Plant Archives Vol. 25, Supplement 2, 2025 pp. 479-489 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-2.058

MICROGREENS: TINY LEAVES, TREMENDOUS POTENTIAL – REVOLUTIONIZING NUTRITION AND URBAN FARMING

Sadhana Kongala[1*] and Thallapally Baby Rani[2]
[1]Department of Vegetable Science, SKLTGHU, Mulugu, Siddipet, Telangana, India
[2]Department of fruit science, College of Horticulture, Mojerla, SKLTGHU, Telangana, India
*Corresponding author E-mail: kongalasadhana14@gmail.com
(Date of Receiving : 05-04-2025; Date of Acceptance : 18-06-2025)

ABSTRACT

Microgreens, the tender, edible seedlings of vegetables and herbs harvested at the cotyledon or first true leaf stage, have emerged as a cutting-edge solution in the realm of functional foods and sustainable agriculture. Celebrated for their vibrant colors, intense flavors, and superior concentrations of nutrients including vitamins, minerals, and antioxidants microgreens bridge the gap between health-conscious diets and modern farming practices. As rapid urbanization and limited arable land challenge conventional agriculture, microgreens offer a highly efficient, space-saving, and water-conserving alternative suitable for indoor, vertical, and hydroponic cultivation systems. This review highlights the historical development, nutritional and health benefits, production techniques, and commercial potential of microgreens, alongside addressing challenges such as contamination risks and short shelf life. With growing consumer awareness and innovations in controlled environment agriculture (CEA), microgreens are poised to revolutionize both home-scale and commercial food systems, promoting food security, dietary diversity, and economic sustainability in a rapidly changing world.

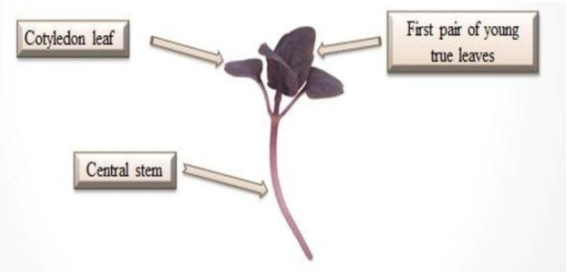
Keywords **:** Microgreens, functional foods, urban farming, nutrition, health benefits, sustainable agriculture.

Introduction

Microgreens are young, tender, edible seedlings of vegetables, herbs, or grains, typically harvested within 7–21 days after germination, when the cotyledons are fully developed and the first true leaves may have emerged. Despite their small size, microgreens are nutrient-dense, offering higher concentrations of vitamins, minerals, and antioxidants compared to their mature counterparts (Kyriacou *et al*., 2016; Xiao *et al*., 2021). Their vibrant colors, distinct flavors, and health-promoting phytochemicals have made them increasingly popular in culinary and health-conscious communities.

Microgreens can be grown using soil, hydroponic systems, or biodegradable substrates, making them ideal for urban agriculture, vertical farming, and indoor cultivation (Di Gioia *et al*., 2020). The short growth cycle, minimal input requirements, and high economic return per unit area further add to their appeal, particularly in regions with limited agricultural land (Poudel *et al*., 2022).

Their rising popularity is also driven by a shift towards sustainable food systems and functional foods. Studies show that species like broccoli, red cabbage, and radish microgreens are rich in bioactive compounds such as glucosinolates, polyphenols, and carotenoids (Zhang *et al*., 2023), contributing to potential health benefits including anti-inflammatory, anti-cancer, and cardiovascular protection.



Historical Development of Microgreens

Microgreens, now recognized as a class of functional foods, have evolved significantly in their role from niche culinary garnishes to mainstream health-focused produce.

The concept of microgreens originated in the United States in the early 1980s, particularly in upscale Californian restaurants where chefs began experimenting with young vegetable greens for their intense flavor, vibrant color, and delicate textures (Kyriacou *et al*., 2016). Initially, only a few varieties like arugula, basil, beets, and cilantro were used, but as demand increased, so did the diversity of crops grown as microgreens.

By the 1990s, microgreens gained momentum in gourmet cuisine due to their aesthetic appeal and flavor concentration (Xiao *et al*., 2012). Their adoption spread globally with chefs and consumers increasingly appreciating their nutritional benefits, leading to scientific interest and agricultural innovation.

The 2010s saw a surge in research on microgreens' nutritional composition, cultivation techniques, and health-promoting bioactive compounds. This interest led to their classification as superfoods, supported by evidence showing that microgreens often contain higher concentrations of vitamins, minerals, and antioxidants than their mature counterparts (Mir *et al*., 2023; Brazaitytė *et al*., 2021).

Technological advancements, such as LED lighting systems, vertical farming, and controlled environment agriculture, have further accelerated microgreens' production and accessibility. These systems allow year-round cultivation with minimal space and water usage, making them ideal for urban agriculture and indoor farming (Pinto *et al*., 2021).

Today, microgreens are not only a culinary trend but also a sustainable and nutritious food option, contributing to food security, dietary diversity, and health promotion.

What are microgreens?

