Millet Microgreens: The Future Functional Food for Sustainable Nutrition

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Abstract

Millet microgreens are emerging as promising functional foods due to their exceptional nutritional composition, rapid growth cycle, and sustainable cultivation practices. These young edible seedlings, harvested during the early growth stage, possess higher concentrations of vitamins, minerals, antioxidants, and bioactive compounds compared to mature plants. Millets, being climate-resilient and nutrient-rich cereals, further enhance the functional and health-promoting properties of microgreens. In recent years, increasing consumer awareness regarding healthy diets, sustainable nutrition, and functional foods has accelerated interest in millet microgreens within modern food systems. Millet microgreens offer several advantages, including low water requirement, short cultivation duration, minimal land usage, and suitability for urban and indoor farming systems. Their applications in salads, smoothies, ready-to-eat foods, nutraceuticals, and value-added functional products demonstrate their growing importance in food processing industries. However, challenges related to shelf life, storage stability, and large-scale commercialization still require advanced preservation and smart packaging technologies. This article discusses the nutritional significance, sustainable production, food processing applications, preservation strategies, and future prospects of millet microgreens. Their integration into future food systems may contribute significantly toward sustainable agriculture, urban food security, and next-generation functional foods.

Keywords: Millet microgreens; Functional foods; Sustainable nutrition; Urban farming; Food processing technologies

1.Introduction

The increasing global demand for nutrient-rich, sustainable, and health-promoting foods has led to growing interest in functional foods and innovative agricultural practices. Modern consumers are becoming more conscious about the relationship between diet and health, resulting in a significant shift toward foods that provide additional physiological benefits beyond basic nutrition. In this context, microgreens have emerged as one of the most promising future foods due to their high nutritional density, rapid cultivation cycle, and environmental sustainability. Microgreens are tender young seedlings harvested at the cotyledon or first true leaf stage, generally within 7–21 days after germination. They are recognized for their attractive appearance, unique flavors, and high concentrations of vitamins, minerals, antioxidants, and bioactive compounds. Compared to mature vegetables, microgreens often contain higher levels of essential nutrients, making them important components of functional and nutraceutical foods (Jindal and Riar, 2026).

Among various crops used for microgreen production, millets have gained considerable attention because of their exceptional nutritional and agronomic properties. Millets are small-seeded cereal crops known for their drought tolerance, climate resilience, and adaptability to poor soil conditions. They are rich in dietary fiber, minerals, polyphenols, and essential nutrients, making them highly suitable for sustainable food systems (Panek et al., 2025). The combination of millet grains with microgreen technology creates a highly nutritious and eco-friendly food product known as millet microgreens.

Millet microgreens offer numerous advantages, including low water consumption, short production time, minimal land requirement, and suitability for urban farming and controlled environment agriculture. Their potential applications in ready-to-eat foods, functional beverages, nutraceuticals, and value-added food products have attracted increasing attention from food scientists, nutritionists, and food processing industries. Furthermore, the growing focus on sustainable nutrition, climate-smart agriculture, and urban food security has strengthened the importance of millet microgreens in future food systems. Despite their significant potential, challenges related to shelf-life stability, microbial safety, processing, and commercialization remain important areas of research. Advanced preservation technologies, smart packaging systems, and innovative cultivation approaches are being explored to improve their commercial viability and consumer acceptance (Seth et al., 2025). Therefore, millet microgreens are increasingly recognized as next-generation functional foods with promising applications in sustainable nutrition, food processing innovation, and future smart food systems.

2. Nutritional Importance of Millet Microgreens

Millet microgreens are gaining considerable attention as nutrient-dense functional foods due to their rich composition of essential nutrients and bioactive compounds. During the early stages of germination and growth, metabolic activities within the seedlings increase significantly, resulting in enhanced concentrations of vitamins, minerals, antioxidants, and phytochemicals compared to mature plants.

