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Divulging Millets: Types, Nutritional Value, Processing Methods and Applications in Processed Food: A Review

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ABSTRACT

Millet grains are beneficial, because they are known as climate-resilient crops; their yield is exceptionally good in areas that are known for water scarcity. It is highly nutritious and its uptake can fight diseases. The main issue with low nutrient content in underdeveloped nations is that cereal-based meals have low bioavailability of minerals like iron and zinc, which causes substantial issues in newborn infants. Food processing procedures improve the nutritional content and bioavailability of food components. Millets are small and round and have a high nutritional content, consisting of carbohydrates (60 to 70%), proteins (7 to 11%), crude fiber (2 to 7%) and fats (1.5 to 5%). In hyperglycemia, millet can reduce glucose *via* the enzymatic hydrolysis of complex carbohydrates. Millets also reduced the chances of heart attack, as they are reliable sources of magnesium. Millets are a good source of phyto-chemicals that help control cholesterol and prevent cardiovascular diseases. Currently, there are distinct methods for processing food. The incorporation of millets in different processed foods is improving people’s health. The methods used for the processing of millet are fermentation, malting, milling and soaking. It is true that considerable efforts have been invested in millet because of its high nutritional value, but its application is still challenging and limited due to its short shelf life. The present review illustrates the different types of millet, its nutritional advantages and challenges surrounding millet-based food, highlighting key methods of processing that could by employed for millet food improvement.

Key words: Method of processing, Millet foods, Millets production, Nutritional value, Processed food, Types of millets.

Millets, often called climate-resilient crops, are small-seeded cereals classified as “secondary seeds” alongside maize and sorghum. Though staple foods in Asia and Africa, they are underutilized in Western diets (Amadou, 2022). Their ability to thrive in harsh conditions-drought, low rainfall and high temperatures-makes them valuable in sustainable agriculture (Hassan *et al*., 2021). Key millet varieties include Pearl (Bajra), Finger (Ragi), Foxtail, Proso, Kodo, Samai and Banti, commonly grown in Asian and African countries. Nigeria and Ethiopia also grow unique strains like Fonio and Tef (Table 1). In recognition of their importance, the UN declared 2023 the “International Year of Millets” (Datta Mazumdar *et al*., 2022). As global hunger and malnutrition rise, millets offer a solution due to their rich nutrient content and low input requirements (Bookwalter *et al*., 1987; Birania *et al*., 2020). In 2010, global millet production reached over 762,000 metric tonnes, with India as the leading producer at approximately 334,500 tonnes (Fig 1). This review highlights the different types of millets, their nutritional composition, millet-based food products and various processing methods.

Types of millets

Pearl millet

Pearl millet, also known as *Pennisetum*, is grown for food in subsistence farming in Africa and India. It covers over 26 million hectares on the Indian subcontinent, yielding 500-600 kg of grain per hectare on average. A crop with a high degree of cross-pollination and yearly tillering diploid (2n = 14) is pearl millet (Hassan *et al*., 2021). Pearl millet is an advantageous crop because it can be grown in places with little resources or in harsh weather, including Rajasthan,

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northwest India and hot, semiarid region (Gowda *et al*., 2022). Drought, heat and depleted, acidic sandy soils with less clay and organic matter are among the other benefits (Dhankar and Chauhan, 1987). Nonetheless, semiarid tropical climates can support the growth of this crop. Pearl millet is mostly used to make porridges and flat, unleavened breads, which are traditional foods (Dhankher and Chauhan, 1987).

Finger millet

Finger millet is a grain crop used for food in Africa and Asia, mostly in different states of India, such as Belhar, Uttar Pradesh, Tamil Nadu, Karnataka and Andhra Pradesh, as well as Nepal (Sood *et al*., 2019). This millet has eight species that are both perennial and annual and belongs to the genus *Eleusine*. This crop takes almost 3 to 6 months to mature and is an annual tuft growing from approximately 40 to 150 cm in height (Hassan *et al*., 2021). Finger millet grows on tropical soils, ranging from red lateritic to sandy loams to black heavy vertisols, in arid areas with 500 mm of annual rainfall (Rathore *et al*., 2019). It can be stored for many years with less insect damage and low loss of viability, as it is an excellent subsistence food crop. Finger millet grain can be used in many ways such as for breads, porridges and fermenting into malt. It is rich in critical amino acids and has a sixteen times greater level than maize (Gowda *et al*., 2022).