Microgreens are young, edible seedlings of vegetables, herbs, or grains that are harvested at the cotyledon stage, typically 7–21 days after germination. They are larger than sprouts but smaller than baby greens, usually consumed raw and used as garnishes or in salads, smoothies, and sandwiches due to their intense flavor, vivid color, and high nutritional value.

These tiny greens are packed with vitamins (like C, E, and K), minerals, antioxidants, and phytochemicals often in higher concentrations than in mature plants. Common microgreens include broccoli, radish, beet, kale, arugula, and basil (Kyriacou *et al*., 2016; Xiao *et al*., 2021).

They're grown in soil or soilless media (like hydroponics or cocopeat) and have become popular in urban farming and health food markets for their fast growth, low space requirements, and health benefits.

Immature Harvesting Growth Stages of Microgreens:

Microgreens are harvested during their early, immature stages of development, typically between 7 to 21 days after germination, depending on the crop species and environmental conditions. The optimal harvest point is after the emergence of the cotyledon leaves and just before or at the onset of the first true leaves (Kyriacou *et al*., 2016). This stage ensures that the plants are still tender, vibrant, and highly concentrated in nutrients and phytochemicals.

The main stages of microgreen growth include:

1. Germination Stage (0–3 days) – where seeds absorb moisture and sprout.
2. Cotyledon Stage (4–7 days) – the seedlings develop their first leaves (cotyledons), marking the beginning of photosynthesis.
3. Pre-True Leaf Stage (7–14 days) – cotyledons are fully expanded and are typically the ideal point for harvesting most microgreens (Xiao *et al*., 2021).
4. True Leaf Emergence (>14 days) – the appearance of the plant's first true leaves; harvesting at this stage may slightly reduce tenderness but increase flavor complexity depending on the species.

Harvesting at these immature stages offers enhanced nutritional density, concentrated flavors, and greater market value for culinary and health-conscious consumers (Xiao *et al*., 2021; Kyriacou *et al*., 2016).

Why Do We Need Microgreens?

Microgreens have gained significant attention in recent years due to their nutritional density, rapid growth, and minimal space requirements, making them ideal for urban farming, health-conscious diets, and food security initiatives

1. **Nutrient-Rich Superfoods:** Microgreens are packed with vitamins, minerals, and antioxidants, often containing 3–40 times higher concentrations of nutrients than their mature counterparts (Xiao *et al*., 2012; Brazaitytė *et al*., 2021). This makes them a valuable addition to diets lacking in fresh produce, especially in urban and arid regions.

2. **Sustainable and Space-Efficient:** Their ability to grow in small spaces using minimal resources, including water and substrate, aligns well with sustainable agriculture goals (Chadha *et al*., 2021). This makes microgreens suitable for vertical farming and indoor cultivation systems.
3. **Short Growth Cycle:** Most microgreens can be harvested within 7–21 days, offering a rapid return on investment and year-round production capabilities even in non-traditional growing areas (Kyriacou *et al*., 2016).
4. **Functional Foods & Health Benefits:** Due to their rich phytochemical content, including polyphenols and glucosinolates, microgreens are associated with potential anti-inflammatory, anti-cancer, and cardiovascular health benefits (Mir *et al*., 2023).
5. **Food Security and Urban Agriculture:** With increasing concerns over global food security, microgreens offer a viable solution for urban and peri-urban agriculture, promoting local food production and reducing dependency on large-scale supply chains (Pinto *et al*., 2021).

Nutritional importance

Microgreens are considered highly nutritious due to their concentration of vitamins, minerals, and antioxidants, which offer several health benefits. These young, edible plants are harvested at an early growth stage, typically within 7-21 days, and are packed with bioactive compounds that can contribute significantly to human health. Their small size and intense flavors make them easy to incorporate into various culinary dishes, making them popular in salads, sandwiches, smoothies, and garnishes. Below are some of the nutritional aspects of microgreens:

1. High Levels of Vitamins and Minerals

Microgreens, such as broccoli, red cabbage, and pea shoots, are excellent sources of essential vitamins like vitamin C, vitamin A, vitamin K, and several B-vitamins (Xiao *et al*., 2012). These vitamins support immune function, skin health, and bone health.

- Vitamin C is crucial for collagen synthesis, wound healing, and acts as a powerful antioxidant.
- Vitamin A is essential for vision, immunity, and cellular function.
- Vitamin K plays a critical role in bone health and blood clotting.

2. Rich in Antioxidants

Microgreens contain high levels of antioxidants like flavonoids, polyphenols, and carotenoids, which help in fighting oxidative stress and preventing chronic diseases such as cancer and heart disease (Xiao *et al*., 2012; Kyriacou *et al*., 2016).

- Carotenoids, like lutein and zeaxanthin, help maintain eye health and reduce the risk of age-related macular degeneration.
- Flavonoids, found in cabbage and radish microgreens, have anti-inflammatory, antimicrobial, and anticancer properties (Mir *et al*., 2023).

