per tray (Rani *et al*., 2019) which increases the water use efficiency and reduce cultivation cost.

Manuring and Fertilization: Unlike mature crops, microgreens require minimal fertilizers since most essential nutrients are already present in the seeds themselves. Therefore, sustainable agricultural practices like organic farming can be effectively implemented without concern for yield loss.

In soilless farming, nutrient solutions are frequently incorporated into the water utilized for misting or irrigation in microgreen cultivation. These solutions are carefully formulated to encompass crucial macro and micronutrients necessary for strong plant growth, including nitrogen, phosphorus, potassium, calcium, magnesium and trace elements. They are customized to suit the unique needs of the microgreens being grown. Through vigilant monitoring of pH levels and nutrient concentrations, growers maintain proper nutrient uptake and prevent any imbalances. This approach affords precise control over nutrient delivery, thereby promoting robust growth and optimizing nutrient absorption by the plants.

Bulk ordering of seeds: By purchasing seeds in bulk quantities, growers can often negotiate lower prices per seed, reducing the overall cost of production. This approach is especially beneficial for popular microgreen varieties that are frequently used in commercial cultivation. Additionally, bulk ordering allows growers to plan their seed supply for multiple growing cycles, ensuring continuity of production and minimizing the risk of running out of seeds during peak demand periods. Moreover, bulk ordering may also provide access to discounts, promotions, or special deals offered by seed suppliers for large-volume purchases, further enhancing cost savings.

Seed multiplication: Seed multiplication involves producing your own seeds from the initial seed stock, either through traditional seed saving methods or through controlled breeding and selection processes. This approach offers several advantages for commercial microgreen farming. Firstly, it reduces reliance on external seed suppliers, providing greater control over seed quality, availability, and pricing. Secondly, seed multiplication allows growers to adapt and tailor their seed varieties to specific growing conditions, customer preferences, and market demands. Additionally, by selecting and propagating seeds from the best-performing plants in each growing cycle, growers can gradually improve the genetic traits and performance of their microgreen varieties over time, enhancing overall crop yield, quality, and profitability.

Bulk ordering of seeds enables growers to capitalize on economies of scale, leveraging their purchasing power to negotiate lower prices and secure a steady supply of seeds for their commercial microgreen operations. By buying seeds in larger quantities, growers can benefit from reduced per-seed costs, making cultivation more cost-effective and financially sustainable in the long run (Jones *et al., 2001*). Furthermore, seed multiplication empowers growers to become more self-sufficient and independent in their seed sourcing, reducing their reliance on external suppliers and mitigating the risks associated with fluctuations in seed availability and prices. Through careful selection, propagation, and improvement of their own seed stocks, growers can optimize the performance, resilience, and profitability of their microgreen crops, reinforcing the economic viability and competitiveness of their commercial farming ventures. Overall, both bulk ordering and seed multiplication strategies contribute to cost reduction, supply chain resilience, and long-term success in commercial microgreen cultivation.

In addition to bulk ordering and seed multiplication, commercial microgreen farmers can employ various strategies to enhance cost-effectiveness and profitability. These include efficient resource utilization through techniques like vertical farming and automation, implementing integrated pest management practices, leveraging cooperative purchasing arrangements, diversifying product offerings, exploring value-added products, utilizing direct marketing channels, and continuously improving production practices and business operations (Hati and Singh 2021). By combining these strategies, growers can optimize resource use, minimize costs, and maximize revenue, thereby strengthening the economic viability and competitiveness of their commercial microgreen farming operations.

Home gardening: From a home gardening perspective, microgreen farming not only provides consumers with essential nutritious foods but also offers an excellent hobby and healthy activity for people of all ages during their leisure time. It serves as an excellent means of recreation and exercise for family members. Vegetables grown at home with one's own labor have a special appeal to the palate, and the pleasure and satisfaction derived from this activity are priceless. Additionally, home gardening is an ideal way to teach children responsibility and organization.