Proso millet

Proso millet is commonly known as “Bari” in India. Proso millet was introduced in North America in 1875 by German Russian immigrants. It contains adventitious roots and several shoots. It is a self-pollinating plant, but more than 10% of it is cross-pollinated. Its seeds are smaller than

Table 1: Distinct type of millet crops in India (Gaikwad *et al.* 2021, Bunkar *et al*., 2021).

English names	Species	Local names	States majorly producing millets
Pearl millet	*Pennisetumglaucum*	Bajra	Tamil Nadu, Rajasthan, Uttar Pradesh, Haryana, Gujarat and Maharashtra
Finger millet	*Eleusine coracana*	Ragi, Mandua	Karnataka, Uttarakhand, Tamil Nadu, Maharashtra Andhra Pradesh
Foxtail millet	*Setariaitalica*	Kangni	Tamil Nadu, Uttar Pradesh, Rajasthan, Maharashtra, Karnataka, Andhra Pradesh and Arunachal Pradesh
Kodo millet	*Paspalum scrobiculatum*	Kodra, Harika	Madhya Pradesh, Uttar Pradesh, Chhattisgarh, Tamil Nadu and Maharashtra
Little millet	*Panicum miliare*	Kutki, Sama	Madhya Pradesh, Tamil Nadu, Chhattisgarh, Karnataka, Jharkhand
Barnyard millet	*Echinochlo spp*	Sanwa, Shyama	Uttarakhand, Arunachal Pradesh, Madhya Pradesh, Tamil Nadu, Uttar Pradesh, Nagaland
Sorghum	*Sorgum bicolor*	Jowar	Tamil Nadu, Madhya Pradesh, Andhra Pradesh, Maharashtra and Karnataka
Proso millet	*Panicum miliaceum*	Cheena, Bari	Maharashtra, Bihar, Odisha, Rajasthan, Tamil Nadu

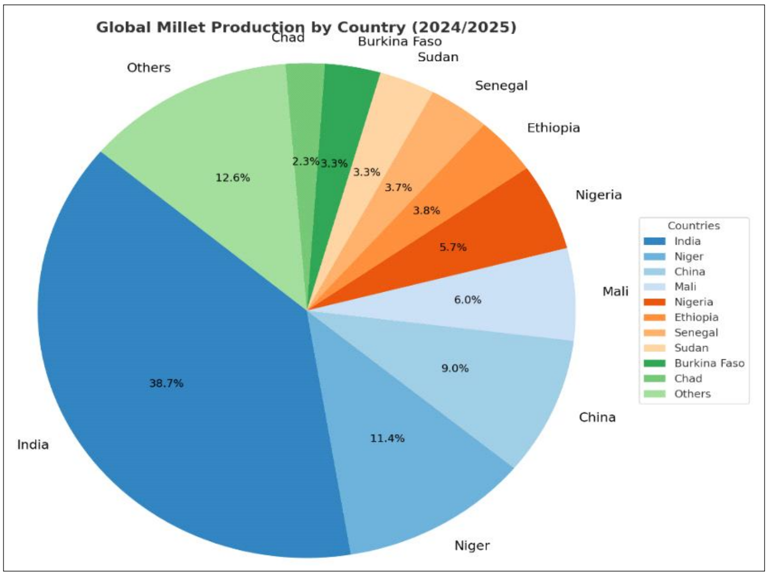

Fig 1: Worldwide Production of Millet (Export Development Authority for Agricultural and Processed Food Products (APEDA).

those of pearl millet and sorghum and are usually oval, approximately 3 mm long and 2mm wide. The seed varies from white cream to yellow, orange, red and black to brown (Gowda *et al*., 2022). It is gluten free and is used in diverse types of food products due to its nutritional value. Proso millet has high niacin content and it is beneficial for preventing pellagra disease caused by the vitamin B3 niacin (Bangar *et al*., 2021).

Foxtail millets

The foxtail millet crop is grown in arid and semiarid regions of Africa and Asia, as well as in other economically developed countries and is used as bird feed. It is also known as the early cultivated crop. It is a small diploid C4 panicoid crop species with a small stature and different accessions vary from 20 to 215 cm tall. Foxtail millet is more water efficient than other millet varieties and produces a good yield (Yang *et al*., 2022). Foxtail millet is a hardy and nutritious pest crop that is grown every year and its seed health-promoting features result in a unique protein composition with a high concentration of essential amino acids. Setarins, which are proline-rich and alcohol-soluble proteins, make up the majority of foxtail seeds. It is constituted of 60% of total proteins and has a lower proportion of disulfide cross-linked proteins, which is higher than that of other cereals and millet (Gowda *et al*., 2022).

