ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2026): 4.97
IJAFS 2026; 8(6): 121-128
www.agriculturaljournals.com
Received: 17-03-2026
Accepted: 21-04-2026

Sharmila K
Ayini India Private Limited, Kanchipuram, Tamil Nadu, India

Dr. Karthika Jeyaraman
Ayini India Private Limited, Kanchipuram, Tamil Nadu, India

Corresponding Author:
Dr. Karthika Jeyaraman
Ayini India Private Limited, Kanchipuram, Tamil Nadu, India

Comparative evaluation of traditional and modern processing techniques on nutritional and functional properties of millets in South India

Sharmila K and Karthika Jeyaraman

DOI: https://www.doi.org/10.33545/2664844X.2026.v8.i6b.1585

Abstract
Millets are nutrient-rich, climate-resilient cereal crops that play an important role in food and nutritional security, particularly in South India. Owing to their high content of dietary fiber, minerals, vitamins, and bioactive compounds, millets have gained increasing attention as functional foods for the prevention and management of lifestyle-related disorders. However, the presence of antinutritional factors and processing-related challenges affects their utilization and consumer acceptance. This review examines the influence of traditional and modern processing techniques on the nutritional and functional properties of millets. Traditional methods such as soaking, germination, fermentation, dehulling, decortication, parboiling, roasting, and pounding enhance nutrient bioavailability, improve digestibility, and reduce antinutritional compounds. Modern processing technologies, including microwave treatment, extrusion cooking, puffing, infrared processing, ohmic heating, cold plasma, high-pressure processing, and ultrasound treatment, further improve product quality, shelf life, sensory characteristics, and processing efficiency. The review also highlights the significance of the International Year of Millets 2023 and various Government of India initiatives promoting millet production and consumption. Despite their potential, challenges such as inadequate processing infrastructure, limited millet-specific machinery, and supply chain constraints continue to hinder large-scale utilization. Integrating traditional processing practices with advanced technologies can enhance the nutritional quality and market value of millet-based products, thereby supporting sustainable agriculture, food security, and public health.

Keywords: Millets, processing technologies, nutritional quality, functional properties, traditional processing, modern processing, food security, sustainable agriculture

1. Introduction
Millets are a group of small-seeded cereal crops belonging to the Poaceae family and are widely cultivated in arid and semi-arid regions due to their remarkable adaptability to harsh environmental conditions. These crops have served as traditional staple foods for centuries in many parts of Asia and Africa, particularly in regions where water availability and soil fertility are limited. In recent years, millets have attracted considerable scientific and commercial interest because of their exceptional nutritional composition and their potential role in promoting sustainable food systems.

Compared with major cereals such as rice and wheat, millets possess higher levels of dietary fiber, essential minerals, vitamins, and various bioactive compounds. They are recognized as rich sources of calcium, iron, magnesium, phosphorus, zinc, and B-complex vitamins. In addition, millet grains contain significant quantities of phenolic compounds, flavonoids, tannins, and other phytochemicals that exhibit antioxidant, anti-inflammatory, and disease-preventive properties. Owing to these nutritional attributes, millets are increasingly considered functional foods capable of contributing to the prevention and management of several non-communicable diseases, including diabetes mellitus, cardiovascular disorders, obesity, and certain gastrointestinal conditions [1].

The low glycemic index of most millet varieties has further enhanced their importance in contemporary dietary recommendations. Regular consumption of millet-based foods has been associated with improved glycemic control, enhanced digestive health, reduced serum cholesterol levels, and better overall metabolic health. Furthermore, millets are naturally gluten-free, making them suitable alternatives for individuals suffering from celiac disease or gluten intolerance [2].

Beyond their nutritional significance, millets contribute substantially to agricultural sustainability. These crops require comparatively lower water inputs, exhibit tolerance to drought and high temperatures, and can be cultivated successfully in marginal soils where other cereals often fail to thrive. Such characteristics make millets particularly valuable in the context of climate change, food insecurity, and the increasing demand for resilient agricultural systems.

Despite their numerous advantages, millet utilization remains relatively limited due to the presence of antinutritional factors such as phytates, tannins, and polyphenols, which can reduce nutrient bioavailability. In addition, challenges related to processing, storage stability, consumer acceptance, and value addition have restricted their large-scale commercialization. Processing technologies therefore play a critical role in improving the nutritional quality, sensory characteristics, digestibility, and shelf life of millet-based products.