3. High Mineral Content

Many microgreens, including sunflower, amaranth, and beetroot, are rich in essential minerals such as calcium, iron, magnesium, potassium, and zinc (Kyriacou *et al*., 2016). These minerals play vital roles in muscle function, bone health, immune system strength, and overall cellular health.

- Calcium and magnesium are essential for bone and muscle health.
- Iron is critical for oxygen transport and energy production.
- Potassium helps maintain electrolyte balance and blood pressure regulation.

4. High Fiber Content

Microgreens also provide a good amount of dietary fiber, which is essential for digestive health. The fiber in microgreens helps regulate bowel movements, reduce cholesterol, and support healthy blood sugar levels (Brazaitytė *et al*., 2021).

5. Anti-inflammatory and Detoxifying Properties

Many microgreens are rich in sulforaphane (from broccoli microgreens) and betalains (from beetroot microgreens), which are compounds known for their potent anti-inflammatory and detoxifying effects. These compounds help in reducing inflammation, detoxifying the liver, and promoting healthy metabolic processes (Xiao *et al*., 2012; Sun *et al*., 2022).

6. Low Caloric Content

Microgreens are low in calories but packed with nutrients, making them an excellent choice for those looking to improve their diet without increasing their caloric intake (Kyriacou *et al*., 2016). They offer an efficient way to enhance the nutritional quality of meals without compromising calorie control.

7. Support Heart Health

Due to their high antioxidant and polyphenol content, certain microgreens like radish and sunflower have been shown to contribute to heart health by reducing inflammation, oxidative stress, and the risk of cardiovascular diseases (Pinto *et al*., 2021).

Health benefits:

Microgreens are not only a flavorful addition to various dishes but also offer numerous health benefits due to their high concentration of bioactive compounds, vitamins, minerals, and antioxidants. Their small size belies the potent health-promoting effects they can have, making them a valuable component of a healthy diet.

1. Rich in Antioxidants

Microgreens are known for their exceptional antioxidant content, which helps protect the body against oxidative stress and inflammation. These antioxidants, such as flavonoids, polyphenols, and carotenoids, can contribute to reducing the risk of chronic diseases like cardiovascular disease, diabetes, and certain cancers.

- Broccoli microgreens, for instance, are particularly rich in sulforaphane, a compound known for its anticancer properties (Sun *et al*., 2022).
- Radish microgreens contain high levels of glucosinolates, which also exhibit strong antioxidant activity and support detoxification in the liver (Mir *et al*., 2023).

2. Support Immune Function

The high levels of vitamin C and vitamin A in microgreens help enhance immune function by promoting the production of white blood cells and supporting cellular defense mechanisms.

- Studies have shown that sunflower microgreens are particularly high in vitamin C, which helps reduce the severity of infections and promotes wound healing (Kyriacou *et al*., 2016).
- Cabbage microgreens, which are rich in vitamin A, play a crucial role in maintaining skin integrity and mucosal barriers, thereby boosting immune responses.

3. Anti-inflammatory Effects

Many microgreens have anti-inflammatory properties, which can help reduce inflammation-related diseases such as arthritis and heart disease.

- The polyphenols and flavonoids in microgreens such as red cabbage and mustard contribute to reduced inflammation by inhibiting pro-inflammatory enzymes (Xiao *et al*., 2012).
- Microgreens like beetroot and radish contain betalains, which have potent anti-inflammatory and antioxidant effects that promote joint health (Sun *et al*., 2022).

4. Heart Health

Microgreens have been shown to support cardiovascular health by lowering blood pressure, reducing cholesterol levels, and improving blood circulation.

- Pea shoots and sunflower microgreens are rich in potassium and magnesium, which help regulate blood pressure and reduce the risk of hypertension (Xiao *et al*., 2012).
- The antioxidants in mustard and radish microgreens also contribute to a reduction in oxidative stress, which plays a major role in cardiovascular disease prevention (Pinto *et al*., 2021).

5. Weight Management and Digestive Health

Due to their low calorie content and high fiber content, microgreens are an excellent choice for individuals looking to manage their weight and promote digestive health.

- The fiber in microgreens such as peas and mustard greens helps regulate bowel movements, prevent constipation, and reduce cholesterol (Kyriacou *et al*., 2016).
- Additionally, the low energy density of microgreens means they can be consumed in larger quantities without contributing significantly to calorie intake, supporting weight management.

6. Skin Health

The high levels of vitamins and antioxidants in microgreens contribute to healthy skin by reducing oxidative damage and supporting collagen production.

- Cabbage microgreens are rich in vitamin K, which helps promote wound healing and improve skin elasticity (Mir *et al*., 2023).
- The antioxidant-rich nature of broccoli microgreens supports the prevention of premature aging and skin conditions by neutralizing free radicals (Xiao *et al*., 2012).

7. Anticancer Properties

Research has suggested that certain microgreens, particularly those from the Brassicaceae family, have

cancer-fighting properties due to their high levels of glucosinolates and sulforaphane.

- Broccoli microgreens are particularly noted for their anticancer properties, as they contain higher levels of sulforaphane than mature broccoli (Sun *et al*., 2022).
- Radish microgreens, containing glucoraphanin, can help neutralize carcinogens and prevent the initiation of cancerous growths (Mir *et al*., 2023).

