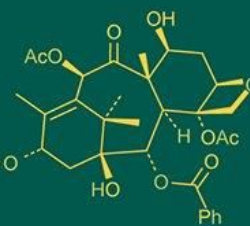
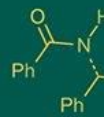
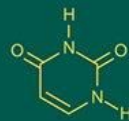
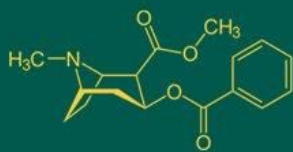


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A comprehensive review on microgreens: Nutritional value, cultivation, health benefits, and future perspectives

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Abstract

Microgreens have gained increasing popularity as food ingredients in recent years because of their high nutritional value and diverse sensorial characteristics. Microgreens are edible seedlings including vegetables and herbs, which have been used, primarily in the restaurant industry, to embellish cuisine since 1996. Microgreens are young vegetable and herb seedlings harvested at the cotyledon stage, typically 7-21 days after germination. Despite their small size, microgreens are packed with intense sensory characteristics such as flavor, texture, aroma, vibrant colors, and an appealing appearance. Because they contain numerous health-boosting compounds like antioxidants, vitamins, minerals, and phenolic substances, microgreens are widely regarded as a new generation of "superfoods" or "functional foods." This review explores the nutritional profile, cultivation techniques, health benefits, applications, challenges, and future directions of microgreens. We discuss their role in sustainable agriculture, urban farming, and the food industry, highlighting their potential in promoting human health. These nutrients are believed to enhance the body's immunity, particularly in the current situation of the COVID-19 threat. Therefore, microgreens can be considered natural supplements. This paper aims to provide an overview of their nutritional properties, a comparison with sprouts, potential bioactive compounds, as well as aspects related to their cultivation, harvesting, marketing, and prospects.

Keywords: Microgreens, nutrition, biologically active compounds, cotyledons, space food

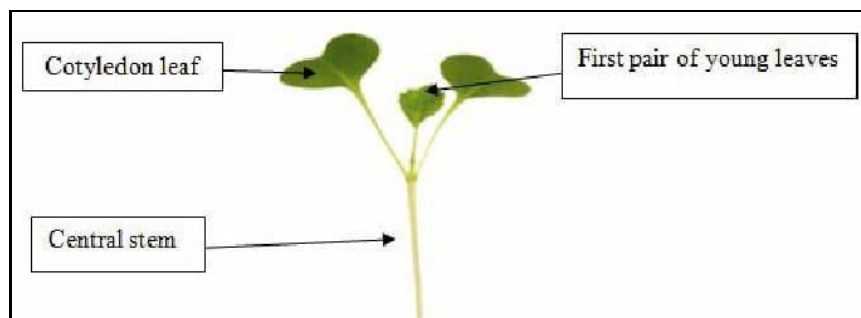
Introduction

Microgreens are edible seedlings of vegetables and herbs that fall between sprouts and baby greens in terms of growth stage. First introduced in high-end restaurants for their aesthetic and flavor-enhancing properties, they have now gained popularity in home gardening, urban farming, and commercial agriculture. Studies indicate that microgreens contain higher concentrations of essential nutrients compared to their mature counterparts, making them a promising superfood. Microgreens, often called "*vegetable confetti*," are a unique category of crops grown from the seeds of vegetables, grains, herbs, and their wild counterparts. These tender, fresh greens exhibit diverse colors, flavors, and textures. They are cultivated from various plant species, including aromatic herbs, wild edibles, and herbaceous plants, and are harvested within days or weeks of germination—specifically during cotyledon development and the emergence of the first true leaves. As functional foods, they provide both nutritional benefits and health-promoting properties, potentially aiding in disease prevention. They are also recognized as excellent carriers of bioactive compounds. Microgreens can be sold as freshly produced merchandise or as live plants growing on a medium, allowing end users to harvest them. Microgreens emerge as a category of edible young vegetables and herbs, harvested once their cotyledon leaves are fully developed and the first true leaves begin to appear, typically within 7 to 21 days after germination. Some of the most important vegetable crops grown as microgreens include broccoli, cabbage, red cabbage, red amaranth, beets, peas, radish, lettuce, and Chinese mustard greens.