Traditional processing methods such as soaking, germination, fermentation, dehulling, roasting, and parboiling have long been employed to enhance millet quality and reduce antinutritional compounds. More recently, advanced processing technologies including microwave treatment, extrusion cooking, infrared heating, ultrasound processing, cold plasma treatment, high-pressure processing, and ohmic heating have emerged as promising approaches for improving product quality and expanding the utilization of millets in modern food systems.

Therefore, understanding the influence of both traditional and modern processing techniques on the nutritional and functional properties of millets is essential for maximizing their potential as sustainable and health-promoting food resources. This review critically examines the effects of various processing technologies on millet quality, discusses recent technological advancements, and highlights future opportunities for the development of value-added millet-based products.

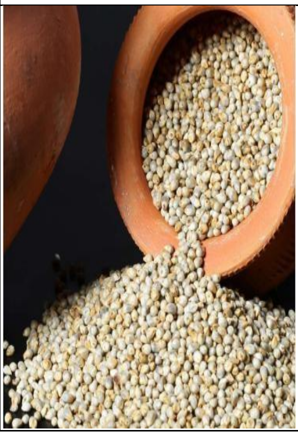
1.1 History and Origin

Millets are among the oldest cereal crops known to humankind and have been cultivated for several millennia across different regions of the world. Historical and archaeological evidence indicates that millet domestication occurred independently in parts of Asia and Africa approximately 8, 000-10, 000 years ago. Excavations conducted in ancient settlements of China and the Indian subcontinent have revealed millet grains and cultivation practices dating back to early agricultural civilizations. The ability of millets to thrive under diverse environmental conditions, including drought-prone and low-fertility regions, contributed significantly to their widespread adoption by ancient societies. These crops served as important staple foods for several early civilizations, including the Harappan civilization of the Indian subcontinent and various dynasties in ancient China. Their resilience, short growing duration, and nutritional richness made them valuable components of traditional farming systems and human diets. Over centuries, millet cultivation expanded beyond its centers of origin and spread throughout Asia, Africa, and parts of Europe. As a result, different millet species adapted to local agro-climatic conditions and became integrated into regional food cultures. Today, millets continue to play a vital role in food security and sustainable agriculture, particularly in regions vulnerable to climate variability and resource limitations.

1.2 Types of Millet

Millets comprise a diverse group of cereal grains that are generally classified into major millets and minor millets based on their cultivation extent, production volume, and economic importance. Major millets include pearl millet (*Pennisetum glaucum*), foxtail millet (*Setaria italica*), proso millet (*Panicum miliaceum*), and finger millet (*Eleusine coracana*), which are widely cultivated and consumed in several countries.

Minor millets consist of barnyard millet (*Echinochloa frumentacea*), little millet (*Panicum sumatrense*), kodo millet (*Paspalum scrobiculatum*), and sorghum (*Sorghum bicolor*). Although cultivated on a relatively smaller scale, these millets possess considerable nutritional value and adaptability to marginal growing conditions. Each millet species exhibits unique nutritional characteristics, processing properties, and agronomic advantages, contributing to their growing importance in sustainable food systems and functional food development.

Millet	Picture	Scientific Name	Common Name	Color	Origin	Key Characteristics
Pearl millet		*Pennisetum glaucum*	Pearl millet, Bajra, Kambu, Sajje, Matza	Color White, grey, pale yellow, brown, or purple.	Tropical West Africa (Sahel)	Nutri cereal high in iron, zinc, and fiber.

Proso millet		*Panicum miliaceum*	Cheena, Common millet, Broom millet, Vari	Color - White cream, yellow, orange	Central and eastern Asia	Rich in antioxidants
Foxtail millet		*Setaria italica*	Italian millet, German millet, Foxtail bristle-grass, Dwarf setaria, and Hungarian millet.	Color - Pale yellow to orange	China	Rich in proteins, fat, dietary fiber, iron, calcium and magnesium
Finger millet		*Eleusine coracana*	Ragi, Mandua, Kodra, Korakan	Color - Light brown to dark brown.	East Central Africa (Uganda)	High in calcium & rich in amino acids
Barnyard millet		*Echinochloa frumentacea*	Bhagar, Sawan, Jhangora, Kudraivali, Oodalu,	Color - White	Japan & India	High fiber, protein and micronutrient rich
Little millet		*Panicum sumatrense*	Kutki, Samai, Samalu,	Color - Grey to straw white	Southeast Asia	Contains high dietary fiber (approx. 37%), which helps manage weight and promotes good digestion.
Kodo millet		*Paspalum scrobiculatum*	Kodara, Ditch millet, Creeping paspalum	Color- Blackish brown to dark brown	India & West Africa	Reduce abnormally high lipid levels and reduce blood pressure.

