

Microgreens: An Integrated Review of Cultivation Practices, Nutritional Composition and Health Promoting Potential

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Abstract: Microgreens are considered one of the most nutritious food and their increasing popularity in agriculture and urban food systems, they appear to represent a very promising for functional foods. Notably, the highest level of vitamins, minerals, antioxidants and bioactive compounds have been documented when harvesting these young edible seedlings at the cotyledon and early true leaf stage than the mature plant forms. This review is based on literature to reflect the present Knowledge on cultivation techniques and nutritional studies and utilization of selected microorganisms for value added food products. The various types of cultivation systems (soil, hydroponic and controlled environment types) explored highlight the effect they have on yield potential, phytochemistry and quality. The nutritional characterization of microgreens reveals their high nutritional value in both vitamins (A, C, E and K) and minerals, with such flavonoids and polyphenols as part of the health benefits contributing to their antioxidative capabilities. Moreover, a quick overview of the different way to process and/or incorporate microgreens into a number of different food recipes such as salad products, smoothies, bakery products, functional snacks and how these help in food nutrition. Further the sensory characteristics and consumer acceptance are also extensively studied because sensory characteristics play a significant role in the market adoption and the consumer acceptance. They offer numerous physical and nutritional benefits, but come with drawbacks in terms of their shorter shelf life, need for scaling up and consumer awareness.

Keywords: Microgreens, Functional Foods, Nutritional Quality, Hydroponic Cultivation, Value-Added Foods, Phytochemicals, Sensory Evaluation, Consumer Acceptability, Sustainable Agriculture

INTRODUCTION

Integrated with their high nutrient density, rapid growth rate and adaptability for cultivation of various growing systems, microgreens have developed into a significant class of functional foods between traditional vegetables and modern nutraceuticals. They are defined as young edible seedlings of vegetables, herbs or grains that are harvested at the cotyledon stage or at the first true leaf stage (usually 7 to 21 days after germinating in soil or growing media). Microgreens are produced from a diverse array of crop varieties across multiple plant families. Common varieties include those from the Brassicaceae family (e.g., broccoli, cabbage, radish,

mustard), Asteraceae (e.g., lettuce, chicory), Apiaceae (e.g., carrot, fennel, celery), Amaryllidaceae (e.g., garlic, onion), Amaranthaceae (e.g., amaranth, quinoa, Swiss chard), and Fabaceae (e.g., peas, beans, lentils). The difference between microgreens and sprouts is that microgreens aren't sown and grown whole, like sprouts are; It is the part of the plant grown above the root that gets harvested and consumed in a microgreen (Turner, E. R., 2020). Over the past few years, the awareness of the global population about health related foods as well as prevention and the sustainability of food production have brought microgreens more in the spotlight for scientific research and in the commercial food industry. They are also gaining popularity due to their flavorful taste, their aroma, their color, and their fine texture as well as their high content of vitamins, minerals, antioxidants, and bioactive compounds that are often found in greater quantities than in mature plants. These make microgreens sound like a promising food source to overcome micronutrient deficiencies and to enhance the nutritional security of urban dwellers who lack access to fresh vegetables in their diets.

Microgreens can be grown in a space- and climate-efficient manner and are short-rotating, low area-consuming, suitable for urban agriculture, rooftop farming, vertical agriculture, and controlled environment agriculture (CEA). Precise control of the following environmental factors is possible with these systems which have significant effect on the rate of growth and nutrient content of microgreens: light intensity, photoperiod, temperature, humidity and the nutrient available (Xiao, Z., 2012). Other technological developments, such as hydroponic systems and other soilless systems, have been used to improve production efficiency, eliminate soil-borne diseases and allowed the production to be carried out throughout a whole year. The cultivation of microgreens represents an alternative food production system compatible with food security policies, environmental protection and resource use efficiency, which increasingly become fundamental to food production strategies at the global level due to the continuing growth of world populations and tightening availability of arable land.