Production constraints and technical barriers in microgreens cultivation: Producing microgreens demands significant quantities of seeds, leading to higher costs. Moreover, they should exhibit high purity levels and be free from pathogenic bacteria or moulds to ensure optimal growth and food safety (Stoleru *et al*., 2016). Also, according to Warriner *et al*. (2003) found that microgreens are more susceptible to bacterial infiltration than mature plants. Bacteria from seeds can integrate into the plant's internal microbial community during germination (Acuña *et al.,* 2023). Despite protective border cells, bacteria can enter through germinating radicals or secondary roots, persisting locally. Unlike mature plants with a Casparian strip barrier, immature plants lack full protection, allowing bacterial penetration into the xylem (Calvo-Polanco *et al.,* 2021).

Microgreens have a very limited shelf life, typically lasting only 3-5 days under optimal conditions (Mir Shah & Mir, 2017). To extend their freshness, it's recommended to keep them with their roots intact in their growth medium and refrigerate them. Depending on the variety and storage conditions, microgreens can maintain their quality for over 14 days. However, exposure to temperatures below freezing can cause damage, and high humidity levels promote microbial growth and decay (Zagory & Kader, 1988). Therefore, it's essential to use a combination of proper refrigeration and modified atmosphere packaging (MAP) to minimize respiration rates, moisture loss and microbial contamination (Berba & Uchanski, 2012; Zagory & Kader, 1988). Immediate consumption after harvest is also recommended to retain the highest quantity and quality of microgreens, especially in household farming settings (Mlinarić *et al.,* 2023). Moreover, research suggests that cultivating microgreens under specific light conditions, such as a blue/red light combination (B:2R), enhances the synthesis of beneficial compounds. However, this may present a technical barrier, as custom designing and implementing such light conditions can be economically challenging.

Promoting the benefits of microgreens and urban agriculture is the need for comprehensive education and awareness campaigns (Enssle, 2020). Without widespread dissemination of information regarding the nutritional value, sustainability and accessibility of microgreens, individuals may lack awareness of their potential benefits. Additionally, limited understanding of urban agriculture initiatives could hinder community engagement and participation in local food production efforts. Overcoming this limitation requires dedicated resources and efforts to develop and implement effective educational programs and outreach strategies, thereby empowering individuals to make informed choices and actively support urban agriculture endeavours (Baudoin and Drescher, 2008)

Common pests and diseases: Common pests that can affect microgreen farming include aphids, thrips, fungus gnats, spider mites and whiteflies (Rao *et al.,* 2023). Aphids are small insects that feed on plant sap and can spread diseases, while thrips leave silver streaks on leaves and can transmit diseases. Fungus gnats lay larvae that feed on plant roots, weakening the plants, and spider mites suck sap from leaves, causing yellowing. Whiteflies also feed on plant juices and can transmit diseases.

Common diseases in microgreen farming include damping-off, powdery mildew, and root rot. Damping-off is a fungal disease that affects seedlings, causing wilting and collapse. Powdery mildew manifests as white spots on leaves and reduces photosynthesis. Root rot, another fungal disease, decays the plant's root system, leading to poor nutrient uptake and wilting (Vertical Farm Daily).

Preventive Measures: Maintaining sanitation is crucial in microgreen farming to minimize the risk of disease transmission. Keep growing trays, equipment and growing media clean and sterile. Ensure proper ventilation to reduce humidity and prevent fungal diseases like damping-off and powdery mildew. Regularly monitor microgreens for signs of pests or diseases and take prompt action if needed. Consider using biological controls such as ladybugs or predatory mites to manage pest populations naturally. Utilize organic pest control methods like neem oil, insecticidal soaps, or diatomaceous earth (Sprout small farms). Opting for well-draining soil or growing media to prevent waterlogged conditions and root rot (Sharma and Gaurav, 2022). By adhering to these practices and remaining vigilant, you can effectively prevent and manage common pests and diseases in microgreen farming.

