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REVIEW ARTICLE OPEN ACCESS

Millets as Superfood: Nutritional Significance, Climate Resilience, and Pathways for Sustainable Development

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Abstract

Millets are a group of small-seeded cereal crops traditionally cultivated in arid and semi-arid regions of Asia and Africa. Although historically marginalized in favor of rice and wheat, millets have re-emerged as nutritionally rich, climate-resilient, and sustainable food crops. This review synthesizes recent literature (2020–2025) to evaluate millets as superfoods, with emphasis on their nutritional composition, health benefits, environmental sustainability, processing innovations, and farmer-level constraints. Millets are rich in dietary fibre, essential micronutrients, antioxidants, and bioactive compounds, making them effective in addressing lifestyle-related diseases such as diabetes, cardiovascular disorders, and micronutrient deficiencies. Environmentally, their low water requirement, tolerance to climatic stress, and adaptability to marginal lands position them as key components of climate-smart agriculture. However, widespread adoption is limited by low productivity, weak market linkages, inadequate processing infrastructure, and policy bias toward major cereals. The review highlights strategic interventions, including policy support, value addition, research investment, and consumer awareness, to unlock the full potential of millets. Strengthening millet-based agri-food systems can simultaneously enhance nutritional security, climate resilience, and farmer livelihoods.

Keywords: Millets, superfoods, nutrition security, climate resilience, farmer constraints, sustainable agriculture.

Introduction

Millets are among the earliest domesticated cereal crops and have historically played a critical role in sustaining food security and livelihoods in marginal and resource-poor agro-ecological regions across Asia and Africa. Their inherent resilience to drought, high temperatures, and poor soil fertility, coupled with low input requirements, made millets indispensable to traditional farming systems and local diets. In addition to their agronomic robustness, millets are nutritionally superior to many major cereals, being rich sources of dietary fibre, essential amino acids, micronutrients such as iron, zinc, and calcium, and bioactive compounds with health-promoting properties. Despite these advantages, the cultivation and consumption of millets declined sharply during the Green Revolution era, largely due to policy, research, and institutional support that strongly favored rice and wheat through irrigation expansion, input subsidies, procurement, and public distribution systems (Pingali, 2015; FAO, 2023). This cereal-centric approach contributed to the marginalization of millets, leading to dietary simplification, increased dependence on water-intensive crops, heightened environmental stress, and the persistence of "hidden hunger" caused by widespread micronutrient deficiencies.

In recent years, however, growing concerns over climate change, water scarcity, declining

agrobiodiversity, and the rising prevalence of non-communicable diseases such as diabetes and cardiovascular disorders have renewed scientific and policy interest in millets as sustainable and health-promoting food crops (Kumar *et al.,* 2022; Reddy *et al.,* 2024). Millets' low glycaemic index, high fibre content, and functional nutritional attributes position them as promising alternatives in diversified and climate-resilient food systems. The United Nations' declaration of 2023 as the International Year of Millets further underscored their global significance by drawing attention to their potential contributions to food and nutrition security, sustainable agriculture, and smallholder farmer livelihoods. Against this backdrop, the present review critically examines millets as "superfoods" by integrating nutritional and health benefits with environmental sustainability and farmer-centric perspectives. By synthesizing evidence across these domains, the review aims to highlight the role of millets in addressing contemporary challenges related to nutrition, climate resilience, and inclusive agricultural development.

Nutritional Composition of Millets

Millets are nutritionally superior to commonly consumed cereals such as polished rice and refined wheat. They provide complex carbohydrates, moderate to high-quality protein, and substantial amounts of dietary fiber. Finger millet is particularly rich in calcium, while pearl millet contains high levels of iron and zinc, which are critical for addressing micronutrient malnutrition (Saleh *et al.,* 2022; Longvah *et al.,* 2023). In addition, millets contain phenolic acids, flavonoids, and antioxidants that exhibit anti-inflammatory and anti-carcinogenic properties (Shobana *et al.,* 2021). Their higher fibre and resistant starch content contribute to slower digestion and improved glycaemic control (Jacob *et al.,* 2024).

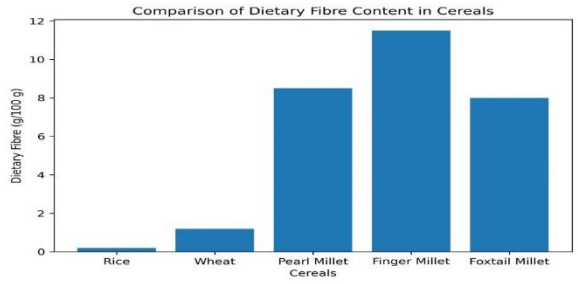

Fig. 1: Fiber content of millets compared to rice and wheat is illustrated.

Millets as Functional and Superfoods

The concept of "superfoods" refers to foods that deliver exceptional health benefits beyond basic nutrition by providing functional components that contribute to disease prevention and overall well-being. Millets strongly meet this criterion owing to their low glycaemic index, high dietary fibre content, substantial antioxidant activity, and the presence of diverse bioactive compounds such as polyphenols, flavonoids, and phytosterols (Rao *et al.,* 2023; Chandrasekara & Shahidi, 2021). These attributes make millets particularly suitable for managing lifestyle-related metabolic disorders, especially in populations with rising incidences of diabetes and obesity. Regular consumption of millets has been associated with improved lipid metabolism, including reductions in total cholesterol, low-density lipoprotein (LDL), and triglycerides, thereby lowering the risk of cardiovascular diseases (Anitha *et al.,* 2021). Millets also help reduce insulin resistance and postprandial glucose spikes due to their slow digestibility and high resistant starch content (Kumar *et al.,* 2022). Furthermore, the fermentable fiber fractions in millets promote the growth of beneficial gut microbiota, enhancing gut health, immune function, and mineral bioavailability. Collectively, these physiological benefits support the classification of millets as functional foods with significant potential for preventive nutrition and public health interventions, particularly in the context of modern dietary transitions and nutrition-related health challenges.