Sorghum		*Sorghum bicolor*	Milo, Great millet, Durra, and Sorgho	Color - White to brown	Northeast Africa	Rich in iron, phosphorus, potassium, and calcium.

2. Literature Review

Millets have attracted considerable research attention owing to their nutritional richness, climate resilience, and potential role in addressing food and nutritional security. These grains are recognized as excellent sources of dietary fiber, essential minerals, vitamins, and bioactive compounds that contribute to various health-promoting effects [4, 9]. However, factors such as antinutritional compounds, poor shelf-life stability, and processing challenges continue to limit their large-scale utilization. Consequently, extensive research has focused on evaluating the impact of traditional and modern processing technologies on the nutritional and functional characteristics of millets [6, 7].

Traditional processing techniques including soaking, germination, fermentation, roasting, decortication, flaking, and grinding have been reported to improve nutrient bioavailability, digestibility, and sensory quality of millet-based foods [4, 5, 7]. These methods reduce antinutritional factors such as phytates, tannins, and polyphenols, thereby enhancing the absorption of essential minerals including calcium, iron, and zinc [7, 9]. Fermentation has been particularly effective in improving protein digestibility, enhancing micronutrient availability, and extending product shelf life through beneficial microbial activity [4, 7]. Recent studies have highlighted the potential of modern processing technologies to further enhance millet quality and functionality. Thermal and non-thermal processing methods such as microwave treatment, extrusion cooking, infrared heating, ultrasound processing, cold plasma treatment, ohmic heating, and high-pressure processing have demonstrated significant improvements in nutritional quality, antioxidant activity, microbial safety, and storage stability [6, 7]. These advanced technologies also contribute to the development of innovative value-added millet products with improved sensory attributes and consumer acceptance [6]. Technological advancements in millet dehulling and polishing have gained increasing importance because these operations directly influence nutrient retention and processing efficiency. Current dehulling systems primarily operate through compression-shearing, abrasion-friction, or centrifugal-impact mechanisms; however, most available machines are modifications of paddy-processing equipment and are not specifically designed for millet grains [8, 11]. As a result, optimization of millet-specific processing equipment remains essential for improving dehulling efficiency, reducing grain losses, and enhancing product quality [8]. Another major challenge associated with millet utilization is the limited shelf life of millet flour. Pearl millet flour, in particular, is highly susceptible to rancidity due to elevated lipase activity and microbial spoilage during storage [7]. Research has demonstrated that appropriate processing interventions, including decortication and advanced thermal treatments, can effectively reduce enzyme activity, improve storage stability, and extend product shelf life while maintaining nutritional quality [7]. Mechanized processing methods also provide better control over processing conditions and minimize nutrient losses compared to traditional household practices [7].

In addition to technological developments, policy-oriented studies have emphasized the importance of millets as climate-resilient crops capable of supporting sustainable agricultural systems and combating lifestyle-related disorders such as obesity and diabetes [2, 3]. The increasing recognition of millets as nutrient-dense and environmentally sustainable food crops, coupled with initiatives such as the International Year of Millets 2023, has stimulated global interest in millet production, processing, and consumption [2, 3]. Overall, the available literature suggests that the integration of traditional knowledge with modern processing technologies offers significant opportunities for enhancing the nutritional quality, commercial value, and consumer acceptance of millet-based products [4, 6, 7, 8, 9].

3. Traditional Processing Techniques

Traditional processing methods have been practiced for centuries to improve the edibility, nutritional quality, digestibility, and storage stability of millet grains. In many rural and tribal communities, millet processing is still carried out using indigenous techniques such as soaking, germination, fermentation, pounding, roasting, and parboiling. Although modern processing technologies have emerged in recent years, traditional methods continue to play an important role because of their affordability, simplicity, and effectiveness in reducing antinutritional factors and enhancing nutrient availability [4, 7, 9].

