

Characterization of Nutritional and Bioactive Compounds in Microgreens for Improved Human Nutrition

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Microgreens are young, edible seedlings of vegetables, herbs, cereals and selected legumes that are harvested at an early stage of development, generally within about 7–21 days after germination. They contain tender stems, cotyledons and, in many species, emerging true leaves. In recent years, microgreens have attracted considerable interest as specialty horticultural crops because of their short production cycle, attractive colours, distinctive flavours, compact production requirement and concentration of nutrients and phytochemicals. Their suitability for household gardens, protected cultivation, vertical farming and controlled-environment agriculture further increases their importance as a modern horticultural crop. The nutritional importance of microgreens extends beyond their vitamin and mineral content. They contain several biologically active plant compounds, including phenolic compounds, flavonoids, carotenoids, anthocyanins, chlorophylls and, particularly in Brassicaceae species, glucosinolates. These compounds contribute to colour, flavour and plant defence and are being investigated for their antioxidant and other biological activities. However, their concentrations vary considerably with species, cultivar, growing medium, nutrition, light, temperature, harvest stage and postharvest handling. Therefore, characterization of individual microgreens is essential before making nutritional comparisons.

Microgreens as Emerging Functional Horticultural Crops

The rapid growth cycle of microgreens provides an important advantage over conventional vegetable production. A crop can move from seed to harvestable product within a few weeks, allowing several production cycles in a relatively small area. This characteristic makes microgreens suitable for urban horticulture, terrace gardens, protected structures and indoor production. Their cultivation can be adapted to soil-based or soilless systems, including cocopeat and other clean growing substrates, hydroponic systems and controlled-environment production. Unlike conventional vegetables, microgreens are generally marketed as fresh, ready-to-eat products. They are used in salads, sandwiches, soups, vegetable preparations and as garnishes. Their intense colours, tender texture and characteristic flavours increase their culinary value. The combination of nutritional quality and sensory appeal has contributed to their development as specialty and functional food crops.





Diversity of Microgreens

A wide range of horticultural crops can be cultivated and consumed as microgreens. Important groups include Brassicaceae, Fabaceae, Amaranthaceae, Apiaceae, Asteraceae and Lamiaceae. Broccoli, radish, mustard, cabbage, kale, pak choi, fenugreek, pea, sunflower, amaranth, beetroot, coriander and basil are examples of commonly studied microgreens. Brassicaceae microgreens such as broccoli, radish and mustard are particularly important because of their glucosinolate content and characteristic pungent flavour. Fabaceae microgreens such as pea and bean provide tender shoots and cotyledons, whereas sunflower microgreens are valued for their larger cotyledons and crunchy texture. Amaranth and beet microgreens can provide attractive red or purple pigmentation, while coriander, basil and fenugreek contribute characteristic aromas and flavours.



Such diversity provides considerable scope for comparative research. A study published in *Scientific Reports* in 2025 compared broccoli, black radish, red beet, pea, sunflower and bean microgreens and reported considerable differences in vitamin C and mineral concentrations among species. Potassium, magnesium, calcium and phosphorus concentrations also varied between the tested crops, demonstrating that microgreens cannot be treated as nutritionally identical products.

Nutritional Characterization

Nutritional characterization is an important component of microgreen research. Major parameters include moisture, dry matter, crude protein, fibre, carbohydrates, ash, vitamins and minerals. Among the vitamins, ascorbic acid, tocopherols, carotenoids and vitamin K compounds are frequently investigated. Minerals such as potassium, calcium, magnesium, phosphorus, iron and zinc are also important when assessing nutritional quality. The 2025 comparative study of six microgreens reported ascorbic acid concentrations ranging from 32.72 to 80.45 mg per 100 g fresh weight among the tested crops. Potassium ranged from

approximately 187 to 416 mg per 100 g fresh weight, while calcium and magnesium also showed substantial differences among species. These findings demonstrate that crop selection can have a major influence on the nutritional characteristics of a microgreen product. From a horticultural perspective, nutritional composition should be evaluated together with fresh yield and production efficiency. A microgreen containing a high concentration of a particular nutrient may not necessarily provide the greatest nutrient yield per unit growing area if its biomass production is low. Therefore, future studies should consider both nutrient concentration and nutrient yield per unit area.