This makes millet microgreens highly beneficial for promoting health and preventing various lifestyle-related diseases (Jindal and Riar, 2026).. Millet microgreens are excellent sources of vitamins such as vitamin C, vitamin E, and vitamin K, which play important roles in immunity enhancement, antioxidant protection, and cellular metabolism. They also contain essential minerals including iron, calcium, magnesium, potassium, and zinc, which contribute to bone health, blood formation, nerve function, and overall physiological activities. In addition, the presence of dietary fiber supports digestive health and improves gut function.

One of the major advantages of millet microgreens is their high antioxidant content. Bioactive compounds such as polyphenols, flavonoids, chlorophyll, and carotenoids help neutralize free radicals and reduce oxidative stress within the body. These compounds are associated with anti-inflammatory, anti-diabetic, anti-cancer, and cardioprotective properties. Finger millet microgreens, for example, are known for their high calcium and phenolic content, while foxtail millet microgreens possess strong antioxidant activity and dietary fiber (Seth et al., 2025).

The germination process also improves nutrient bioavailability by reducing anti-nutritional factors naturally present in millet grains. As a result, nutrients become easier to digest and absorb, increasing their nutritional efficiency. Due to these health-promoting characteristics, millet microgreens are increasingly being incorporated into functional foods, nutraceutical formulations, ready-to-eat products, smoothies, salads, and health supplements. Furthermore, the low glycemic index and high fiber content of millet microgreens make them suitable for diabetic and health-conscious consumers. Their rich nutrient profile, combined with sustainable production methods, positions millet microgreens as promising future foods capable of supporting both human health and sustainable nutrition systems.

3. Types and Characteristics of Millet Microgreens

Millet microgreens can be produced from several millet varieties, each possessing unique nutritional and functional characteristics. Commonly cultivated millet microgreens include finger millet (Eleusine coracana), foxtail millet (Setaria italica), pearl millet (Pennisetum glaucum), little millet (Panicum sumatrense), barnyard millet (Echinochloa frumentacea), and kodo millet (Paspalum scrobiculatum). These millet species differ in seed size, germination behavior, nutrient composition, growth rate, flavor profile, and antioxidant potential (Vashisht and Pradhan, 2026).

Finger millet microgreens are particularly valued for their high calcium and phenolic content, whereas foxtail millet microgreens possess superior dietary fiber and antioxidant activity. Pearl millet microgreens are rich in proteins and micronutrients, while barnyard millet microgreens are recognized for their low glycemic index and suitability for diabetic diets. The diversity among millet varieties provides opportunities for developing specialized functional foods and nutraceutical products with enhanced nutritional properties. In addition to their nutritional advantages, millet microgreens exhibit attractive colour, texture, and flavor characteristics that improve consumer acceptability and food product quality. Their rapid germination and adaptability to controlled cultivation systems further support their application in sustainable food production and urban agriculture.

Fig. 1. Flow chart illustrating the cultivation technology and timeline of millet microgreens from seed selection to post-harvest utilization

4. Bioactive Compounds and Health Benefits of Millet Microgreens

Millet microgreens are rich sources of bioactive compounds that contribute significantly to their functional and therapeutic properties. During germination and early seedling development, enzymatic and metabolic activities increase the synthesis of phenolic compounds, flavonoids, carotenoids, chlorophyll, vitamins, and antioxidant enzymes. These compounds play a crucial role in reducing oxidative stress and protecting the body against various chronic diseases. The antioxidant properties of millet microgreens help neutralize free radicals and minimize cellular damage associated with aging, inflammation, cardiovascular diseases, diabetes, and cancer. Phenolic compounds and flavonoids present in millet microgreens exhibit anti-inflammatory and anti-diabetic activities by regulating glucose metabolism and reducing inflammatory responses. Additionally, chlorophyll and carotenoids contribute to detoxification processes and immune enhancement.

The high dietary fiber content of millet microgreens also supports digestive health, improves gut microbiota balance, and aids in weight management. Furthermore, germination reduces anti-nutritional factors such as phytates and tannins, thereby improving mineral bioavailability and nutrient absorption. These health-promoting properties have increased the utilization of millet microgreens in functional foods, nutraceuticals, and preventive nutrition systems.