Growing process of microgreens

The growing process of microgreens involves several steps, from seed selection to harvesting, that ensure the production of nutrient-dense young plants. Microgreens are typically grown in a short period, usually between 7 to 21 days, depending on the variety.

1. Seed Selection and Variety Choice

Choosing the right seeds is crucial to the success of microgreens. Various varieties of plants, such as radishes, broccoli, sunflower, pea shoots, and mustard, are commonly grown as microgreens due to their fast germination and high nutritional content. Some varieties, like arugula, cilantro, and basil, are preferred for their unique flavors and health benefits (Xiao *et al*., 2012).

2. Soaking the Seeds

Some seeds, such as sunflower and pea shoots, benefit from soaking before planting. This step helps to soften the seed coat and speeds up germination. Typically, soaking lasts for 4 to 12 hours, depending on the seed type. Soaking improves germination rates and ensures that seeds are ready for quick growth (Mir *et al*., 2023).

3. Choosing Growing Medium

Microgreens can be grown in various mediums, including soil, coconut coir, hydroponic mats, or other soilless substrates. Coconut coir is a popular medium as it is lightweight, retains moisture, and offers good aeration, leading to healthy root development (Kyriacou *et al*., 2016). Hydroponic systems are also gaining popularity due to their water-efficient nature, though they require more careful management of water and nutrient levels (Pinto *et al*., 2021).

4. Sowing the Seeds

Microgreens are typically planted densely to maximize yield in limited space. Seeds are spread uniformly over the growing medium and lightly pressed into place. The depth of planting is usually shallow, with seeds just lightly covered or left exposed (depending on the seed type). For uniform growth, seeds should be spaced closely, but not so much that they overcrowd and inhibit their growth (Mir *et al*., 2023).

5. Germination and Environmental Conditions

During the germination phase, the growing environment must be controlled. Microgreens generally require temperatures between 18°C to 22°C (65°F to 72°F) for optimal germination. They also need high humidity to encourage seed sprouting, which can be achieved through covering trays with a plastic lid or a humidity dome (Xiao *et al*., 2012). Adequate light is not required during the initial germination phase, but once the seeds sprout, they need exposure to light for photosynthesis.

6. Lighting

After germination, microgreens require adequate light for optimal growth. LED grow lights are commonly used in indoor settings, as they provide the necessary spectrum for plant development. Natural light can also be sufficient, particularly in regions with abundant sunlight. The lighting period generally ranges from 12 to 16 hours per day (Kyriacou *et al*., 2016). Too much light can cause heat stress, while too little light may hinder the growth and flavor development of the microgreens.

7. Watering and Nutrient Management

Proper watering is essential for the successful growth of microgreens. The growing medium should be kept moist but not waterlogged. The use of a gentle misting system or regular light watering helps to maintain the necessary moisture levels without disturbing the delicate seedlings. For optimal growth, nutrients are sometimes supplemented using a weak liquid fertilizer (Pinto *et al*., 2021). Hydroponic systems often use nutrient-rich water solutions, ensuring plants receive all the necessary elements without the need for soil (Mir *et al*., 2023).

8. Harvesting

Microgreens are generally ready for harvest within 7 to 21 days, depending on the variety and growing conditions. Harvesting is done when the first true leaves appear, and the plants are approximately 2-3 inches tall. Harvesting is typically done by cutting the greens at the base using a sharp knife or scissors (Xiao *et al*., 2012). Care must be taken to avoid damaging the plants or surrounding seedlings during this process.

9. Post-Harvest Handling

After harvesting, microgreens should be washed gently to remove any residues from the growing

medium. They are then dried carefully to prevent spoilage. Microgreens should be stored in a cool, dry place, preferably in the refrigerator, to maintain their freshness. Proper packaging is important to prevent moisture buildup, which can lead to mold or rot (Pinto *et al*., 2021).

Commercial Flats for Growing Large Quantities

Repurposed shallow food container (lid becomes saucer)

Really we can grow in anything like disposable glasses

Stage of Cutting and harvesting microgreens

Difference Between Sprouts and Microgreens

Sprouts and microgreens are both young forms of edible plants, but they differ significantly in cultivation method, growth stage, nutritional content, safety, and usage.

Parameter	Sprouts	Microgreens	References
Definition	Germinated seeds consumed whole (root, seed, and shoot)	Young seedlings harvested just above the soil line	Xiao et al., 2012; Mir et al., 2023
Growth Medium	Grown hydroponically without soil (in water or moist cloth)	Grown in soil or a growing medium like cocopeat	Kyriacou et al., 2016
Time to Harvest	2–5 days after germination	7–21 days after germination	Pinto et al., 2021
Parts Consumed	Entire sprout including seed, root, and shoot	Only the shoot (stem and first true leaves)	Brazaitytė et al., 2021
Light Requirement	Grown in dark or low light	Require natural or artificial light for photosynthesis	Chadha et al., 2021
Nutrient Content	Rich in enzymes and some vitamins	Higher concentration of vitamins, minerals, antioxidants	Xiao et al., 2012; Mir et al., 2023
Risk of Contamination	Higher (due to moist, warm, dark growth conditions)	Lower (grown in light with better air circulation)	Mir et al., 2023
Usage	Commonly used in salads, sandwiches, stir-fries	Used as garnish, in smoothies, salads, or health foods	Pinto et al., 2021

Sprouts

Microgreens

Common Types of Microgreens and Their Nutritional Traits

1. Red Cabbage (*Brassica oleracea var. capitata*)

High in vitamin C, vitamin E, and anthocyanins and contains glucosinolates, which have potential anti-cancer properties (Xiao *et al*., 2012).