3.1 Soaking

Soaking is one of the simplest and most widely adopted household processing methods for millet grains. During soaking, grains are immersed in water for several hours, allowing hydration and activation of endogenous enzymes. This process softens the grain structure, reduces cooking time, and facilitates the leaching of water-soluble antinutritional compounds such as phytates and tannins. Consequently, the bioavailability of essential minerals including iron, calcium, and zinc is improved. Soaking also enhances digestibility and serves as an important pretreatment step for subsequent processes such as germination and fermentation [4, 7, 9].

3.2 Germination

Germination, also known as sprouting, is a biological process that initiates metabolic activities within the grain and substantially improves its nutritional profile. During germination, hydrolytic enzymes become active and promote the breakdown of complex carbohydrates, proteins, and lipids into simpler compounds that are more readily digestible. Studies have reported reductions in tannins, phytates, and polyphenolic compounds following germination, thereby increasing mineral bioavailability and protein digestibility. Germinated millet flours are widely utilized in infant foods and health-oriented products due to their improved nutritional quality and functional properties [4, 7, 10].

3.3 Fermentation

Fermentation is among the oldest food-processing techniques and involves the action of beneficial microorganisms that convert carbohydrates into organic acids and other metabolites. The process improves flavor, aroma, texture, and shelf life while simultaneously enhancing nutritional quality. Fermentation has been shown to reduce antinutritional compounds, improve protein digestibility, and increase the bioavailability of micronutrients. Traditional fermented millet products such as porridges, beverages, and sourdough-based foods are commonly consumed in several Asian and African countries. Owing to its nutritional and sensory benefits, fermentation remains one of the most effective traditional processing techniques for millet utilization [4, 7].

3.4 Decortication

Decortication refers to the partial removal of the outer layers of millet grains through manual or mechanical methods. This process helps eliminate the fibrous husk and improves the palatability and cooking characteristics of millet products. Decortication can also reduce certain antinutritional factors; however, excessive removal of the outer layers may result in losses of dietary fiber, minerals, and bioactive compounds that are concentrated in the bran fraction. Therefore, optimization of decortication is necessary to balance nutritional quality and consumer acceptability [7, 8].

3.5 Dehulling

Dehulling is an essential operation in millet processing, particularly for small millets that possess an indigestible outer husk. The process facilitates the removal of the husk and improves cooking quality, texture, and digestibility. However, nutrient losses may occur during dehulling because portions of the bran layer are removed along with the husk. The efficiency of dehulling depends on grain characteristics, moisture content, and the type of machinery employed. Effective dehulling technologies are therefore crucial for maximizing nutrient retention and processing efficiency in millet-based food production [8, 11].

3.6 Pounding

Pounding is a traditional mechanical process used to remove husk and bran layers from millet grains. It is commonly performed using wooden or stone mortars and pestles. Moistening the grains before pounding facilitates husk removal and improves milling efficiency. Although pounding remains widely practiced in rural communities, it is labor-intensive and often results in inconsistent product quality. Nevertheless, it continues to be an important processing method where access to mechanized equipment is limited [4, 9].

3.7 Parboiling

Parboiling involves the partial cooking of millet grains through steaming before drying and dehulling. This treatment promotes the migration of nutrients from the outer layers into the endosperm and improves grain hardness, thereby reducing breakage during milling. Parboiling also enhances cooking quality, storage stability, and resistance to insect infestation. Furthermore, the process contributes to improved nutrient retention and consumer acceptability of millet-based foods [5, 7].

3.8 Roasting

Roasting is a dry-heat processing technique widely employed to improve the sensory characteristics of millet grains. Exposure to controlled temperatures develops desirable flavors, aromas, and color through Maillard reactions and caramelization processes. Roasting also reduces moisture content, improves shelf life, and enhances digestibility by partially modifying starch and protein structures. Additionally, the process contributes to microbial reduction and the development of unique flavor profiles that increase consumer preference for millet-based products [4, 9].

4. Modern processing techniques

Modern processing technologies have emerged as effective approaches for improving the nutritional quality, functional properties, safety, and shelf life of millet-based products. Compared to conventional methods, these technologies offer better process control, enhanced product consistency, reduced processing time, and improved retention of nutrients and bioactive compounds. Modern processing techniques can be broadly classified into thermal and non-thermal processing methods [6, 7].