Barnyard millets

Barnyard millet is called the “Oldest Millet of India.” This millet was grown in two different agro-ecosystems in India: one in Tamil Nadu’s Deccan Plateau and another in Uttarakhand north-mid hills. Barnyard millet is the second most important crop in India after finger millet, with a productivity of approximately eighty-seven thousand tons (Avantika *et al*., 2025). The straw of barnyard millet can be given as fodder to animals because it is rich in protein and calcium. Barnyard millet is composed of approximately 11.1% to 13.9% protein and 65% carbohydrates in the form of polysaccharides and dietary fiber. Barnyard millet is considered most effective in preventing constipation, reducing blood cholesterol, slowing blood flow during digestion and reducing blood glucose and lipid levels (Lydia Pramitha *et al*., 2023).

Kodo millet

Kodo millet originated in India and is commonly called Araka. Kodo millet should be cultivated in areas near or in tropical and subtropical regions. It is widespread in arid and semiarid regions of Indian and African countries and grows easily in poor soils. Kodo beans are also noted for their nutritional content, which includes 8.35% protein, 1.45% fat, 65.65% carbs and 2.95% ash. It is a good reserve for starvation and areas where food is not easily available. Kodo millet is rich in dietary fiber, polyphenols, protein and calcium (Lydia Pramitha *et al*., 2023). Magnesium can reduce migraines and heart attacks and Kodo millet is a reliable source of magnesium. Food technologists and nutritionists are increasingly interested in this millet due to its several health advantages and ability to fight many diseases (Dekka *et al*., 2023).

Little millet

Little millet is known as *Panicum sumatrense;* among the minor millet, it is the most popular crop in southern Karnataka and is called “saave or same”. The yield of little millet is extremely low due to its cultivation on marginal and sub marginal lands and negligence in its cultivation practices. Presently, in India, it is grown on more than half a million hectares (Dekka *et al*., 2023). It is a useful source of minerals, vitamins, carbohydrates (approximately 67.0 g/100 g), fat (4.79 g/100 g) and protein (7.7 g/100 g). Although little millet is small, it is more nutritious than other grains (Sabuz *et al*., 2023). It contains high levels of calcium, iron, zinc and potassium as well as good amounts of vitamin B. The most important advantage of this millet is that it has high fiber content, which is a good substitute for rice (Niharika *et al*., 2020).

Sorghum

Sorghum, often known as tropical cereal grass, is the fifth most important cereal crop by cultivated area and production. This crop is grown in poorly irrigated areas that suffer from low rainfall and drought, where crops are not suitable for cultivation. Sorghum is cultivated as food and fodder; however, millet is produced entirely for food. Sorghum is a reliable source of calories and protein for people in Africa and Asia. Globally, 39% of sorghum is consumed as food and approximately 54% is used as animal feed. The sorghum species is bicolor and varies from white and yellow to brown, red and black. Phenolic compounds are present in all sorghum with vitamin B (Kumar *et al*., 2018).

Agricultural significance of millets

The demand for food has increased dramatically with the growing world population. Compared with millet, 50% of the total caloric intake comes from rice, wheat and corn, which are the most important staples (Bora, 2013). Millet cultivation can be a solution to this problem because millet can grow with little irrigation on soils with low fertility and acidic to alkaline soils with a pH between 4.5 and 8 and is characterized by obvious nutritional benefits (Amadou, 2022). Rice plants grow poorly and yield relatively little on saline soils with salinities greater than 3 dS/m. As an alternative to rice, pearl millet and crabgrass can grow on saline soils with salinities of up to 11-12 dS/m. Millet is also a suitable alternative for grain growth and can grow in acidic soil. Millet is a climate-resilient crop and has low water requirements during the growing season (Awasthi *et al*., 2025). Millet belongs to the C4 grain category, which absorbs more carbon dioxide from the environment and turns it into oxygen, making it water efficient, so it requires less input and is more environmentally friendly. This proves that sorghum can help fight climate change and drought and reduce carbon dioxide levels in the atmosphere (Dekka *et al*., 2023) (Table 2).