India lags significantly behind in rankings due to its poor performance in child wasting and stunting, both of which stem from malnutrition and micronutrient deficiencies. The growing global challenge of malnutrition has led to an increased demand for nutrient-rich foods. In recent years, there has been a remarkable rise in both the production and productivity of food

grains and horticultural crops, ensuring sufficient supply for our rapidly growing population. Microgreens, an emerging

category of edible greens, hold immense potential to address various nutrient deficiencies.



Nutritional Composition of Microgreens

Microgreens are considered 'functional foods' due to their dense nutritional content. Their nutrient profile varies depending on the species, growing conditions, and harvesting time. Although a wide range of microgreens are currently being cultivated, scientific data about their direct potential to affect human physiological functions is not widely available. Nowadays, many herbs and vegetables are grown as microgreens. Brassicaceae (broccoli, cabbages, radish), Fabaceae (fenugreek, sweet pea, alfalfa), Apiaceae (carrot, parsley, celery), Asteraceae, Amaranthaceae, and many other taxonomic families are commonly cultivated. There is strong evidence of a huge abundance of bioactive compounds containing carotenoids, vitamins or minerals, glucosinolates and polyphenols.



Vitamins: Phylloquinone, also known as fat-soluble vitamin, recognized as vitamin K1, is highly present in the Amaranthaceae, Brassicaceae, and Lamiaceae families. The level of phylloquinone concentrations fluctuated between 0.6 to 4.1g fresh weight. Among the species, red garnet amaranth had the highest concentration (4.1g fresh weight), followed by green basil (3.2 g), red cabbage (2.8 g fresh weight), and magenta spinach (0.9g fresh weight). Compared to mature amaranth and cabbage, phylloquinone has been detected at a lower level (0.41 to 1 fresh weight.14 g fresh weight), respectively. Besides 72 phylloquinone's role in blood coagulation and maintaining healthy bone tissue through the prevention of vascular calcification, it has been established that phylloquinone also has immunosuppressive and anticancer effects.

Vitamin C (total ascorbic acid) is considered as the sum of free ascorbic acid and dehydroascorbic acid, which are highly bound in the Malvaceae, Brassicaceae, or Cucurbitaceae families declared that ascorbic acid was the most abundant in all evaluated microgreens (e.g., fenugreek, radish, roselle, etc.) with concentrations ranging from 41.6 to almost 140 mg/hundred grams. Severe deficiency in vitamin C could result in scurvy, and increased risks of many non-communicable diseases such as cancers, arthritis, or Alzheimer's disease.

The most biologically active form of vitamin E (protect cells from damage) is α -tocopherol, which, along with tocotrienols, belongs to the vitamin E family. However, α -tocopherol is the most abundant variant found in plants. Microgreens from the Brassicaceae and Apiaceae families are particularly rich sources of this compound. Furthermore, supplementation with tocopherols has been linked to the prevention of age-related diseases such as cardiovascular disorders (Xiao *et al.*, 2012) [12].

Minerals: Several studies have indicated that microgreens serve as excellent sources of minerals, many of which are essential nutrients. Previous findings revealed that lettuce microgreens possess notably higher concentrations of essential minerals, including calcium, iron, zinc, magnesium, and manganese, compared to fully matured lettuce plants.

Polyphenols: The nutritional and functional benefits of microgreens are largely attributed to their high content of vitamins, minerals, sugars, and carotenoids. However, one of the most critical factors contributing to their health benefits is their abundance of phytochemicals, particularly phenolic compounds. These compounds are classified into various subcategories, including flavonoids, phenolic acids, tannins, stilbenes, and lignans. Nevertheless, microgreens from commonly cultivated families such as Brassicaceae, Apiaceae, Lamiaceae, and Malvaceae exhibit remarkable antioxidant activity, with levels ranging from 303.3 mmol/kg in jute to 878.3 mmol/kg in cress. Studies confirm that the Brassicaceae family demonstrates the highest antioxidant capacity, followed by Lamiaceae.

Microgreens as space food

Maintaining optimal nutrition is essential for space travelers to counteract the stresses of prolonged space travel, such as weight loss, oxidative stress caused by space radiation, protein oxidation, hematological changes, increased muscle proteolysis, vision impairment, and overall health system alterations. Preventing harmful effects that lead to tissue

damage requires prioritizing the consumption of whole foods rich in antioxidants rather than relying solely on supplements. For example, consuming carotenoids through a whole-food-based diet is a highly effective protective measure. These include β -carotene, which serves as a precursor to vitamin A for retinal function, as well as zeaxanthin and lutein, which help shield the eyes by absorbing excessive light exposure. Cultivating bioactive compound-rich, particularly carotenoid-dense, vegetables as part of space life support systems (SSLs) is a crucial objective for future missions. Microgreens are particularly promising as a potential food source for astronauts on long-duration missions due to their short growth cycle, higher nutrient density compared to mature plants, and ability to thrive in compact, controlled environments. Their suitability for spaceflight is further enhanced by the fact that crew members can harvest them directly, ensuring freshness and high-quality nutrition.