4.1 Thermal Processing Technologies

4.1.1 Microwave Technology

Microwave processing utilizes electromagnetic waves to generate heat within food materials through molecular vibration and dielectric heating. This technology has gained considerable attention in millet processing because of its ability to rapidly reduce moisture content, inactivate enzymes, and decrease antinutritional factors while preserving nutritional quality [6, 7]. Studies have reported substantial reductions in lipase activity following microwave treatment, thereby minimizing lipid oxidation and extending the storage stability of millet flour. Microwave heating has also been shown to improve antioxidant activity and facilitate the breakdown of phytates and other antinutritional compounds, enhancing mineral bioavailability. Owing to its energy efficiency, shorter processing time, and environmentally friendly nature, microwave technology is considered a promising tool for value addition in millet-based foods [6, 7].

4.1.2 Extrusion Cooking

Extrusion cooking is a high-temperature, short-time processing technology that combines thermal and mechanical energy to transform raw ingredients into expanded and ready-to-eat products. During extrusion, starch gelatinization, protein denaturation, and structural modifications occur, resulting in improved digestibility and desirable textural characteristics [5, 6, 10]. Processing variables such as feed moisture, screw speed, barrel temperature, and formulation significantly influence the quality of extruded products. Extrusion has been reported to reduce antinutritional compounds, improve water absorption properties, enhance product expansion, and generate appealing sensory attributes. Consequently, extrusion technology is extensively utilized in the development of innovative millet-based snacks, breakfast cereals, and functional foods [5, 6].

4.1.3 Puffing
Puffing is a high-temperature short-time processing technique commonly employed for the production of expanded cereal products. The process involves rapid heating of conditioned grains, resulting in moisture vaporization and expansion of the grain structure. Puffed millet products possess improved texture, enhanced flavor, and increased consumer acceptability [4, 9]. The technique is widely used in the manufacture of ready-to-eat snacks and breakfast foods. In addition to improving sensory properties, puffing modifies starch structure and digestibility, thereby influencing the nutritional and functional characteristics of millet-based products [4, 9].

4.1.4 Infrared Technology
Infrared (IR) processing is an emerging thermal technology that transfers heat through electromagnetic radiation. The method offers rapid and uniform heating with reduced energy consumption compared to conventional thermal treatments. Infrared treatment has been reported to improve microbial safety, reduce spoilage, and extend the shelf life of grains and grain products [6, 7]. Furthermore, infrared processing may enhance dehulling efficiency by altering the structural properties of millet grains before milling. Due to its ability to provide efficient heat transfer while maintaining product quality, infrared technology has gained increasing interest as a pretreatment strategy in millet processing [6, 8].

4.1.5 Ohmic Heating
Ohmic heating, also known as electrical resistance heating, involves the generation of heat within food materials through the passage of an electric current. This technology provides rapid and uniform heating throughout the product, minimizing thermal gradients and reducing processing time [6]. Compared with conventional heating methods, ohmic heating offers advantages such as improved energy efficiency, reduced nutrient losses, and better preservation of sensory attributes. Structural modifications induced during ohmic heating may also influence starch gelatinization, cooking characteristics, and textural properties of grains. These attributes make ohmic heating a promising alternative for the processing of millet-based foods [6, 7].

4.2 Non-Thermal Processing Technologies
4.2.1 Cold Plasma Technology
Cold plasma is an innovative non-thermal processing technology that generates reactive oxygen and nitrogen species capable of modifying food surfaces and inactivating microorganisms. The technology has attracted considerable interest because of its effectiveness in enhancing food safety without causing significant thermal damage to nutrients [6]. In millet processing, cold plasma treatment has been reported to reduce microbial load, modify starch structure, improve functional properties, and decrease antinutritional factors. The technology also contributes to enzyme inactivation and improved storage stability, making it a promising intervention for the development of safe and high-quality millet products [6, 7].

4.2.2 High-Pressure Processing
High-pressure processing (HPP) is a non-thermal preservation technology that subjects food products to pressures ranging from 100 to 800 MPa. The process effectively inactivates spoilage microorganisms and enzymes while preserving the nutritional and sensory quality of foods [6]. Application of HPP to millet-based products has been shown to improve textural stability, reduce retrogradation, and enhance functional properties. Since the treatment involves minimal thermal exposure, valuable nutrients and bioactive compounds are better retained compared to conventional thermal processing methods. HPP therefore represents a sustainable and effective technology for the production of high-quality millet foods with extended shelf life [6].