Production costs and profit margins: Production costs in the microgreen industry include initial setup expenses for equipment, infrastructure, and growing systems. For soil-less systems like hydroponics or aeroponics, these costs can be significant due to the need for specialized equipment such as grow lights, nutrient delivery systems, and climate control mechanisms. Ongoing operational costs include nutrient solutions, labor for seeding, monitoring growth, harvesting, and packaging, as well as energy costs for lighting and temperature control in indoor systems. Packaging and distribution costs, depending on market channels, can also add to the overall production expenses. Despite the efficiency of hydroponic systems, water and waste management also represent a recurring cost (Velazquez-Gonzalez *et al.,* 2022)

Profit margins in the microgreen industry are generally high due to the premium prices commanded by these nutrient-dense crops. Microgreens can be sold for ₹1,500 to ₹4,000 per kilogram (Hug a Plant,2024), and their rapid growth cycle of 7-14 days allows for multiple harvests per year, significantly increasing revenue potential. With profit margins ranging from 30% to 50%, especially in urban or controlled environment farms, the industry offers strong profitability. Scaling up operations and catering to niche markets can further increase margins, as can selling to premium markets like restaurants and health food stores (Shah *et al*., 2023). However, market saturation and supply chain volatility are risking that producer need to consider when projecting long-term profitability.

Market analysis: In their 2020 study, Michell et al. evaluated consumer acceptance and sensory perceptions of six microgreens species, finding high overall acceptability. The mean liking scores ranged from 6.0 (slightly acceptable) to 7.9 (acceptable). Red-coloured species such as bull’s blood beet, red cabbage, and red garnet amaranth received the highest appearance ratings, while tendril pea scored the highest for flavour (7.8). Arugula had the lowest flavour acceptability (5.8) and the highest ratings for astringency, bitterness, sourness, and heat. Females generally rated appearance and texture higher than males, especially for arugula and broccoli. Participants' familiarity with microgreens was moderate, with most encountering them in markets, restaurants, or through media. Food neophobia negatively impacted acceptability, indicating that openness to new foods enhances the acceptance of microgreens. Principal component analysis showed that overall acceptability was positively associated with favourable sensory attributes like sweetness and texture and negatively with bitterness and sourness. These findings underscore the need for consumer education on the benefits and uses of microgreens to enhance their market appeal. Future research should investigate the bioactive compounds in microgreens and their sensory perceptions across diverse populations, considering factors such as cost, availability, and sustainability to promote wider consumption, particularly in urban areas where finding nutritious food is increasingly challenging due to the prevalence of adulterated foods.

Sustainable microgreens: Sustainability in microgreen production focuses on efficient resource use, minimal environmental impact, and local food security. Microgreens require less water and land compared to traditional crops, making them ideal for urban agriculture. Techniques like hydroponics and vertical farming help conserve water and energy, while organic growing methods reduce reliance on synthetic inputs (Rathor *et al*., 2024). The quick growth cycle of microgreens reduces food waste, and their small-scale cultivation limits transportation needs, lowering carbon footprints. Additionally, microgreens support biodiversity by attracting pollinators and beneficial insects, contributing to ecological balance. Their high market value and rapid turnover make them economically viable for small-scale farmers, promoting sustainable, local food systems.

2. CONCLUSION

In conclusion, this article highlights the pivotal role that microgreens play in urban agriculture and the advancement of sustainable food systems. These tiny, nutrient-dense plants offer exceptional nutritional value, providing concentrated amounts of vitamins, minerals and antioxidants that surpass those of their mature counterparts. Their culinary versatility makes them a valuable addition to a wide range of dishes, enhancing both flavour and visual appeal.

Microgreens' efficient cultivation methods, such as hydroponics and vertical farming, are particularly well-suited for urban environments where space and resources are limited. These methods maximize resource efficiency, conserve water, and reduce the reliance on conventional agricultural inputs, making microgreens an ideal solution for addressing food security challenges in densely populated areas.