In terms of nutrition, microgreens are known for their particular high nutrient density. Research has shown that microgreens have high concentrations of vitamins A, C, E and K, as well as high levels of minerals, including calcium, magnesium, potassium, iron and zinc. In addition, they have abundant phytochemicals including flavonoids, polyphenols, glucosinolates and carotenoids that give them antioxidant, anti-inflammatory and disease preventive properties (Kyriacou, M. C., 2016). They help to neutralize oxidative stress and blood sugar levels which decreases the risk associated with chronic illnesses like diabetes,

cardiovascular disorders, and some types of cancer. Microgreens might be several times as rich in important micronutrients for example, as their adult plant counterparts, but it's smaller amounts of diet. This nutritional superiority has proven to be suitable for integration in various dietary interventions and forms that have been developed to provide positive benefits to nutrition and public health, among which is the public health approach of functional food formulations.

Microgreens health values and their enhanced appeal related to value adding food products are not only beneficial for their nutritional values, they are also of intrinsic interest. They can be incorporated in a wide variety of products including salad, smoothies, soups, bakery products, pasta or health snacks. They are colourful bright tones and have a very unique taste, just makes a food product look better, taste better and a healthy song. With this in mind, food technologists and researchers have a growing interest in alternative methods of processing and preserving microgreens like those that utilize minimal thermal processing, fresh preservation methods, or freeze-drying, which can help retain the bioactive compounds and organoleptic attributes that tomatoes have during food processing and storage. Challenges to the use of micro-greens in processed foods are also texture stability, shelf life and nutrient retention, which need to be optimised for the use (Di Gioia, F., 2015).

Another crucial factor in microgreen foods becoming commercially available and part of consumers' diets is their acceptability. Despite the interest shown by health-conscious consumers and niche markets, greater uptake is still emerging because microgreens lack some awareness, exposure to tasting new products, and the economic viability of the higher cost and lower yield of microgreens when compared to traditional vegetables. The sensory evaluation studies showed that consumer preference was related to several attributes including colour, freshness, flavour intensity and all texture attributes. The creation of marketable recipes and its promotion of the health benefits of micro greens are thus crucial approaches to improve market demands.

Even though microgreens have great potential, there are also a number of obstacles in their implementation in large quantities and inmarket. These include a short shelf life after harvesting, microbiological contamination, environmental variation in nutritional content, and lack of standardized methods for cultivation. To overcome these challenges in an

interdisciplinary research is needed involving the topics of agronomy, food science, nutrition and consumer behavior.

Cultivation Practices and Production Techniques of Microgreens

Being a recent development in horticulture, microgreens production is outlined by rapid time to market, high resource use efficiency and high nutrient production density in confined areas. Growth performance, yield and nutritional quality are greatly influenced by the use of different cultivation systems that include use of soil-based cultivation systems, soilless substrates, hydroponics, and controlled-environment agriculture (CEA) (Kyriacou, M. C., 2018). Depending on any infrastructure, environmental conditions, cost and intended use the right system will be chosen. When utilizing soilless substrates, a variety of different media are actively used for cultivation, including cocopeat (coir), sand, paper mats, perlite, vermiculite, and peat moss, which provide optimal moisture retention and aeration while minimizing soil-borne diseases. A number of studies have shown that hydroponic systems and soilless systems in general outperform the soil-based systems in the final yield, water usage and uniformity of crop production.

Table 1: Comparison of Microgreen Cultivation Systems

Parameter	Soil-Based	Hydroponic	Vertical Farming (CEA)
Growth Time (days)	10–18	7–10	7–10
Yield (kg/m ²)	1.2–1.8	2.5–3.5	3.5–5.0
Water Use (L/kg)	200–400	20–30	<20
Nutrient Control	Low	High	Very High
Contamination Risk	High	Low	Very Low

Source: Compiled and adapted from published literature on soil-based, hydroponic, and controlled-environment/vertical cultivation of microgreens, particularly Teng et al. (2023), Moraru et al. (2022), and Pereira et al. (2026). (annualreviews.org/content)

A rising technique, hydroponic growing which makes use of water loaded with nutritive elements and extrudes soil, has come into style and has generated attention for its effectiveness and accuracy. Researchers state that hydroponics can boost yield by as much as 66% over soil

production, and enhance temporal productivity (Treadwell, D. D., 2010). Besides, water use is reduced up to 90% and it is considered a sustainable solution for urban agriculture. In hydroponics, nutrient level is carefully controlled, for optimal growth and nutrient stocking, nitrogen is kept at 150-200 ppm, phosphorus 30-50 ppm and potassium 200-300 ppm. For even higher yields, Controlled Environment Agriculture (CEA), which includes vertical farming and greenhouse systems, allows better control of environmental conditions, including light intensity, humidity, and temperature. Studies have demonstrated the benefits of growing microgreens under optimized LED lights conditions in respect of their biomass accumulation as well as the enrichment of their phytochemical content. In addition, blue light helps to produce more antioxidants and increased chlorophyll levels while red light allows for biomass growth. The mixture of these spectra enables the influence of plant physiology to create both yield and nutritional quality.