Why microgreens in space?

Nutritional value: Microgreens are packed with nutrients and can supplement the diets of astronauts on long-duration missions, where pre-packaged food can degrade over time.

Psychological benefits: Growing and consuming fresh food can improve the psychological well-being of astronauts.

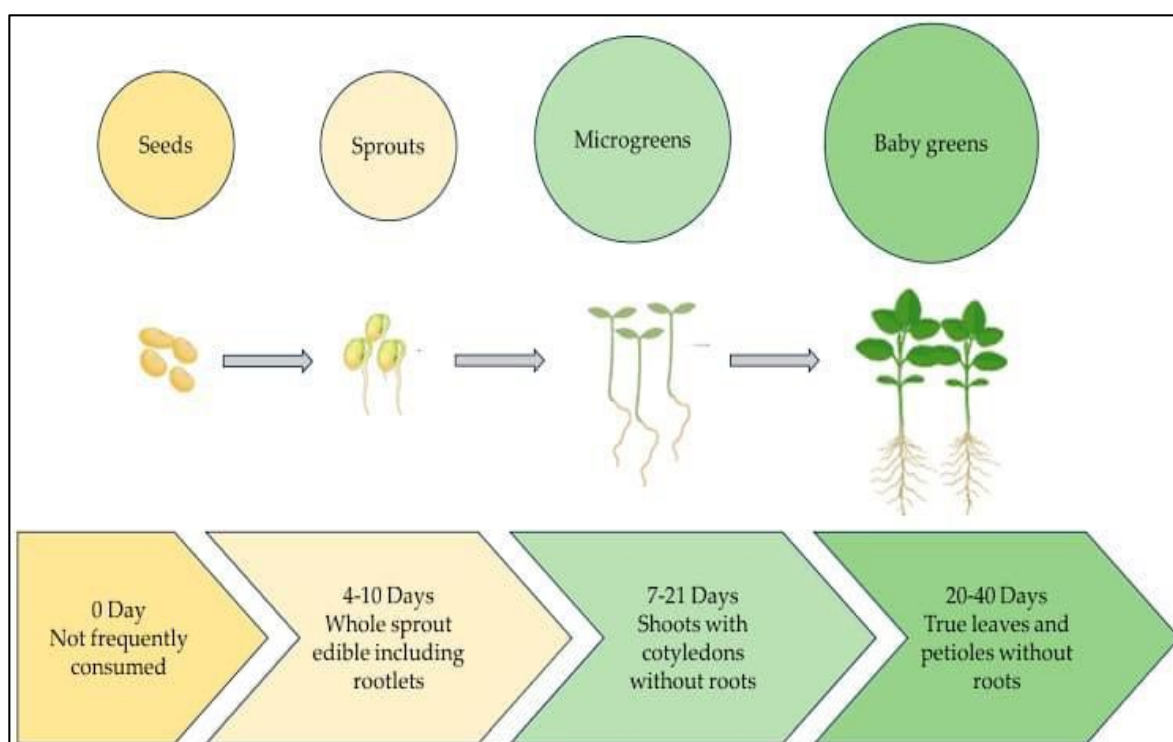
Space-friendly: Microgreens grow quickly and require minimal space, making them ideal for space cultivation.

Examples of microgreens for space: Broccoli, Radish, Basil, Sunflower, Kale, Peas, Cabbage, Amaranth

Cultivation Techniques of Microgreens

Materials used

Microgreens are easy to cultivate in both small-and large-scale settings. They can be grown indoors, outdoors, or in controlled environments using various methods. Microgreens can be cultivated by individuals for household consumption. Growing small batches at home is relatively simple; however, producing and marketing high-quality microgreens on a commercial scale is significantly more challenging. Achieving the right mix at the ideal harvest stage is one of the most crucial aspects of successful production. The duration from seeding to harvest varies greatly depending on the crop. When planting a combination of species in a single tray, growers should select plants with similar growth rates to ensure the entire tray can be harvested simultaneously. Alternatively, different plants can be grown separately and mixed after harvesting. Cultivating microgreens is not highly expensive since they require minimal equipment and materials. For commercial production, growing trays should have proper drainage. The size of the trays should be chosen based on space availability, ease of handling, and convenient transportation of live microgreens. It is recommended to use inert growing media such as cocopeat, vermiculite, or a mixture of cocopeat, vermiculite, and perlite in a 3:1:1 ratio.