By harnessing the potential of microgreens, we can significantly improve the nutritional quality of our diets and contribute to the development of innovative, sustainable agricultural practices. Furthermore, the integration of microgreens into urban agriculture can foster community engagement, promote local food production, and reduce the environmental impact associated with long-distance food transportation.

Embracing microgreens in urban agriculture represents a significant step towards creating a healthier, more resilient food system that benefits both people and the planet. As we continue to face global challenges related to food security and sustainability, the adoption of microgreens can play a crucial role in building a sustainable future for urban communities.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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 writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Acuña, J.J., Hu, J., Inostroza, N.G. *et al.* Endophytic bacterial communities in ungerminated and germinated seeds of commercial vegetables. *Sci Rep* **13**, 19829 (2023). https://doi.org/10.1038/s41598-023-47099-4

Adewoyin, O. B. (2023). Pre-Harvest and Postharvest Factors Affecting Quality and Shelf Life of Harvested Produce. In *New Advances in Postharvest Technology*. IntechOpen.

Ampim PAY, Obeng E, Olvera-Gonzalez E. Indoor Vegetable Production: An Alternative Approach to Increasing Cultivation. Plants (Basel). 2022 Oct 25;11(21):2843. doi: 10.3390/plants11212843. PMID: 36365296; PMCID: PMC9657353.

Arif Sadik Polash M., Arif Sakil Md., Sazia Shahida and Alamgir Hossain Md. (2019). Selection of suitable growing media and nutritional assessment of microgreens. *Agricultural Research Journal*, 56(2), 752-756.

Baudoin, W., and Drescher, A. (2008). Urban agriculture for sustainable poverty alleviation and food security. *FAO: Rome, Italy*.

Berba, K. J., & Uchanski, M. E. (2012). Postharvest physiology of microgreens. Journal of Young Investigators, 24, 1–5.

Bhaswant M, Shanmugam DK, Miyazawa T, Abe C, Miyazawa T. Microgreens-A Comprehensive Review of Bioactive Molecules and Health Benefits. Molecules. 2023 Jan 15;28(2):867. doi: 10.3390/molecules28020867. PMID: 36677933; PMCID: PMC9864543

Bhaswant, M., Shanmugam, D. K., Miyazawa, T., Abe, C., & Miyazawa, T. (2023). Microgreens—A comprehensive review of bioactive molecules and health benefits. *Molecules*, *28*(2), 867.

Bindu (2018). Hydroponics: Soil- Less Farming, A Sustainable Agriculture System. *Journal of emerging technologies and innovative research*.

Cahill, Thomas & Hardiman, Gary. (2020). Nutritional challenges and countermeasures for space travel. Nutrition Bulletin. 45. 98-105. 10.1111/nbu.12422.

Calvo-Polanco M, Ribeyre Z, Dauzat M, Reyt G, Hidalgo-Shrestha C, Diehl P, Frenger M, Simonneau T, Muller B, Salt DE, Franke RB, Maurel C, Boursiac Y. Physiological roles of Casparian strips and suberin in the transport of water and solutes. New Phytol. 2021 Dec;232(6):2295-2307. doi: 10.1111/nph.17765. Epub 2021 Oct 21. PMID: 34617285; PMCID: PMC9298204.

Chandra Sahu, K., and Satapathy, M.K. (2021). Landless Urban Rooftop Farming Context of Soilless Culture for Microbe Frees Cultivation, Roof Security and Environmental Sustainability. *Asian Research Journal of Agriculture*.

Choe, U., Yu, L. L., & Wang, T. T. (2018). The science behind microgreens as an exciting new food for the 21st century. *Journal of agricultural and food chemistry*, *66*(44), 11519-11530.

Cooking with shy (2024). https://cookingwithshy.com/2024/04/10/harvesting-happiness-microgreens-culinary-inspiration/

Despommier, D. (2013). Farming up the city: the rise of urban vertical farms. *Trends in biotechnology*, *31*(7), 388-389.

Di Gioia, F., & Santamaria, P. (2015). Microgreens - Novel fresh and functional food to explore all the value of biodiversity. Bari: ECO-logica srl.