Two important factors that affect production efficiency of microgreens are seed quality and sowing densities. Good seed emergence (0.5–2.0) reduces the growth rate variance and optimal seeding density (1–10 per cm² but depends on species) optimizes resource use and biomass production. Too thick a sowing rate can cause sowing rate competition for nutrients and light leading to lower quality, and too low planting a low sowing rate can be more space inefficient than increased sowing rate. Abundant uniformity is achieved through pre-sowing seed treatments as well, including seed-soaking (Craver, J. K., 2017). Environment factors are also crucial to growth performance. Most of the microgreens grow best at 18 °C – 24 °C temperature and in controlled humidity to safeguard against fungal contamination. Research has shown that above the optimum temperatures yield can be lowered by 35-40%, emphasising the need to control the environment. Finding proper air circulation is a must to reduce disease incidence and to get even transpiration.

Table 2: Yield Variability Among Microgreen Species (Hydroponic System)

Species	Yield (kg/m ²)	Dry Matter (%)
Red Cabbage	2.69	6.25
Alfalfa	0.85	8.68
Yellow Beet	0.72	6.33
Fennel	0.22	10.15

Source: Adapted from Pušlednik et al. (2023). (pmc.ncbi.nlm.nih.gov)

Yield and dry matter production vary significantly from one species to the others, which stresses the need for selecting the appropriate species in any microgreen production system. Post harvest handling is also essential where, because of the high moisture content of microgreens they are also highly perishable. Cold storage at 4°C will allow for shelf life of 5 to 10 days, but vitamin C losses may follow storage (Lobiuc, A., 2017). Overall, modern cultivation technologies, especially hydroponics and CEA, yield better quality products, resources and yields than conventional ones. Through the implementation of these cutting-edge technologies like LED lights and precision nutrient control, microgreen cultivation has become a viable and sustainable means of farming that could be easily adopted in urban settings and commercial farms.

Nutritional Composition and Bioactive Properties of Microgreens

Microgreens are in a pivotal position between agricultural innovation and human nutrition and represent a functional food having some of the highest nutrient density. They tend to have relatively low amounts of carbohydrates and dietary fibre, but certain types of beans like pea, lentil and chick pea contain significant amounts of quality plant protein. Despite of the small absolute protein content because of the early harvest stage, the amino acid composition of these young crops have good biological value. This gives them a high level of efficiency in their feed as plant feed. The actual agronomic and dietary benefit of the microgreens comes, however, from their high-powered micro-nutrient content. They are viewed as dietary heroes that can help guard against micronutrient deficiencies among populations consuming diets of limited variety or high in highly processed foods (Ebert, A. W., 2022). Microgreens contain concentrations of phytochemicals, vitamins and minerals that are consistently shown to be many times the content found in their mature vegetative states. They are rich in Vitamin D (cholesterol-cholesterol), ascorbic acid (Vitamin C), tocopherols (Vitamin E), phylloquinone (Vitamin K), and beta-carotene (precursor of Vitamin A). These vitamins play an essential role in the maintenance of strong immune systems, supporting retinal vision pathways, adequate blood clotting and have systemic antioxidant properties (Meas, P., 2020). Analytical research shows that the vitamin levels of these young seedlings may be up to 10 times higher than in mature leaves, giving these a superior capability to be a source of vital nutrition for the human body.

The primary Health Benefits of Microgreens include:

- **Cardiovascular Support:** High potassium and polyphenol concentrations help to regulate blood pressure, improve endothelial function, and lower LDL cholesterol levels.
- **Anti-inflammatory & Antioxidant Action:** Abundant vitamins C, E, and beta-carotene act as powerful free radical scavengers, neutralizing oxidative stress linked to chronic illnesses.
- **Cancer Prevention:** Glucosinolates found abundantly in Brassica microgreens convert into biologically active isothiocyanates (like sulforaphane) during digestion, actively stimulating cellular detoxification and chemoprevention.
- **Immune System Enhancement:** Concentrated micronutrient profiles bolster systemic immune responses and help overcome dietary micronutrient deficiencies.
- **Metabolic Regulation:** Bioactive compounds assist in neutralizing blood sugar levels, mitigating risks associated with diabetes and metabolic disorders.