4.2.3 Ultrasound Processing
Ultrasound processing utilizes sound waves above the audible frequency range to induce physical and chemical changes in food systems through cavitation phenomena. High-intensity ultrasound generates localized pressure and temperature changes that improve mass transfer, modify starch structures, and enhance hydration properties [6, 7]. Research has demonstrated that ultrasound treatment can improve water absorption, increase solubility, enhance functional characteristics, and reduce processing time in millet products. Furthermore, the technology offers opportunities for improving texture, digestibility, and product quality while maintaining nutritional integrity. As a result, ultrasound has gained increasing attention in the development of innovative millet-based foods and bakery applications [6, 7].

Modern processing technologies offer substantial opportunities for improving the utilization of millets in value-added food products. The integration of these advanced approaches with traditional processing practices can contribute to enhanced nutritional quality, improved shelf life, greater consumer acceptance, and sustainable industrial-scale production of millet-based foods [6, 7, 8].

5. International year of millets 2023: Initiatives and proposed activities
The Indian government proposed to the United Nations for declaring the year 2023 as the International Year of Millets (IYOM). With the support of 72 other countries, the United Nations General Assembly (UNGA) officially declared 2023 as the International Year of Millets on March 5, 2021. The initiative of the Indian government for celebrating IYOM 2023 involves increasing awareness of the nutritional benefits of millets and enhancing the acceptability of value-added millet products across the country and around the world. The International Year of Millets offers a significant opportunity to:

- Enhance the contribution of millets to food security.
- Increase global millet production.
- Improve efficiency in processing, transport, storage, and consumption of millets.
- Promote sustainable production practices and ensure millet quality with the involvement of stakeholders (APEDA, 2023).

6. Government initiatives for millet promotion
Recognizing the nutritional, environmental, and economic significance of millets, the Government of India has implemented several initiatives to promote millet cultivation, processing, value addition, and consumption. These efforts aim to enhance farmers' income, improve

nutritional security, and encourage the adoption of climate-resilient crops in sustainable agricultural systems.

One of the major initiatives was the Initiative for Nutritional Security through Intensive Millet Promotion (INSIMP), launched under the National Food Security Mission (NFSM). The program focused on increasing millet productivity through the distribution of quality seeds, improved agronomic practices, and financial support to farmers. Subsequently, millet development activities were integrated into the National Food Security Mission (NFSM) to expand millet cultivation across different agro-climatic regions of the country.

The National Mission for Sustainable Agriculture (NMSA) promotes millet cultivation due to its low water requirement, drought tolerance, and adaptability to marginal lands. Similarly, the Rainfed Area Development Programme (RADP) encourages millet-based farming systems in rainfed regions, thereby enhancing livelihood security and resource-use efficiency. The Rashtriya Krishi Vikas Yojana (RKVY) provides financial assistance to states for the development of millet production, processing infrastructure, and value-added products.

The declaration of 2023 as the International Year of Millets (IYM 2023) by the United Nations, following India's proposal, further accelerated millet promotion activities. Various awareness campaigns, farmer training programs, research initiatives, exhibitions, and market development activities were organized to increase consumer awareness and global demand for millet-based products. In addition, government schemes such as the Public Distribution System (PDS), Mid-Day Meal Scheme, and Integrated Child Development Services (ICDS) have increasingly incorporated millets to improve dietary diversity and nutritional outcomes. These initiatives collectively contribute to strengthening millet value chains, supporting rural livelihoods, and promoting sustainable food systems.

7. Challenges and future prospects

Despite their recognized nutritional and environmental benefits, several challenges continue to limit the large-scale production, processing, and commercialization of millets. One of the major constraints is the lack of specialized processing technologies and machinery designed specifically for different millet varieties. Most existing processing equipment is adapted from rice or wheat processing systems, resulting in lower processing efficiency and higher grain losses. Inadequate infrastructure for storage, transportation, and post-harvest handling further contributes to quality deterioration and economic losses. Millets are susceptible to moisture absorption, lipid oxidation, insect infestation, and fungal contamination during storage, which adversely affects shelf life and consumer acceptability. Furthermore, the fragmented supply chain and limited market linkages restrict the availability of millet-based products in mainstream markets.

