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Microgreens as Nutrient-Efficient Crops for Sustainable and Urban Food Systems

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Abstract

Global food systems face growing challenges due to urbanization, climate change, limited farmland, and micronutrient deficiencies. This situation calls for crop production methods that focus on nutrition and sustainability. Microgreens, which are harvested at the cotyledon or early true-leaf stage, are a nutrient-dense crop capable of providing high levels of vitamins, minerals, and bioactive compounds in short growth cycles and small spaces. Their biological efficiency comes from early harvesting, which focuses metabolic resources in edible tissues while reducing structural biomass and resource use. Advances in controlled environment agriculture enhance microgreen productivity and nutritional quality by precisely controlling light, temperature, and nutrient levels. From a nutritional standpoint, microgreens are rich sources of antioxidants, micronutrients, and phytochemicals that promote oxidative balance, reduce inflammation, and support metabolism, making them valuable additions to preventive diets. Their fit with decentralized and urban production systems enhances local food security, lessens dependency on supply chains, and maintains nutritional quality through shorter paths from farm to consumer. Even with challenges related to shelf life, food safety, cost, and limited breeding efforts, microgreens show great potential as versatile crops at the intersection of gardening innovation, public health, and sustainable food system design.

Keywords: farming, Microgreens, Nutritional density and Urban agriculture.

1. Introduction

Global food systems are increasingly pressured by rapid urban growth, climate change, reduced farmland, and ongoing micronutrient shortages. Traditional agricultural methods have primarily focused on yield and calories, often neglecting nutritional quality, sustainability, and equitable access to fresh produce, particularly in urban areas (FAO, 2019; Kyriacou *et al.*, 2016). These issues have sparked interest in crop production methods that emphasise nutritional efficiency, resource utilisation, and flexibility in unconventional growing environments. Vegetables and leafy greens are vital sources of vitamins, minerals, antioxidants, and dietary fibre, but their nutritional value often suffers due to seasonality, postharvest losses, chemical use, and lengthy supply chains (Xiao *et al.*, 2013; Mir *et al.*, 2017). As a result, alternative plant foods that provide high nutritional value with fewer resources are gaining popularity. Microgreens, which are young edible seedlings harvested 7 to 21 days after germination at the cotyledon or early true-leaf stage, serve as a promising alternative. Even with their small size, microgreens have strong flavours and high levels of vitamins, minerals, and bioactive compounds (**Bhaswant *et al.*, 2023; Partap *et al.*, 2023**). Their quick growth, minimal space requirements, and suitability for controlled environment agriculture make them efficient crops relevant to plant science, nutrition, and urban food system design.

2. Crop Efficiency

Microgreens exemplify a shift from traditional yield-based assessments to assessments of biological and nutritional efficiency. Unlike mature vegetable crops that invest heavily in structural growth, microgreens are harvested early, concentrating metabolic activity and nutrient accumulation in edible tissues. This approach allows for a high nutritional yield within a short production period and limited space **(Kyriacou *et al.*, 2016).** During their cotyledon stage, rapid cell division and active synthesis of primary and secondary metabolites occur, supported by seed reserves and early photosynthesis. As the structural biomass development is minimal, vitamins, minerals, antioxidants, and phytochemicals are found in higher concentrations per unit of fresh weight compared to mature plants, where nutrient dilution occurs as growth continues (Xiao *et al.*, 2013; Balik *et al.*, 2025).

Microgreens generally reach harvest maturity in 7 to 21 days, allowing for multiple production cycles and reducing their exposure to long-term biotic and abiotic stresses (Renna *et al.*, 2018). Their shallow root systems and short growing periods result in lower water, nutrient, and land requirements compared to conventional vegetable production. Controlled environment systems further boost microgreen efficiency. Careful regulation of light quality, day length, temperature, humidity, and seed density optimizes both yield and nutritional quality. Adjusting LED light spectra, in particular, has been shown to raise levels of bioactive compounds without extending the growing period (Zhang *et al.*, 2021; Partap *et al.*, 2023). Together, these features position microgreens as ideal crops for quality-focused agriculture.

3. Nutritional Density

Microgreens are renowned for their high nutritional density, considering their small size and brief growth time. Harvesting them early keeps concentrated pools of essential nutrients and phytochemicals that decrease in later growth stages (Xiao *et al.*, 2012; Kyriacou *et al.*, 2016).

Representative Nutritional Composition (per 100 g fresh weight)

While nutrient levels vary among different types, commonly consumed microgreens like broccoli, red cabbage, radish, and arugula usually show the following ranges:

- Energy: 25–35 kcal
- Protein: 2.0–4.0 g
- Dietary fiber: 1.5–3.0 g
- Vitamin C: 20–60 mg
- Vitamin K: 100–400 μg
- Vitamin E (α-tocopherol): 1.0–4.5 mg
- β-carotene: 2.5–7.5 mg
- Calcium: 40–120 mg
- Iron: 0.6–2.5 mg
- Potassium: 250–450 mg

Based on fresh weight, these values often match or exceed those of mature vegetables, particularly for vitamins C, E, K, and carotenoids (**Xiao *et al.*, 2012; Xiao *et al.*, 2013**).