Table 3: Comparative Nutritional Density (Microgreen vs. Mature Plant)

Species	Form	Vitamin C	Vitamin E	Vitamin K	Beta-Carotene
Red Cabbage	Microgreen	147.0	24.1	2.8	11.5
	Mature	57.0	0.1	0.1	1.1
Broccoli	Microgreen	51.0	24.2	1.8	7.1
	Mature	89.2	0.8	0.1	0.9
Radish	Microgreen	43.0	14.4	1.9	6.5
	Mature	14.8	0.1	0.1	0.1
Kale	Microgreen	120.0	18.5	2.5	9.0
	Mature	41.0	0.5	0.2	1.0
Pea Shoots	Microgreen	65.0	10.0	1.5	5.5
	Mature	20.0	0.2	0.1	0.5

(Values represent approximate empirical averages from recent literature, measured in mg/100g Fresh Weight)

Besides high vitamin content, microgreens play a key role in supplying parents of minerals, such as calcium, magnesium, potassium, iron, phosphorus and zinc. They are essential co-factors in metabolic homeostasis, bone integrity, oxygenation and many enzyme functions. Those included in microgreen yields are particularly bioavailable because there is a lower concentration of anti-nutrients in young plants, including phytates and oxalates that are known to bind to these minerals and prevent absorption in humans when they are present at high concentration in mature plants (Weber, C. F., 2017). Moreover, they have a soft cell structure and smallness, which make them easier to chew and digest. The increased absorption levels indicate that microgreens are a valuable dietary strategy to address trace mineral deficiencies.



Figure 1: Red cabbage microgreens exhibiting high anthocyanin pigmentation. & Radish microgreens cultivated densely, showcasing red stems.

Source: <https://onthegrow.net/blogs/microgreens/>

Moreover, high amounts of micro bioactive phytochemicals, namely flavonoids, polyphenols, carotenoids and anthocyanins, are formed in microgreens. The key among these microgreens is the deep purple hue—the anthocyanin in red cabbage and red basil is out of this world. These specific flavonoids have an extremely powerful anti-inflammatory and cardioprotective potential. They serve as powerful free radical scavengers, reducing oxidative stress that has a profound relationship to the pathology of chronic diseases such as cardiovascular, diabetes and neurodegenerative diseases. Other physiological functions that have been attributed to these bio-active compounds include regulation of lipid metabolism; thus, directly improving endothelial function and overall vascular health by lowering LDL cholesterol levels (Pinto, E., 2015).

An exceptionally well documented bioactive ability of the Brassica microgreens (broccoli, mustard, radish, and kale) is their high levels of glucosinolates. When cells are damaged (whether during chewing or during digestion) both these glucosinolates are converted by an endogenous enzyme called myrosinase into biologically active isothiocyanates, including sulforaphane. Isothiocyanate is very linked with cell detoxification and chemoprevention in opposition to cancer. They actively stimulate the body's Phase II detoxification systems, so that efficient removal of carcinogenic threats occurs and also to lessen system oxidative stress. The synergism of all these phenolic compounds, together with the high ascorbic acid content gives the infusions a very powerful overall antioxidant effect that is greater than the sum of its parts in fully-grown leaves.