Consumer-related factors also present significant challenges. Although awareness of millet health benefits has increased, many consumers remain unfamiliar with millet-based foods due to traditional perceptions, limited product diversity, longer preparation times, and sensory preferences favoring refined cereals such as rice and wheat. Additionally, the availability of subsidized cereals through government distribution systems often reduces the economic competitiveness of millets. Future research and development should focus on the design of millet-specific processing technologies, development of innovative value-added products, optimization of non-thermal processing methods, and enhancement of storage stability. Emerging technologies such as cold plasma, high-pressure processing, ultrasound treatment, and artificial intelligence-assisted process optimization offer considerable opportunities for improving product quality and industrial scalability. Strengthening market infrastructure, promoting consumer awareness, and encouraging public-private partnerships will be crucial for expanding millet consumption and ensuring sustainable growth of the millet sector.

8. Conclusion

Millets are nutrient-dense, climate-resilient cereal crops that possess significant potential to contribute to global food and nutritional security. Their rich composition of dietary fiber, proteins, minerals, vitamins, and bioactive compounds makes them valuable ingredients for the development of functional and health-promoting foods. However, the presence of antinutritional factors and challenges associated with processing and storage necessitate the adoption of suitable processing technologies. Traditional processing methods, including soaking, germination, fermentation, dehulling, decortication, parboiling, and roasting, have been widely used to enhance nutrient bioavailability, improve digestibility, and reduce antinutritional compounds. Recent advancements in processing technologies such as microwave treatment, extrusion cooking, infrared heating, ohmic heating, cold plasma, ultrasound, and high-pressure processing have further improved the nutritional quality, shelf life, safety, and sensory attributes of millet-based products. Nevertheless, excessive processing may result in the loss of valuable nutrients and dietary fiber, highlighting the need for optimized processing conditions.

The growing global emphasis on sustainable agriculture, coupled with government initiatives and increasing consumer awareness, has created new opportunities for millet-based food systems. Integrating traditional knowledge with advanced processing technologies can facilitate the development of nutritious, safe, and value-added millet products while supporting environmental sustainability, farmer livelihoods, and public health. Continued research, technological innovation, and policy support will be essential to fully realize the potential of millets as future-ready crops for resilient and sustainable food systems.

References

1. Jaybhaye RV, Pardeshi IL, Vengaiah PC, Srivastav PP. Processing and Technology for Millet Based Food Products: A Review. 2014.
2. Shahla K. Millets in Food Policy and Promotion. 2024.
3. Narayan Jadhav, Deepak J Londhe. Policy Support for the Promotion of Millets: Current Status and Its Impact. 2023.
4. Ahmed SM Saleh, Qing Zhang, Jing Chen, Qun Shen. Millet Grains: Nutritional Quality, Processing, and Potential Health Benefits. 2013.
5. Rasika A, Chavan SM, Jayant Ghatge, Sravya Gopi, Prathapan K. Review Paper on Millet: Production, Nutrients, Processing, and Food Products for Health and Sustainability. 2024.
6. Nanje Gowda NA, Kaliramesh Siliveru, Vara Prasad PV, Yogita Bhatt, Netravati BP, Chennappa Gurikar.

Modern Processing of Indian Millets: A Perspective on Changes in Nutritional Properties. 2022.
7. Janani Latha Ravi, Sandeep Singh Rana. Maximizing the Nutritional Benefits and Prolonging the Shelf Life of Millets through Effective Processing Techniques: A Review. 2024.
8. Shagolshem Mukta Singh, Jayasree Joshi T, Srinivasa Rao P. Technological Advancements in Millet Dehulling and Polishing Process: An Insight into Pretreatment Methods, Machineries and Impact on Nutritional Quality. 2024.
9. Laraib Yousaf, Dianzhi Hou, Humna Liaqat, Qun Shen. Millet: A Review of Its Nutritional and Functional Changes During Processing. 2021.
10. Sneh Punia Bangar, Shweta Suri, Santanu Malakar, Nitya Sharma, William Scott Whiteside. Influence of Processing Techniques on the Protein Quality of Major and Minor Millet Crops: A Review. 2022.
11. Singh, *et al*. Technological Advancements in Millet Dehulling and Polishing Process. 2024.