Health Benefits of Millets

Scientific evidence highlights that millets confer a wide range of health benefits, making them uniquely suited to address contemporary nutrition challenges. Their low glycaemic index and high dietary fiber content contribute to effective blood glucose regulation, making millets particularly beneficial for the management and prevention of diabetes. Millets also support improved cardiovascular health by lowering serum cholesterol levels and providing antioxidant compounds that reduce oxidative stress and inflammation. In addition, the prebiotic properties of millet dietary fiber enhance gut health by promoting beneficial gut microbiota and improving overall digestive function. Millets are also rich sources of essential micronutrients, especially iron and calcium, which help reduce the prevalence of micronutrient deficiencies such as anaemia and support bone health. Owing to this combination of nutritional and functional attributes, millets have the unique capacity to simultaneously combat undernutrition and lifestyle-

related disorders, positioning them as valuable components of sustainable and health-oriented diets (Anitha *et al.,* 2021; Reddy *et al.,* 2024).

Processing Innovations and Value Addition

Traditional millet processing methods are often labor-intensive, time-consuming, and largely manual, which has historically limited consumer acceptance and large-scale commercialization, particularly in urban markets. Activities such as de-hulling, grinding, and decortication require considerable drudgery, especially for women, and inadequate processing infrastructure has contributed to post-harvest losses and inconsistent product quality. In recent years, however, significant advances in processing technologies—including improved mechanical de-hulling, extrusion cooking, fermentation, and malting—have transformed the millet value chain by enhancing nutrient bioavailability, digestibility, shelf life, and sensory attributes of millet-based foods (Sharma *et al.,* 2023; Devi *et al.,* 2022). These technological interventions not only reduce anti-nutritional factors such as phytates but also improve flavour, texture, and consumer appeal, making millets more compatible with modern dietary preferences. The emergence of diversified ready-to-eat and ready-to-cook millet products, including flakes, noodles, bakery items, snack foods, and functional beverages, has significantly expanded urban and health-conscious consumer demand. Furthermore, the growth of small- and medium-scale processing enterprises and private-sector participation has created new income and employment opportunities across the millet value chain, benefiting farmers, processors, and entrepreneurs alike. Collectively, improved processing and value addition are critical for enhancing millet consumption, market integration, and the economic viability of millet-based agri-food systems.

Constraints in Millet Development: Farmer-Level Challenges

Despite multiple advantages, millet cultivation remains limited due to low yields, inadequate access to improved seed varieties, weak market infrastructure, and limited price assurance. Policy bias toward rice and wheat, combined with insufficient research investment and declining consumer preference for traditional foods, further discourages farmers (Pingali, 2015; FAO, 2023). Lack of decentralized processing units increases post-harvest drudgery, especially for women, reducing the attractiveness of millet cultivation (Reddy *et al.,* 2024).

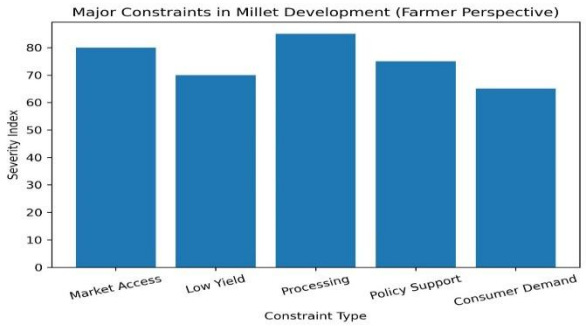

Fig. 2: Major constraints in millet development based on farmer-level severity perception (illustrative index).

Strategies and Solutions for Promoting Millet Cultivation

Effective mainstreaming of millets requires a set of integrated and coordinated interventions across policy, production, processing, and markets. Strong policy support is essential, particularly through assured minimum support prices, public procurement mechanisms, and the inclusion of millets in nutrition and food security programmes, as these measures help stabilize demand and enhance farmer confidence (FAO, 2018; Government of India, 2023). Enhancing productivity through the development and dissemination of improved, biofortified, and climate-resilient millet varieties is critical for sustaining yields under climate variability and improving nutritional quality (ICRISAT, 2021). Equally important is the promotion of processing and value addition at local and regional levels, which reduces drudgery, minimizes post-harvest losses, and generates rural employment opportunities (NITI Aayog, 2018). Alongside these interventions, consumer awareness and market development through nutrition education, branding, and private-sector engagement are vital for increasing acceptance and demand for millet-based products (FAO & WHO, 2019). Collectively, these strategies can enhance farmer incomes while simultaneously delivering improved nutritional security and positive environmental outcomes (Padulosi *et al.,* 2015).

Conclusion

Millets have re-emerged as nutritionally superior, climate-resilient, and socio-economically significant crops, justifying their recognition as modern superfoods. Their rich nutrient composition, functional properties, and low glycaemic index make them effective in addressing malnutrition and lifestyle-related diseases. From an environmental perspective, their resilience to climatic stress and low resource requirements positions them as key components of

sustainable agriculture. However, the full potential of millets remains underutilized due to persistent farmer-level constraints, weak markets, inadequate processing infrastructure, and historical policy neglect. Addressing these barriers through coordinated research investment, supportive policies, value addition, and consumer engagement is essential. Integrating millets into mainstream agri-food systems can simultaneously enhance nutrition security, climate resilience, and farmer livelihoods, particularly in developing economies.

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