Divya Sathyanarayan (2014). Economic Times Available at: https://economictimes.indiatimes.com/industry/services/hotels-/-restaurants/five-stars-hotels-growing-own-veggies-or-sourcing-from-local-growers-to-save-money/articleshow/37539603.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst

Ebert AW. Sprouts and Microgreens—Novel Food Sources for Healthy Diets. *Plants*. 2022; 11(4):571. https://doi.org/10.3390/plants11040571

Ebert, A. W. (2022). Sprouts and microgreens—Novel food sources for healthy diets. *Plants*, *11*(4), 571.

EUTM Organics. Available at: https://www.etumorganics.co/post/5-most-popular-microgreens-for-chefs#google_vignette

Flores, M., Hernández-Adasme, C., Guevara, M. J., & Escalona, V. H. (2024). Effect of different light intensities on agronomic characteristics and antioxidant compounds of Brassicaceae microgreens in a vertical farm system. *Frontiers in Sustainable Food Systems*, *8*, 1349423.

Franks, E., & Richardson, J. (2009). *Microgreens: A guide to growing nutrient-packed greens*. Gibbs Smith.

Gebreegziher, W. G. (2023). Soilless culture technology to transform vegetable farming, reduce land pressure and degradation in drylands. *Cogent Food & Agriculture*, *9*(2), 2265106.

Gunjal, M., Singh, J., Kaur, J., Kaur, S., Nanda, V., Sharma, A., & Rasane, P. (2024). Microgreens: cultivation practices, bioactive potential, health benefits, and opportunities for its utilization as value-added food. *Food Bioscience*, 105133.

Hati, A. J., & Singh, R. R. (2021). Smart indoor farms: Leveraging technological advancements to power a sustainable agricultural revolution. *AgriEngineering*, *3*(4), 728-767.

Hayes, J. D., Kelleher, M. O., & Eggleston, I. M. (2008). The cancer chemopreventive actions of phytochemicals derived from glucosinolates. *European journal of nutrition*, *47*, 73-88.

Heimer K A Hart A M Martin L G and Rubio-Wallace S 2009. Examining the evidence for the use of vitamin C in the prophylaxis and treatment of the common cold. *J Am Acad Nurse Pract* 21: 295-300.

Hendriks, A. (2021). *Producing a more valuable crop: improving nutritional value, shelf life, taste, and appearance in microgreens using pre-harvest light treatments* (Master's thesis).

Hodges R E, Baker E M, Hood J, Sauberlich H E and March S C. (1969). Experimental scurvy in man. *Am J Clin Nutr* 22: 535-48.

Hug a Plant, (2023). https://hugaplant.com/pages/microgreens-wholesale?srsltid=AfmBOoqOOZnTzEVFW7I64J9nfVNgWW0qMEfqPWzUq9QsHfaA3-wMyxQ3.

Jayachandran, A., Jain, S., Saini, S., Maurya, P., Subhasmita, S., Shukla, K. K., & Kiran, B. (2022). Hydroponics: An art of soil less farming. *The Pharma Innovation Journal*, *11*(9), 1049-1053.

Jones, P. C., Lowe, T. J., Traub, R. D., & Kegler, G. (2001). Matching supply and demand: The value of a second chance in producing hybrid seed corn. *Manufacturing & Service Operations Management*, *3*(2), 122-137.

Kumar, S., Jasmin, L. B., & Saravaiya, S. (2018). Microgreens: A new beginning towards nutrition and livelihood in urban-peri-urban and rural continuum. *Technologies and sustainability of protected cultivation for hi-valued vegetable crops. Navsari Agricultural University, Navsari*, 246-262.

Kyriacou, M. C., El-Nakhel, C., Pannico, A., Graziani, G., Zarrelli, A., Soteriou, G. A., & Rouphael, Y. (2021). Ontogenetic variation in the mineral, phytochemical and yield attributes of brassicaceous microgreens. *Foods*, *10*(5), 1032.