5. Cultivation Technology of Millet Microgreens

The cultivation technology of millet microgreens, as illustrated in Figure 1**,** involves a systematic process beginning with the selection of high-quality millet seeds followed by seed soaking and pre-treatment to improve germination efficiency. The seeds are then sown in suitable growing media such as coco peat, soil mixtures, or hydroponic systems under controlled environmental conditions including optimum temperature, humidity, and light intensity. Within 7–14 days, the microgreens reach the harvest stage characterized by cotyledon expansion and early leaf development. After harvesting, post-harvest handling operations such as washing, packaging, and refrigerated storage are carried out to maintain freshness and quality before utilization in salads, smoothies, functional foods, and ready-to-eat products.

6. Millet Microgreens and Sustainable Nutrition

Millet microgreens play an important role in sustainable nutrition due to their high nutritional value, rapid growth cycle, and minimal resource requirements. They support sustainable food production by requiring less water, reduced land area, and minimal fertilizers compared to conventional crops, thereby reducing environmental impact and conserving natural resources. In addition, millets are naturally drought-tolerant and climate-resilient crops capable of adapting to harsh environmental conditions, making millet microgreens suitable for climate-smart agriculture and future food security systems. Their ability to grow efficiently in urban farming systems such as rooftop farming, indoor cultivation, and vertical farming further enhances their significance in modern sustainable agriculture. Furthermore, millet microgreens contribute to localized food production and urban nutrition by providing fresh, nutrient-rich foods while reducing dependence on long supply chains, thereby strengthening food security and promoting environmentally sustainable food systems (Figure 2).

7. Applications in Food Processing

7.1 Functional Foods

Millet microgreens are widely regarded as functional foods because of their rich concentration of bioactive compounds, vitamins, minerals, and antioxidants that provide health benefits beyond basic nutrition. Their incorporation into functional food products can improve nutritional quality and promote overall wellness. Millet microgreens are increasingly utilized in nutraceutical formulations, fortified foods, dietary supplements, and immunity-enhancing products due to their antioxidant and anti-inflammatory properties. Their high nutrient density makes them suitable ingredients for developing health-oriented food products targeting lifestyle-related disorders such as diabetes, cardiovascular diseases, and obesity(Kaya and Yardımcı, 2025).

Fig. 2. Sustainable nutrition and urban farming potential of millet microgreens in future food systems

7.2 Ready-to-Eat Foods

The attractive appearance, pleasant flavour, and nutritional richness of millet microgreens make them suitable ingredients for ready-to-eat foods. They are commonly incorporated into salads, sandwiches, wraps, smoothies, soups, and meal bowls to enhance both nutritional and sensory qualities. With increasing consumer demand for convenient and healthy food products, millet microgreens are becoming important components of modern ready-to-eat formulations. Their fresh texture, vibrant colour, and nutrient profile improve product appeal while supporting health-conscious dietary habits.

7.3 Beverage Applications

Millet microgreens are increasingly used in functional beverages and health drinks because of their rich antioxidant and bioactive composition. They can be incorporated into green juices, smoothies, detox beverages, and fortified health drinks to improve nutritional functionality and health benefits. The presence of chlorophyll, vitamins, minerals, and phytochemicals contributes to the antioxidant and detoxifying properties of these beverages. Growing consumer preference for natural and plant-based beverages has further enhanced the application potential of millet microgreens within the beverage industry.

7.4 Bakery and Snack Products

Dried millet microgreen powders can be incorporated into bakery products and healthy snack formulations to improve nutritional quality and functional properties. Millet microgreens are increasingly utilized in fortified biscuits, breads, crackers, pasta products, nutrition bars, and extruded snacks due to their high fiber, antioxidant, and micronutrient content. Such value-added products are gaining popularity among consumers seeking healthy alternatives to conventional processed foods. Incorporation of millet microgreens also enhances the functional and commercial value of bakery and snack products (Ikade et al., 2024).