2. Broccoli (*Brassica oleracea var. italica*)

Rich in sulforaphane, a powerful antioxidant and contains glucoraphanin and vitamin K (Brazaitytė *et al*., 2021).

3. Kale (*Brassica oleracea var. acephala*)

Contains beta-carotene, calcium, iron, and polyphenols and is known for its anti-inflammatory and anti-oxidative properties.(Pinto *et al*., 2021).

4. Radish (*Raphanus sativus*)

High in vitamin C, phenolics, and isothiocyanates, which help in detoxification (Mir *et al*., 2023).

5. Amaranth (*Amaranthus spp*.)

Rich in vitamin K, calcium, iron, and antioxidants like rutin and quercetin and contains anti-inflammatory properties and boosts heart health (Kyriacou *et al*., 2016).

6. Beetroot (*Beta vulgaris*)

Contains betalains (antioxidants), iron, potassium, and folate and promotes heart health and may help lower blood pressure (Sun *et al*., 2022).

7. Basil (*Ocimum basilicum*)

High in volatile oils like eugenol, vitamin A, vitamin K, and manganese and is known for its anti-inflammatory and antimicrobial properties (Brazaitytė *et al*., 2021).

8. Pea Shoots (*Pisum sativum*)

Rich in protein, vitamin C, folate, and dietary fiber and promotes digestion and supports immune health (Mir *et al*., 2023).

9. Cilantro (*Coriandrum sativum*)

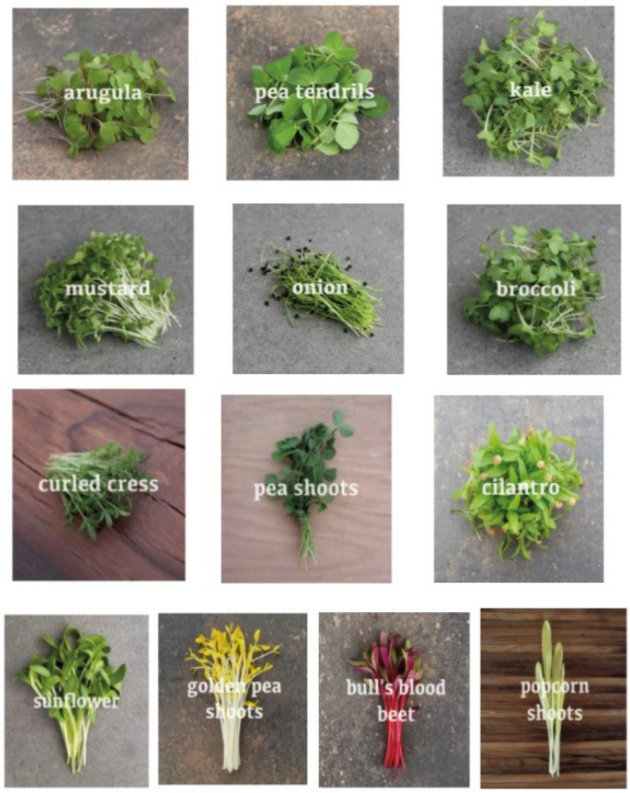
Contains vitamin A, vitamin C, potassium, and essential oils and known for its detoxifying properties and digestive benefits (Pinto *et al*., 2021).

10. Sunflower (*Helianthus annuus*)

High in zinc, iron, protein, and vitamin E and promotes skin health and acts as a natural antioxidant (Kyriacou *et al*., 2016).

Key Insights:

- *Brassica microgreens* like broccoli, kale, and red cabbage contain significant levels of antioxidants, glucosinolates, and other bioactive compounds beneficial for human health (Xiao *et al*., 2012; Brazaitytė *et al*., 2021).
- Amaranth and beetroot microgreens provide pigments like betalains and anthocyanins that offer strong antioxidant effects and help combat inflammation (Sun *et al*., 2022).
- Pea shoots are a great source of protein and fiber, making them a valuable addition to plant-based diets (Mir *et al*., 2023).



Adverse effects

While microgreens are widely considered to be highly nutritious and beneficial to health, there are some potential adverse effects associated with their consumption. These effects can be linked to improper handling, contamination, or excessive consumption. Below are the key adverse effects:

1. Risk of Contamination

Microgreens are typically grown in a high-moisture environment, which can encourage the growth of harmful microorganisms such as Salmonella, E. coli, and Listeria. If proper hygiene and sanitation are not maintained during the growing, harvesting, and storage processes, these pathogens can contaminate microgreens, leading to foodborne illnesses. A study by Manning *et al*. (2021) highlighted that leafy greens, including microgreens, are among the top foods linked to foodborne disease outbreaks.