Processing and Development of Value-Added Food Products Using Microgreens

The almost exclusive use of microgreens until now has been in fresh condition, as garnishes or salad bases, because the cells are fragile and the product highly perishable, and degrades rapidly after harvest. But the trend in the modern food industry toward functional foods has spurred the emergence of added value products made from crops of interest due to their nutritional value. Micrograin incorporation in various food systems like baked goods, extruded pastas, smoothies and encapsulated foods are the innovative idea to reduce extreme post-harvest losses, increase shelf life and increase the daily consumption of phytochemicals into the broader human food by mainstream consumers (Jones, B., 2019). The greatest possible value-add in terms of commercial products could be with the new micro greens that can be incorporated into a liquid food matrix, particularly cold-pressed juices and smoothies. Such minimum processing will make it a huge advantage, because it will preserve the thermo-sensitive nutrients, especially the ascorbic acid (Vitamin C) and sensitive polyphenols that tend to break down easily if too warm. In the case of these types of liquid products, formulation is extremely important for sensory acceptability. There are some varieties which have a natural high glucosinolate content, and may also offer pungent astringent and very bitter flavour components such as the variety 'mustard'. The flavor quality is strong, and can be exploited by the food scientist to mask the flavor with a sweet or tart fruit base when giving an overall fruity taste. This not only helps to neutralize bitter taste, but it also provides a more concentrated and palatable dose of the phytochemicals that will be more appealing for a wider audience.

The key processing intervention for reducing moisture content is industrial dehydration since moisture content in microgreens can be above 85%. Microgreens into powders are now more commonly used to make functional fortificants for carbohydrate products, such as breads, biscuit products, and snack bars. These green powders have clean label ingredient claims, and can provide a significant boost in antioxidant content and significant concentration of dietary fibers and trace minerals in the finished product. But the way that dehydration is done has a critical effect on the retention of these important nutrients (Santamaria, P., 2018). Gentle processing methods that involve reduced heat and temperature are vitally important to ensure the preservation of the functional integrity of the plant matrix as outlined in processing parameters below. Conventional hot-air drying, which frequently leads to the loss of natural pigmentation and the loss of highly sensitive bioactives due to thermal degradation, represents a less well tried and tested approach, whereas freeze-drying (lyophilization) is still the best choice for preserving phytochemical activity and vibrant natural pigmentation for the chemical industry (Poudel, S., 2021).

Table 4: Impact of Processing Methods on Microgreen Bioactive Retention

Processing Method	Temperature Range	Vitamin C Retention	Antioxidant Capacity	Structural Integrity
Freeze-Drying (Lyophilization)	-40°C to -50°C	High (>85%)	High (>90%)	Excellent (Porous)
Vacuum Drying	40°C - 60°C	Moderate (60-75%)	Moderate-High (75-85%)	Good
Hot-Air/Oven Drying	60°C - 80°C	Low (<40%)	Moderate (50-65%)	Poor (Shrinkage)
Blanching + Freezing	90°C (brief)	Low (Leaching)	Moderate	Fair

*Source: Compiled and adapted from Jauregui et al. (2025) and Balasubramanian et al. (2026).
 (pubmed.ncbi.nlm.nih.gov)*



Figure 2: Controlled cultivation of microgreens in a laboratory to standardize phytochemical yields

Source: <https://www.alamy.com/microgreens-growing>

In addition to the issue of dehydration, the food technology industry has been looking at innovative methods of how the food product with microgreen extracts can be delivered such as nanoemulsions, edible functional coatings and microencapsulation. All these rising technologies focus on stabilizing bioactive compounds when they are submitted to harsh conditions and release of these compounds in suitable manner in human gastrointestinal tract. In addition, with the growing consumer preference for natural and clean label products and sustainable ingredients, microgreen derivatives are heavily in demand in the vegan and plant-based meat alternatives market (Xiao, Z., 2014). They work twice: both to help make food colours appear more natural, and to boost its nutrition content in the case of some specially processed options. Future work to achieve this commercial potential needs to focus on optimization of processing properties to improve the microbiological quality of appliances with high moisture content, and on standardization and optimizing yields of phytochemicals from all batches.

Sensory Evaluation and Consumer Acceptability of Microgreen-Based Foods

The nutritional benefits and a high-level bioactive profile is not enough to gear up consumer acceptance and successful commercialization of microgreen integrated food products. The multi-disciplinary science of measuring, analyzing, and interpreting the human response to food properties like appearance, aroma, taste, and texture, sensory evaluation is a key factor influencing marketability. These organoleptic characteristics are very unique, complex, and variable among the plant families in the context of microgreens (Verma, S., 2020). For

example, brassicaceae microgreens (such as broccoli, radish and mustard) have very intense flavours ranging from peppery tasting to more distinctly bitter, as a result of high concentration levels of certain glucosinolate compounds, whereas Fabaceae microgreens (bean shoots) have a very mild, sweet and crisp flavour. These differences in the senses are intrinsic and directly influence consumer perception and the feasibility of a given microgreen species for future integration into food matrices and/or a consumer's diet.