Bioactive Compounds and Phytochemical Potential

The phytochemical composition of microgreens is one of their most important research characteristics. Phenolic acids, flavonoids, carotenoids and anthocyanins are among the compounds commonly measured. Brassica microgreens additionally contain glucosinolates, which are characteristic secondary metabolites of the Brassicaceae family. Phenolic compounds and flavonoids are widely studied because of their antioxidant activity in laboratory assays. Carotenoids contribute to yellow, orange and green pigmentation and have important biological functions. Anthocyanins are particularly associated with red, purple and blue pigmentation. Glucosinolates and their hydrolysis products are major subjects of research in broccoli, radish, mustard and other Brassica microgreens. The presence of these compounds supports the classification of microgreens as potential functional foods. Nevertheless, the presence of a bioactive compound should not automatically be interpreted as proof of a particular therapeutic effect in humans. Much of the evidence concerning antioxidant, anti-inflammatory or other biological activities comes from laboratory, animal or preliminary studies. Human dietary intervention research is still needed to establish the magnitude and consistency of health effects.

Factors Influencing Nutritional Quality

Microgreen nutritional quality is strongly influenced by production conditions. Genotype, seed quality, sowing density, growing medium, water availability, nutrient management, temperature, humidity, light intensity, light spectrum and harvest age can all influence plant growth and biochemical composition. Light is particularly important because it regulates photosynthesis, plant morphology and pigment formation. In controlled environments, LED lighting provides an opportunity to manipulate light intensity and spectrum. Research has shown that environmental and cultural factors can be used to influence the growth and nutritional characteristics of microgreens. Nutrient management also provides opportunities for improving crop quality. Appropriate nitrogen, phosphorus, potassium and micronutrient supply can influence biomass production and biochemical composition. Biofortification with selected minerals is another promising area of research. However, nutrient enrichment strategies should be scientifically validated to ensure that they improve nutritional quality without creating excessive accumulation or compromising food safety.

Production Technology





Microgreen production can be started with relatively simple infrastructure. Clean trays, quality seed, suitable growing media, water and adequate light are the basic requirements. Cocopeat and other soilless substrates are commonly used because they provide good moisture retention and root aeration. Seed quality is particularly important because the crop is harvested at a very young stage. Healthy seed with high germination capacity produces uniform stands and improves marketable yield. Seed should be free from visible contamination and should be appropriate for edible microgreen production. Water management requires careful attention. Excess moisture can reduce aeration and encourage microbial growth, while insufficient moisture can cause poor germination and uneven crop establishment. Clean water and hygienic production practices are essential because microgreens are often consumed raw or minimally processed. Harvesting is generally undertaken when the cotyledons are fully developed and the first true leaves are emerging, although the optimum stage differs among crops. Harvest age can influence yield, texture, colour and phytochemical concentration. Consequently, the selection of an appropriate harvest stage is an important component of quality management.

Food Safety and Postharvest Handling

Food safety is particularly important in microgreen production. The warm and humid conditions used for seed germination can also favour microbial multiplication when sanitation is inadequate. Contamination can occur through seed, water, growing media, equipment, workers or packaging. Recent reviews therefore emphasize the importance of hygienic production and suitable postharvest handling. Clean production trays, good-quality water, hygienic harvesting tools and appropriate handling practices should be integrated throughout production. Because microgreens are frequently eaten fresh, preventing contamination is preferable to relying entirely on postharvest decontamination. Postharvest processing can also modify nutritional and phytochemical composition. Drying, blanching, freezing and juicing may affect phenolics, carotenoids, glucosinolates and antioxidant activity. Recent research indicates that minimal processing can help retain several important bioactive compounds, although the optimum method depends on the species and intended product.