2. Pesticide Residue

If microgreens are grown with the use of pesticides, these chemicals can remain on the plants after harvesting. Since microgreens are often consumed raw, the pesticide residues may not be eliminated, potentially causing harmful health effects. For instance, pesticide exposure has been associated with various health problems, including endocrine disruption, cancer, and neurological damage, especially

when consumed in large amounts over time (Nigg *et al*., 2021).

3. Allergic Reactions

Although rare, some individuals may experience allergic reactions to certain microgreens. Common allergens in microgreens may include proteins found in plants such as mustard or sunflower seeds. These allergic reactions can lead to symptoms like rashes, itching, and gastrointestinal discomfort (Nabavi *et al*., 2020).

4. Excessive Nutrient Intake

While microgreens are rich in vitamins, minerals, and antioxidants, consuming them in large quantities may lead to nutrient imbalances. For instance, microgreens, particularly those high in vitamin K (like mustard and kale), can interfere with blood-thinning medications such as warfarin. Consuming large amounts of microgreens in a short period could lead to unwanted health issues for individuals on medication (Bertazzoni *et al*., 2020).

5. Oxalates in Microgreens

Certain microgreens, particularly spinach and beet greens, contain oxalates, which can bind to calcium and form kidney stones in susceptible individuals when consumed in excess. Although the amount of oxalates in microgreens is relatively low compared to mature leafy vegetables, individuals prone to kidney stones should be cautious of excessive intake (Trinder *et al*., 2019).

6. Gastrointestinal Disturbances

Overconsumption of microgreens can sometimes lead to gastrointestinal discomfort, particularly in individuals with sensitive stomachs. Since they are high in fiber, eating large quantities of microgreens may cause bloating, gas, or digestive upset (Lo *et al*., 2021).

Remedies

Here are some key remedies to mitigate the adverse effects associated with microgreens consumption:

1. Ensure Hygienic Cultivation and Handling

Always grow microgreens in a sanitary environment, using clean trays, tools, and hands. Use potable water for irrigation and rinsing. Avoid animal manure or compost unless it's properly sterilized. Sterilize seeds (e.g., soaking in food-grade hydrogen peroxide) to reduce microbial contamination risk. (Manning *et al*. 2021)

2. Use Organic or Safe Pesticide-Free Practices

Prefer organic methods or integrated pest management to avoid harmful pesticide residues. If any plant protection is needed, ensure only approved biopesticides or non-toxic treatments are used. (Nigg *et al*., 2021)

3. Moderate Consumption

Avoid excessive daily intake, especially of microgreens rich in vitamin K (e.g., kale, mustard) or oxalates (e.g., spinach, beet). Individuals on blood-thinning medication should consult doctors before consuming certain varieties. (Bertazzoni *et al*. 2020)

4. Store Properly

Consume freshly harvested microgreens or store them at 4°C or lower in a clean, dry container. Avoid storing in humid conditions, which promote microbial growth. Lo *et al*. (2021).

5. Allergy Awareness

Be cautious with microgreens derived from allergenic plants (e.g., mustard, sunflower). Introduce new varieties in small amounts and observe for any allergic reactions. (Nabavi *et al*., 2020)

6. Select Trusted Sources

Buy microgreens from certified producers who follow good agricultural practices (GAP). For home growers, follow guidelines by agricultural extension agencies or certified horticultural standards.

7. Rinse Before Consumption

Even if homegrown, gently rinse with clean water before consumption to remove any dust, spores, or residues.

Utility of Microgreens in Home and Commercial Usage

Microgreens have gained significant popularity in both home kitchens and commercial agriculture due to their nutritional density, aesthetic appeal, and rapid growth cycle. In home settings, they offer a convenient way to grow fresh, nutrient-rich greens with minimal space, making them ideal for urban gardening and indoor cultivation (Xiao *et al*., 2022). Many health-conscious consumers prefer microgreens for daily dietary supplementation, as they can be grown year-round on windowsills or balconies with basic tools and minimal inputs (Poudel *et al*., 2021).

Commercially, microgreens are widely used in high-end restaurants, salad mixes, and nutraceutical products due to their vibrant colors, intense flavors, and high content of vitamins, antioxidants, and

minerals (Kyriacou *et al*., 2021). The short production cycle (usually 7–21 days) makes them economically viable for small-scale entrepreneurs and urban farms using vertical or hydroponic systems (Choe *et al*., 2022). They are also used in functional food markets, offering a premium product with added health benefits.

Recent studies also suggest their potential role in sustainable agriculture, as microgreens require significantly less water and fertilizer compared to mature crops, making them a more eco-friendly option (Mehta *et al*., 2023). This dual utility nutritional and environmental adds to their growing demand across domestic and commercial sectors.

Living miccrogreens being sold in USA

Troubleshooting in microgreen cultivation

Microgreen production, though relatively simple, can face several challenges that may affect quality, yield, or safety. Identifying and resolving issues at early stages is critical to maintain healthy growth and ensure marketable produce.