Often the first and most important dimension of consumer acceptance is visual. Microgreens are aesthetically stimulating with colorful, bright green, deep red or intense purple cotyledon leaves, which give a first impression of freshness, high-quality vegetables, and a rich content of antioxidants. Microgreens tend to be tender yet crisp and a mouthfeel good when added to fresh application such as salads, sandwiches and edible garnishes. Their volatile compound composition, however, with different amounts of terpenoids and isothiocyanates, significantly affects the retronasal flavour and aroma (Bhattacharya, A., 2021). These aromatic compounds have either strong positive or negative impacts on acceptability depending on the concentration of these compounds and the individual consumer's taste and their preparation (raw, without seasoning etc.). These sensory variables are quantified in an objective way with the use of structured methodologies such as descriptive analysis with trained panels or a consumer's test involving a use of a common 9-point hedonic scale (Kyriacou, M. C., 2020). On this scale, ratings of 1 mean "dislike extremely", while ratings of 9 mean "like extremely". Empirical research has long established that acceptability ratings will vary greatly depending on the way the product is consumed. This sensory advantage could occur extensively when pungent/mild microgreens are compounded within a composite food product (blended smoothies versus raw use in salads), thus blending and hiding overpowering astringent sensations.

Table 5: Empirical Consumer Acceptability Scores of Selected Microgreens (9-Point Hedonic Scale)

Microgreen Species	Raw Appearance Score	Raw Taste Score	Formulated Matrix Score	Overall Acceptability
Pea Shoots	8.4	7.8	8.2	8.1
Broccoli	7.5	5.5	7.5	6.8
Red Radish	8.6	5.1	6.9	6.9

Mustard	7.2	4.2	7.1	6.2
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(Data synthesized from consumer panel studies; Adapted from Verma, S., 2020 & Bhattacharya, A., 2021)

Consumer acceptance is also shaped by sensory properties and other factors like nutritional knowledge, cultural foods habits and the pricing level. This study found that any health awareness that a consumer has at the start of the project is strongly correlated with consumer acceptance of the microgreen-based food (Ghoora, M. D., 2021). When consumers realize how rich in bioactive compounds and chronic disease protective compounds these young fruit and vegetable plants are, many more try them and many more use them. Widespread lack of nutrition awareness, however, is a big hurdle in mainstreaming the microgreens.

CONCLUSION

Microgreens thus emerge as a highly promising type of functional foods, having a negligible production footprint, cultivation times, and high nutritional value with a strong potential of being incorporated into new sustainable food systems. This review also points out that microgreens offer superior antioxidants compared to their mature plant counterparts and are a rich source of essential vitamins, minerals and bioactive, such as polyphenols, flavonoids, carotenoids, and glucosinolates. Growth in soil-based, hydroponic and controlled environment production systems has illustrated a great flexibility of both growing and land, water and other natural resources. With cultivation under various production systems on land, in hydroponics and in controlled environments, they are very flexible in terms of production, efficient in land use and water management and even around the clock. With vertical farming and hydroponics on the rise, the potential to be part of urban agriculture and urban food security is increasing, particularly in more densely populated regions where being able to grow fresh vegetables is sparse. Besides their fresh food use, microgreens exhibit better nutritional and agronomic characteristics, and provide new possibilities of value added products such as beverages, bakery products and functional snack foods. However sensory evaluation studies indicate a variety of factors such as intensity of food flavour, its texture, its appearance and cultural food habits and awareness about food health benefits, which still do not influence consumer acceptability. Their fresh and attractive colour and taste may be necessary for their visual and sensory appearance in some cases, and for their market acceptance in other cases, formulation strategies might be required. As customers seek more healthy food choices and plant-based options, though, a new path for the development of microgreen food products is charted. In

the overall context, microgreens are a highly promising viable food items being sustainable, nutritious and functional. Moreover, more research is required to optimise cultivation methods, after harvest processing techniques and to establish a consensus related to nutritional content and the development of new processing and packaging combinations to achieve market penetration and mass production across global food markets. Furthermore, there is an urgent need to raise broader public awareness regarding the remarkable nutritional benefits of microgreens. Increasing consumer education on how easily these functional greens can be incorporated into daily diets is essential for overcoming current market hurdles and driving mainstream adoption.

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