Microgreens for Human Nutrition

Microgreens can contribute to dietary diversification by providing a range of plant-derived nutrients and bioactive compounds in a small portion of fresh produce. Their different colours, flavours and textures can encourage the incorporation of additional plant foods into meals. Instead of relying on a single species, consumers can use mixtures of green, red, purple and aromatic microgreens. The nutritional value of microgreens should, however, be considered as part of an overall balanced diet. They are not substitutes for conventional

vegetables, fruits, pulses, cereals or other major food groups. Their principal advantage is the possibility of adding a concentrated and diverse plant component to meals. A 2025 review described microgreens as potential functional foods because of their combination of vitamins, minerals, antioxidants and other bioactive compounds, while also emphasizing the influence of production and processing practices on quality.

Scope for Value Addition

Microgreens offer opportunities beyond fresh-market sales. Fresh shoots can be incorporated into salads, sandwiches, wraps, soups and traditional vegetable preparations. They can also be explored for use in smoothies and other food products. Drying and powder production may extend the range of applications, but processing conditions must be carefully selected because heat and oxygen can affect sensitive nutrients and phytochemicals. Recent research has specifically examined non-thermal processing approaches for maintaining or enhancing nutritional and bioactive characteristics. For farmers and rural entrepreneurs, microgreens can provide a high-value niche crop where local demand exists. Small production units can be established close to urban markets, reducing transportation time. Restaurants, hotels, supermarkets and direct-to-consumer markets may provide opportunities for marketing, although profitability depends strongly on production cost, labour, packaging, market price and consistent consumer demand.

Research Opportunities

Microgreens provide a wide research platform for horticultural scientists. Comparative evaluation of species and cultivars can be conducted for germination percentage, plant height, leaf area, fresh yield, dry matter, chlorophyll, carotenoids, vitamins, minerals, total phenolics, flavonoids and antioxidant activity. Future experiments can also evaluate organic and inorganic nutrient sources, biofertilizers, micronutrient enrichment, different growing media, seed densities and irrigation regimes. Controlled-environment experiments involving LED light intensity, colour spectrum and photoperiod could identify production protocols for maximizing both yield and nutritional quality. A particularly useful research approach would be to establish a Microgreen Nutritional Quality Index based on yield, vitamin concentration, mineral content, phenolics, flavonoids and antioxidant capacity. Such an approach could help identify microgreen genotypes suitable for nutritional production rather than selecting cultivars only on the basis of fresh yield. Another important research area is the relationship between genotype $\times$ environment $\times$ nutrition. Two cultivars of the same species may respond differently to identical environmental conditions. Therefore, standardized production protocols should be developed for individual species and cultivars rather than applying a single management recommendation to all microgreens.

Future Prospects

The future of microgreen production is closely associated with controlled-environment agriculture, urban horticulture, precision nutrition and functional food development. Vertical production systems can increase output per unit floor area, while sensor-based systems may allow more precise control of irrigation, temperature, humidity and light. The increasing availability of LED technology also provides opportunities to manipulate crop quality. Research is moving towards optimizing production not only for maximum biomass but also for specific nutritional and phytochemical characteristics. For India, microgreens have particular potential in urban and peri-urban horticulture. Production can be integrated into protected structures, rooftops, educational institutions, restaurants and small entrepreneurial units. Local species such as fenugreek, coriander, amaranth, mustard and other familiar crops could be explored alongside internationally popular microgreens.

Conclusion

Microgreens represent an emerging group of functional horticultural crops with considerable potential for nutritional diversification and value-added production. Their short crop duration, compact growth, diverse colours and flavours, and concentration of nutrients and bioactive

compounds make them attractive for modern horticulture. The nutritional and phytochemical composition of microgreens is strongly influenced by species, cultivar and production environment. Therefore, characterization of individual crops is essential for identifying superior genotypes and developing crop-specific production technologies. Current research supports their potential as nutrient-rich foods, but claims regarding specific health benefits should be based on appropriate human evidence rather than solely on laboratory antioxidant measurements. Future research should integrate horticulture, plant nutrition, phytochemistry, controlled-environment agriculture, food safety and postharvest technology. With scientific production and appropriate quality standards, microgreens can become an important component of urban horticulture, functional food production and diversified human nutrition.