1. Poor Germination

Causes include low-quality seeds, improper moisture, or incorrect temperature. Use of high-vigor, pathogen-free seeds and maintaining optimal conditions (20–25°C with consistent moisture) can enhance germination rates (Choe *et al*., 2022; Poudel *et al*., 2021).

2. Fungal Diseases (Damping-Off)

Overwatering, poor air circulation, and contaminated media can lead to fungal infections like damping-off. Management includes use of sterilized growing media, good ventilation, and sometimes biological control agents (Kyriacou *et al*., 2021).

3. Leggy or Elongated Seedlings

This usually results from low light intensity or high temperatures. Providing adequate light (200–400 $\mu mol \cdot m^{-2} \cdot s^{-1}$) from LED or natural sources and maintaining moderate temperatures (18–22°C) can prevent etiolation (Mehta *et al*., 2023).

4. Uneven Growth or Patchy Stands

Uneven seeding, poor media contact, or inconsistent watering often lead to irregular stands. Ensuring even seed distribution and gently pressing seeds into the medium improves uniformity (Xiao *et al*., 2022).

5. Yellowing of Leaves (Chlorosis)

Often due to nutrient deficiencies, especially nitrogen or iron. Using a balanced, dilute nutrient solution can remedy this, especially in hydroponic systems (Chatterjee *et al*., 2022).

6. Contamination or Food Safety Concerns

Microgreens can be vulnerable to microbial contamination if grown in unsanitary conditions. Using potable water, sanitizing equipment, and avoiding the use of manure-based composts reduces contamination risk (Zhang *et al*., 2021).

7.Mold Growth

High humidity and dense sowing can promote mold. Good spacing, airflow, and careful watering practices help avoid mold issues (Ghoora *et al*., 2020).

Future Trends in Microgreens Cultivation

The cultivation of microgreens is rapidly evolving with innovations in technology, sustainability, and nutrition. Future trends are shaping the way microgreens are grown, marketed, and consumed:

1. Integration with Smart Farming and IoT

Smart sensors, automated irrigation systems, and AI-based decision support tools are increasingly being integrated into microgreen farming, allowing real-time monitoring of light, humidity, nutrient levels, and growth (Mehta *et al*., 2023; Choe *et al*., 2022).

2. Vertical and Urban Farming Expansion

Microgreens are ideal for vertical farming due to their short growth cycle and space efficiency. Urban farming initiatives are promoting microgreens as a local, fresh, and sustainable food option, reducing transportation costs and carbon footprint (Kyriacou *et al*., 2021).

3. Nutritional Biofortification

Future research is focusing on enhancing the nutritional profiles of microgreens through biofortification fortifying crops with essential vitamins, minerals, and phytochemicals to combat malnutrition (Chatterjee *et al*., 2022; Ghoora *et al*., 2020).

4. Organic and Sustainable Cultivation Systems

Consumers are showing increasing preference for organically grown microgreens. Sustainable practices such as compostable growing mats, biodegradable packaging, and closed-loop hydroponic systems are gaining traction (Xiao *et al*., 2022).

5. Genomic and Breeding Innovations

Breeding for improved yield, shelf life, and nutrient content is being supported by molecular tools and genomics. CRISPR and marker-assisted selection are being explored for microgreens with tailored health benefits (Zhang *et al*., 2021).

6. Functional Food and Health Market Expansion

With growing awareness of food as medicine, microgreens are being positioned as superfoods, driving demand in nutraceuticals, functional food products, and dietary supplements (Kyriacou *et al*., 2021).

7. Customization for Culinary and Aesthetic Appeal

Chefs and food designers are increasingly using microgreens for their color, flavor, and texture, prompting breeding programs to develop specialty varieties catering to the gourmet market (Poudel *et al*., 2021).

Conclusion

Microgreens represent a dynamic and promising sector in sustainable agriculture, combining high nutritional value, short cultivation cycles, and suitability for urban and vertical farming systems. Their dense concentrations of vitamins, minerals, antioxidants, and bioactive compounds offer significant health benefits, making them an ideal functional food for modern diets. As advancements in smart farming, biofortification, and controlled-environment agriculture continue to evolve, microgreens are set to play a pivotal role in future food systems. Furthermore, their adaptability for home gardening and commercial production supports food security, economic viability, and environmental sustainability. With increasing consumer awareness and demand, microgreens hold substantial potential for innovation, diversification, and integration into mainstream agriculture and health-focused industries.

References

Bertazzoni, A., Colombo, R., & Fiorentino, G. (2020). Potential adverse effects of high vitamin K consumption from microgreens on anticoagulant therapy. *Clinical Nutrition*, **39**(11), 3356–3363.

Brazaitytė, A., Jankauskienė, J., Samuolienė, G., *et al*. (2021). The nutritional value of microgreens depends on light wavelength. *Agronomy*, **11**(2), 403.