Sowing: Soaking is a crucial step that accompanies early seed sowing, as it enhances germination. Seeds are spread on the growing medium and then covered with a paper towel, vermiculite, or cocopeat as needed. Typically, larger seeds are covered with vermiculite or cocopeat, while smaller seeds are covered with a paper towel.

Nutritional requirement: As cultivation of microgreens is intended to offer natural edibles for the advanced fitness of

people, fertilizer requirements for microgreens producing are terribly small, which will certainly be finished through natural sources. Or else, spray a solution of 10 ml CaCl_2 , i.e., 1.10 g keep with 10 liters of water.

Harvesting: Microgreens are ready for harvest when they reach the first true leaf stage, typically growing to about 2 inches in height. The time required from planting to harvesting varies by crop, ranging from 7 to 21 days.

Harvesting is done by cutting just above the soil surface using scissors after the first set of true leaves has appeared. Certain varieties can regrow and be cut multiple times. This method allows growers to lift the mats by hand, hold them vertically, and use an electric knife or trimmer to cut the microgreens, which then fall neatly into a clean collection container. Since microgreens are highly perishable, they must be washed and cooled immediately after harvesting.

Post-harvest management

Post-harvest management is crucial for microgreens due to their short shelf life. Therefore, effective storage and transportation strategies are essential. Commercially, microgreens are typically stored in plastic clamshell containers and refrigerated at temperatures between 2.5 °C and 3.5 °C, preserving their freshness for up to seven days. Additionally, biodegradable clamshell containers are available for packaging.

Health Benefits of Microgreens

Microgreens offer several health benefits, including improved cardiovascular health, diabetes management, anti-cancer properties, and immune system support. Since the number of vitamins, minerals and beneficial plant compounds are high in microgreens, eating green vegetables is associated with decreasing danger of many diseases. Microgreens are also blessed with such vital nutrients to protect us from diseases. Heart disease: Microgreens have great content of antioxidants e.g. polyphenols which can reduce the risk of heart disease.

Applications for Microgreens

Microgreens are used in culinary applications, functional foods, nutraceuticals, sustainable agriculture, and urban farming. Microgreens can be used in adding flavor, texture, and nutrition to dishes as a garnish, a key ingredient, or a topping for salads, sandwiches, soups, smoothies, and more.

Challenges and Future Perspectives

Despite their benefits, microgreens face challenges such as short shelf life, production costs, and market awareness. Future research should focus on improving storage techniques and expanding commercial applications. Research on microgreens has primarily been conducted on a small scale, involving a limited number of researchers and focusing on specific target areas. However, there is still a vast range of unexplored opportunities in this field. While some microgreen varieties have been studied and analyzed, many have yet to be commercialized. The impact of sunlight on microgreen development and nutritional value has been thoroughly examined, but the effects of low night temperatures on their growth, nutrient composition, and potential food safety risks remain largely unstudied.

Conclusion

In today's fast-paced world, maintaining a proper diet and good health is crucial. Microgreens offer a modern solution to micronutrient deficiencies and can be easily incorporated into daily meals in various ways. These tiny greens are highly nutritious and may even reduce the risk of certain diseases. Since they are easy to grow at home, they provide an affordable way to boost nutrient intake without requiring large amounts of vegetables. Microgreens belong to a new category of vegetables known as "functional foods,"

offering benefits beyond their basic nutritional value. Due to their high nutrient content and lack of pesticide residues, they serve as a vital tool in the fight against malnutrition. They are also a potential food source for astronauts, as they can be freshly harvested in space. Additionally, microgreens present a great opportunity for agri-business startups since they require only up to 21 days to grow, making them a short-term yet profitable crop. Given the current global health scenario, further research is needed to ensure their safety and quality. This will help the food industry address some of the challenges faced by fully grown vegetables and contribute to healthier diets worldwide. Microgreens represent a promising functional food due to their rich nutritional content, ease of cultivation, and numerous health benefits. Advances in agricultural technology, post-harvest processing, and consumer awareness will play a key role in expanding their market.

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