Lester, G. E., Xiao, Z., Luo, Y., & Wang, Q. (2013, September). Microgreens: assessment of nutrient concentrations. In *HortScience. Journal of Agriculture and Food Science* 48:9, pp. S235-S236.

Ma, S., Tian, S., Sun, J., Pang, X., Hu, Q., Li, X., & Lu, Y. (2022). Broccoli microgreens have hypoglycemic effect by improving blood lipid and inflammatory factors while modulating gut microbiota in mice with type 2 diabetes. *Journal of Food Biochemistry*, *46*(7), e14145.

Milos Vukcevic, (2023) Microgreens vs Sprouts: A Comprehensive Comparison. *Micro green silo.* https://www.microgreensilo.com/microgreens-vs-sprouts/

Mir, S. A., Shah, M. A., & Mir, M. M. (2017). Microgreens: Production, shelf life and bioactive components. *Critical Reviews in Food Science and Nutrition*, *57*(12), 2730–2736. https://doi.org/10.1080/10408398.2016.1144557.

Mlinarić S, Piškor A, Melnjak A, Mikuška A, Šrajer Gajdošik M, Begović L. Antioxidant Capacity and Shelf Life of Radish Microgreens Affected by Growth Light and Cultivars. *Horticulturae*. 2023; 9(1):76. https://doi.org/10.3390/horticulturae9010076

Nath, P., Sakharam, J., Kale, K. R. J., & Mahawar, M. K. (2015). Tiny But Mighty. *Processed Food Industry*.

Paradiso, V. M., & Renna, M. (Eds.). (2021). *Ongoing Research on Microgreens: Nutritional Properties, Shelf-life, Sustainable Production, Innovative Growing and Processing Approaches*. MDPI.

Paraschivu, Mirela, Cotuna, Otilia, Sărăţeanu, Veronica, Carmen, Durau & Păunescu, Ramona. (2022). Microgreens -Current Status, Global Market Trends and Forward Statements. Scientific Papers Series Management, *Economic Engineering in Agriculture and Rural Development* 21(3).

Partap, M., Sharma, D., Deekshith, H. N., Thakur, M., Verma, V., & Bhargava, B. (2023). Microgreen: A tiny plant with superfood potential. *Journal of Functional Foods*, *107*, 105697.

Pinto, E., Almeida, A. A., Aguiar, A. A., & Ferreira, I. M. (2015). Comparison between the mineral profile and nitrate content of microgreens and mature lettuces. *Journal of Food Composition and Analysis*, *37*, 38-43.

Rajan, P., Lada, R. R., & MacDonald, M. T. (2019). Advancement in indoor vertical farming for microgreen production. *American Journal of Plant Sciences*, *10*(08), 1397.

Rani, S., Singh, N., Maurya, S. B., & Phour, M. (2019). Microgreen farming A new approach for nutrient rich greenfood for remote locations. *Indian Farming*, *69*(2).

Rani, S., Singh, N., Maurya, S. B., & Phour, M. (2019). Microgreen farming A new approach for nutrient rich greenfood for remote locations. *Indian Farming*, *69*(2).

Rao, S. M., Sayyed, K., & Shaheed, S. S. A. (2023). Microgreen Farming. *Research and Reviews in Agriculture Science Volume III*, 13.

Rathor, A. S., Choudhury, S., Sharma, A., Nautiyal, P., & Shah, G. (2024). Empowering vertical farming through IoT and AI-Driven technologies: A comprehensive review. *Heliyon*.

Renna, M., Montesano, F. F., Serio, F., & Gonnella, M. (2021). The Mediterranean diet between traditional foods and human health through culinary examples. In *Gastronomy and food science* (pp. 75-99). Academic Press.

Robert Berghage and Elsa Sánchez. Growing Microgreens. Penn State Extension. Available at: https://extension.psu.edu/growing-microgreens

Seidelmann S B Claggett B Cheng S Henglin M Shah A Steffen L M Folsom A R Rimm E B Willett W C and Solomon S D 2018. Dietary carbohydrate intake and mortality: a prospective cohort study and meta-analysis. *The Lancet Publ Health* 3: 419-28.