Chadha, M. L., Bhatt, B. P., Kumar, R., & Saha, S. (2021). Microgreens: A new dimension to vegetable production. *Indian Journal of Agricultural Sciences*, **91**(8), 1135–1140.

Chatterjee, S., Samanta, T., & Dutta, S. (2022). Effect of nutrient management on microgreens quality. *Vegetable Science*, **49**(3), 255–261.

Choe, U., Yu, J., & Wang, T. T. Y. (2022). Commercial viability of microgreens in controlled environments: A case study. *Journal of the Science of Food and Agriculture*, **102**(5), 1723–1731.

Di Gioia, F., Renna, M., Santamaria, P., & Serio, F. (2020). Microgreens production: Considerations for the development of an innovative and sustainable horticultural system. *Agronomy*, **10**(10), 1426.

Ghoora, M. D., Balaraman, S., & Srividya, N. (2020). Growth dynamics and microbial quality of hydroponically grown microgreens. *Journal of Food Science and Technology*, **57**, 223–230.

Kyriacou, M. C., Rouphael, Y., Di Gioia, F., Kyratzis, A., Serio, F., Renna, M., De Pascale, S., & Colla, G. (2016). Micro-scale vegetable production and the rise of microgreens. *Trends in Food Science & Technology*, **57**, 103–115.

Kyriacou, M. C., Rouphael, Y., Di Gioia, F., & Renna, M. (2021). Microgreens: A novel food product to address nutrition security and health. *Frontiers in Plant Science*, **12**, 709923.

Kyriacou, M. C., Rouphael, Y., Di Gioia, F., Kyratzis, A., Serio, F., & Renna, M. (2021). Microgreens as a component of space life support systems: A scenario of food production on Mars. *Frontiers in Plant Science*, **12**, 665682.

Lo, C. Y., Zhang, Q., & Ellis, K. (2021). Gastrointestinal disturbances linked to excessive microgreens consumption: A case study. *Journal of Clinical Gastroenterology*, **55**(9), 851–856.

Manning, M., Smith, L., & Rodriguez, J. (2021). Foodborne disease outbreaks associated with fresh produce: Microgreens as a potential risk factor. *Foodborne Pathogens and Disease*, **18**(4), 281–289.

Mehta, C. M., Lakra, A., & Prasad, R. (2023). Sustainability and resource-use efficiency of microgreens: A review. *Agronomy for Sustainable Development*, **43**, 27

Mir, R.A., Kamili, A.N., Kaur, N., & Bhat, J.A. (2023). Nutritional and functional properties of microgreens: A comprehensive review. *Heliyon*, **9**(6), e15857.

Nabavi, S. M., Russo, G. L., Daglia, M., & Nabavi, S. F. (2020). Allergic reactions to microgreens: Risks and mitigation strategies. *Journal of Allergy and Clinical Immunology*, **145**(3), 865–872.

Nigg, H. N., Patel, R., & Thomas, A. (2021). Pesticide residues in microgreens: Health implications and mitigation strategies. *Environmental Toxicology and Chemistry*, **40**(10), 2761–2770.

Pinto, R. S., Lopes, M. S., & Costa, L. (2021). Microgreens: Cultivation, health benefits, and potential as functional food. *Food Reviews International*, 1–21.

Poudel, P. B., Adhikari, L., & Raturi, R. (2022). Microgreens: Emerging functional food and potential horticultural enterprise. *Journal of Applied Horticulture*, **24**(1), 1–7.

Poudel, P., Dixon, M., & Laskar, A. (2021). Home cultivation of microgreens: Prospects and challenges. *Urban Agriculture & Regional Food Systems*, **6**(1), e20008.

Sun, J., Yang, Y., Zhang, X., Wang, Y., & Zhang, Z. (2022). Bioactive compounds and health benefits of beetroot and beetroot microgreens: A review. *Journal of Functional Foods*, **90**, 104978.

Trinder, M., Huang, Y., & Patel, A. (2019). The role of oxalates in kidney stone formation: A consideration of microgreens in the diet. *Journal of Urology and Nephrology*, **28**(2), 68–74.

Xiao, Z., Codling, E. E., Luo, Y., Nou, X., Lester, G. E., & Wang, Q. (2021). Microgreens of Brassicaceae: Mineral composition and content of 30 varieties. *Journal of Food Composition and Analysis*, **100**, 103921.

Xiao, Z., Lester, G. E., Luo, Y., & Wang, Q. (2012). Assessment of vitamin and carotenoid concentrations of emerging food products: Edible microgreens. *Journal of Agricultural and Food Chemistry*, **60**(31), 7644–7651.

Xiao, Z., Lester, G. E., Luo, Y., & Wang, Q. (2022). Microgreens: Consumer preferences and production potential. *Horticultural Reviews*, **49**, 67–100.

Zhang, G., Ma, L., & Deng, L. (2021). Sanitary practices for microgreens production to ensure food safety. *Journal of Food Safety*, **41**(6), e12973.

Zhang, Y., Zhang, W., Guo, J., Wang, Q., & Yang, X. (2023). Comparative analysis of antioxidant profiles in selected microgreens. *Food Chemistry*, **401**, 134024.