In addition to traditional nutrients, microgreens are rich in bioactive compounds, including phenolics, flavonoids, anthocyanins, and glucosinolates. Brassicaceae microgreens are particularly notable for their glucosinolate-derived compounds, which are linked to antioxidant and cellular protective functions (Mir *et al.*, 2017; Partap *et al.*, 2023). Their tender tissues and low lignification might also enhance digestion and nutrient absorption, though comprehensive studies on human bioavailability remain scarce (Renna *et al.*, 2018).

From a public health standpoint, microgreens offer a practical solution for addressing micronutrient deficiencies. Small additions to diets can significantly increase vitamin and mineral intake without changing portion sizes or eating habits. Additionally, controlled environment cultivation allows for targeted boosts of specific nutrients through environmental adjustments rather than genetic modifications (Zhang *et al.*, 2021).

4. Human Health and Nutraceutical Relevance

Microgreens are becoming increasingly recognized for their role in preventive nutrition, thanks to their high levels of bioactive compounds that impact oxidative balance, inflammation, and metabolic control. Instead of being treated as medication, they serve as everyday dietary ingredients that help maintain long-term health (Bhaswant *et al.*, 2023).

Oxidative stress and chronic low-grade inflammation contribute to the development of diseases like heart disorders, diabetes, and neurodegenerative conditions. Microgreens offer a wide variety of antioxidant molecules, including ascorbic acid, carotenoids, tocopherols, phenolic acids, and flavonoids, which work together to support redox balance and influence inflammatory pathways (Xiao *et al.*, 2013; Zhang *et al.*, 2021). Micronutrient inadequacy is still a global issue affecting immune system function, metabolism, and growth. Microgreens provide meaningful amounts of minerals like iron, calcium, magnesium, and zinc, along with folate and antioxidant vitamins. They help meet dietary needs, especially for urban populations with limited access to fresh food (Balik *et al.*, 2025; FAO, 2019).

Although clinical evidence is still developing, initial results suggest that adding microgreens to balanced diets may help improve metabolic health. Their strong flavour and soft texture encourage consumer acceptance and support regular consumption without large portions (**Renna *et al.*, 2018**).

5. Microgreens in Urban Farming and Sustainable Food Systems

Urban growth has increased the distance between food production and consumption, revealing vulnerabilities in centralized supply chains. Microgreens are ideally suited for urban and nearby settings due to their fast growth, small space needs, and high nutritional yield (Riggio *et al.*, 2019).

They can be grown in unconventional spaces like rooftops, indoor locations, vertical farms, and community areas using shallow trays and soil or soilless substrates. This setup allows for decentralized food production at household, institutional, and community levels, improving access to fresh, nutrient-rich foods (Kyriacou *et al.*, 2016). From a sustainability viewpoint, microgreens make efficient use of resources. Their short production cycles and low biomass lessen water and nutrient demands, while controlled environments reduce waste and environmental impact through careful management of inputs (Zhang *et al.*, 2021). Growing microgreens close to consumption points shortens supply chains, reducing the need for refrigeration and long transport, which decreases energy use and greenhouse gas emissions while maintaining nutritional quality (Mir *et al.*, 2017).

6. **Challenges, Constraints, and Conceptual Gaps**

Despite their benefits, several challenges hinder the wider use of microgreens. A key issue is their short shelf life after harvest, due to high respiration rates and fragile tissues, which complicates storage and distribution beyond local markets. Modified atmosphere packaging and cold-chain methods have enhanced shelf life, yet standardized postharvest protocols continue to be absent (Mir *et al.*, 2017; Ghidelli & Pérez-Gago, 2018).

Food safety is another challenge. Dense planting, high moisture levels, and early harvesting raise the risk of microbial contamination without strict hygiene practices. Regulations for microgreens are still developing, leading to inconsistent safety standards in different areas (Turner *et al.*, 2020).

Economic accessibility also remains a concern, as microgreens are often sold as premium products due to the high costs of controlled environments, quality seeds, and labour-intensive harvesting. Research has focused largely on compositional analysis, with relatively few long-term human studies examining bioavailability, health effects, and practical dietary integration (Bhaswant *et al.*, 2023). Moreover, specific breeding programs for microgreens are mostly non-existent, representing an area for potential genetic improvement.

7. Future Directions and Conceptual Roadmap

The future of microgreens relies on cooperative advances in crop breeding, controlled environment technology, nutrition research, and policy support. Creating microgreen-specific breeding programs that target quick growth, uniformity, higher phytochemical content, and better shelf life would significantly boost efficiency and scalability. Improvements in controlled environment agriculture, backed by sensor-based monitoring and data management, are expected to enhance standardization, safety, and resource efficiency. More human studies are needed to confirm health claims and support evidence-based dietary recommendations.

Policy integration and consumer education are essential to widen access beyond niche markets. Understanding microgreens as multifunctional parts of nutrition-sensitive and sustainable food systems, rather than just specialty crops, creates a clear pathway for their broader use.

8. Conclusion

Microgreens represent a blend of crop innovation, nutritional density, urban adaptability, and health importance. Their value lies not in replacing traditional vegetables but in enhancing diets with essential nutrients and bioactive compounds through efficient production processes. By focusing on nutritional efficiency rather than biomass yield, microgreens highlight a move toward more resilient and nutrition-centred food systems.

Their suitability for controlled environments and urban farming boosts local food production and nutrition security, especially in limited space areas. Tackling issues related to shelf life, food safety, affordability, and research support will be crucial for unlocking their full potential. With coordinated advancements in breeding, technology, research, and policy, microgreens can play a significant role in promoting sustainable agriculture and improving health outcomes.

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