Sekhon, B.S., Pedada, S., and Kamatyanatti, M. (2018). Recent Advances In Soil-Less Vegetable Production: A Review. *Journal of emerging technologies and innovative research*.

Shamsiri, R. (2007). Principles of Greenhouse Control Engineering. *Institute of Advanced Technology Universiti Putra Malaysia*.

Sharma, Gaurav. (2022). Rooting Media for Raising Hi-Tech Nursery in Vegetable Crops. Available at: https://www.researchgate.net/publication/357869060_Rooting_Media_for_Raising_Hi-Tech_Nursery_in_Vegetable_Crops

Singh, A., Singh, J., Kaur, S., Gunjal, M., Kaur, J., Nanda, V., Ullah, R., Ercisli, S. & Rasane, P. (2024). Emergence of microgreens as a valuable food, current understanding of their market and consumer perception: A review. *Food Chemistry: X*, 101527.

Singh, M., Nara, U., Rani, N., Pathak, D., Kaur, K., & Sangha, M. K. (2023). Comparison of Mineral Composition in Microgreens and Mature leaves of Celery (Apium graveolens L.). *Biological Trace Element Research*, *201*(8), 4156-4166.

Sprout Small Farms. Available at: https://sproutsmallfarms.com/?p=230

Stoleru, T., Ioniță, Alexandrina, & Zamfirache, Magdalena. (2016). Microgreens-a new food product with great expectations. *Romanian journal of biology*, *61*, 7-16.

Treadwell, D., Hochmuth, R., Landrum, L., & Laughlin, W. (2010). Microgreens: A New

Specialty Crop. University of Florida IFAS Extension, (July), 1–3.

Vertical Farm Daily Available at: https://www.verticalfarmdaily.com/article/9606105/troubleshooting-common-microgreen-problems-a-guide-to-maintaining-healthy-crops/

Waterland, N. L., Moon, Y., Tou, J. C., Kim, M. J., Pena-Yewtukhiw, E. M., & Park, S. (2017). Mineral content differs among microgreen, baby leaf, and adult stages in three cultivars of kale. *HortScience*, *52*(4), 566-571.

Westerterp-Plantenga M S Nieuwenhuizen A Tome D Soenen S and Westertero K R 2009. Dietary protein, weight loss, and weight maintenance. *Annu Rev Nutr* 29: 21-41.

Wikipedia contributors. (2023, November 30). *Microgreen*. Wikipedia. Available at: https://en.wikipedia.org/wiki/Microgreen#:~:text=Microgreens%20are%20vegetable%20greens%20(not,sweetness%20and%20spiciness%20to%20foods.

Wojdyło, A., Nowicka, P., Tkacz, K., & Turkiewicz, I. P. (2020). Sprouts vs. microgreens as novel functional foods: Variation of nutritional and phytochemical profiles and their in vitro bioactive properties. *Molecules*, *25*(20), 4648.

Xiao, Z., Codling, E. E., Luo, Y., Nou, X., Lester, G. E., & Wang, Q. (2016). Microgreens of Brassicaceae: Mineral composition and content of 30 varieties. *Journal of Food Composition and Analysis*, *49*, 87-93.

Xiao, Z., Nou, X., Luo, Y., & Wang, Q. (2014). Comparison of the growth of *Escherichia coli* O157: H7 and O104: H4 during sprouting and microgreen production from contaminated radish seeds. Food Microbiology, 44, 60–63.

Zagory, D., & Kader, A. A. (1988). Modified atmosphere packaging of fresh produce. Food Technology, 42, 70–77.

Zhang, Y., Xiao, Z., Ager, E., Kong, L., & Tan, L. (2021). Nutritional quality and health benefits of microgreens, a crop of modern agriculture. *Journal of Future Foods*, *1*(1), 58-66.

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