7.5 Personalized Nutrition Products

The growing demand for personalized nutrition has created new opportunities for the utilization of millet microgreens in customized food formulations. Their nutrient-rich composition makes them suitable for designing specialized foods for athletes, diabetic patients, elderly populations, and health-conscious consumers. Millet microgreens can be integrated into personalized meal plans, dietary supplements, nutraceutical products, and functional food systems tailored to individual nutritional requirements. Their incorporation into precision nutrition strategies aligns with the future trend toward personalized healthcare and preventive nutrition.

8. Processing and Preservation Challenges

Despite their exceptional nutritional benefits, millet microgreens are highly perishable due to their delicate structure and high moisture content. Post-harvest deterioration, moisture loss, nutrient degradation, and microbial contamination are major challenges limiting their shelf life and commercial distribution. Therefore, appropriate preservation and packaging technologies are essential to maintain product quality and safety (Jindal and Riar, 2026). Refrigerated storage is one of the most commonly used methods for extending shelf life by slowing respiration and microbial growth. Modified atmosphere packaging (MAP) techniques are also utilized to regulate oxygen and carbon dioxide levels inside packaging systems, thereby preserving freshness and reducing spoilage. In addition, edible coatings prepared from biodegradable materials can help reduce moisture loss and improve storage stability (Kaya and Yardımcı, 2025).

Advanced preservation technologies such as freeze drying, cold plasma treatment, and non-thermal processing methods are increasingly being investigated for millet microgreens. Freeze drying helps retain nutrients, color, and bioactive compounds, while cold plasma technology offers effective microbial decontamination without significantly affecting nutritional quality. Integration of smart packaging systems and active packaging technologies may further improve the shelf stability and commercial viability of millet microgreens in future food industries (Raza et al., 2026).

9. Future Trends and Innovations

The future of millet microgreens is closely associated with advancements in smart agriculture, sustainable food processing, and functional food development. Emerging technologies such as hydroponics, aeroponics, IoT-based cultivation monitoring, and AI-assisted environmental control systems are improving cultivation efficiency and resource utilization. Vertical farming systems integrated with automated nutrient management and LED lighting are expected to support large-scale urban production of millet microgreens.

In the food processing sector, increasing interest in personalized nutrition, nutraceuticals, and clean-label functional foods is likely to expand the commercial applications of millet microgreens. Smart packaging systems equipped with freshness indicators and antimicrobial technologies may improve product safety and storage stability. Furthermore, millet microgreens may find applications in clinical nutrition, sports nutrition, and future space food systems because of their high nutrient density and sustainable production methods. Growing consumer awareness regarding health, sustainability, and environmentally friendly foods is expected to increase market demand for millet microgreens globally. Their integration into future sustainable food systems may contribute significantly toward nutritional security, climate-smart agriculture, and innovative food processing industries.

10. Conclusion

Millet microgreens are emerging as highly promising functional foods with exceptional nutritional, environmental, and commercial potential. Their rich composition of vitamins, minerals, antioxidants, and bioactive compounds makes them valuable ingredients for functional foods, nutraceuticals, and health-oriented food products. In addition to their nutritional benefits, millet microgreens support sustainable agriculture through low water consumption, reduced land requirements, and suitability for urban farming systems. The increasing demand for healthy, sustainable, and convenient food products has accelerated interest in millet microgreens within modern food processing industries. Their applications in ready-to-eat foods, functional beverages, bakery products, and personalized nutrition systems demonstrate their versatility and future market potential. However, challenges related to shelf-life stability, preservation, and commercialization require further technological advancements and research. Overall, millet microgreens represent an innovative approach toward future sustainable nutrition and climate-resilient food systems. Integration of advanced cultivation technologies, smart packaging systems, and sustainable processing methods can further enhance their role as next-generation functional foods capable of supporting global food security and human health.

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