Nutritional value of millets

India has more undernourished countries and approximately 15.2% of the population of India falls into this category. According to the Global Hunger Report of 2017, India holds the 10th position among the 119 countries that are undernourished (Mahajan *et al*., 2021). India is a staple food in some areas and ranks sixth in the world for agricultural grain production when compared to Bangladesh, Sri Lanka and Nepal. They can aid in the global fight against vitamin deficiencies because they are a rich source of vital nutrients (Sabuz *et al*., 2023).

Macronutrients

Millet has a special place in terms of nutrition because it is superior to major cereal grains (Lydia Pramitha *et al*., 2023). Millets are high in fibre, low in glycemic index, rich in bioactive components and gluten-free proteins that are good for your health (Bora *et al*., 2019). Incorporating both types of millet into a diet can provide a variety of health benefits, from improving bone health and muscle repair to supporting weight management and blood sugar control (Amadou, 2022). The proteins contained in millet are rich in essential amino acids such as lysine, valine and methionine and like millet, millet contains approximately 44.7% of the total amino acid content (Gowda *et al*., 2022). Finger millet had the lowest lipid content, while pearl millet had the greatest (Bookwalter *et al*., 1987). Crude fibre and dietary fibre are present in millets, such as barnyard millet, which has an average crude fibre content of 12.8 g/100 g (Shahidi and Chandrasekara, 2013). The largest percentage of dietary fibre is present in small amount in Kodo millet, at 38% and 37%, respectively. This shows that millet is a low-glycemia food and hence good for the health of diabetic patients (Saleh *et al*., 2013). Soluble polysaccharides are potent prebiotics that are present in finger millet (Amadou *et al*., 2011).

Micronutrients

The nutrients that are present at extremely low levels are called micronutrients. Minerals and vitamins are in this category because they are especially important for normal body functions, such as building bones, clotting of blood, signaling processes, oxygen transportation, production of cell energy, maintaining a normal heartbeat, fat and protein synthesis, providing immunity to the body and helping the nervous system function normally (Chandrasekara *et al*., 2012). Millet has a higher mineral content (1.7 to 4.3/100 g) than both rice and wheat. Osteoporosis is a disease that occurs due to iron deficiency and an enormous number of people are suffering from this disease. Finger millet is a thorough source of calcium and helps in preventing osteoporosis (Birania *et al*., 2020). Pearl millet and barnyards are the main sources of iron for expectant mothers and help avoid anaemia (Bookwalter *et al*., 1987). Vitamin B, such as riboflavin, niacin, folic acid and beta carotene, is present more in millet than in rice and wheat. The foxtail millet had a greater thiamine content of approximately 0.60 mg/100 g. This shows that adding millet to the diet can help overcome nutrient deficiencies (Bangar *et al*., 2021) (Table 2).

Millet processing methods

There are different methods for processing millet (Fig 2).

Decortication or dehulling

The dehulling technique is called decortication; in this technique, pericarp is removed from cereal grains by using texture, color and cooking quality (Joshi *et al*., 2023). The crucial process of decortication keeps the endosperm of the millet intact and removes just the pericarp, which has the highest concentration of polyphenols (Chandrasekara *et al*., 2012 and Malleshi, 1989). In this method, 12-30% of the kernels are removed. Loss of fibre, ash and fat is the result of over decoration. Thus, phytates are significantly reduced by the decortication process. Protein, insoluble fibre, ash, fat, lysine and a few other amino acids are also lost at the same time. This process increases starch digestibility by removing amylase inhibitors (Birania *et al*., 2020).

Milling

Millet, which is widely grown in our country, is the basis of nutrition for the most part, so it is less popular and due to the lack of milling technology, is not suitable to produce

Table 2: Acceptability of millet parameters (Bora, 2013).

Millet: A climate resilient crop and an alternative for Sustainable Agriculture and Healthy world			
In security of Food	For nutritional safety	From disease safety	For economic safety
1. Resistant to	1. Rich in amino acids climatic stress, pests and diseases.	1. It is gluten free: Good and bioactive compounds.	1. Climate Resilient for celiac disease.
2. Excellent food income for farmers. world climate.	2. Source of micronu source for combating	2. Low GI: Preferable for -trients like calcium, hunger in challenging 3. Can help to fight with anemia,calcium defici- ency *etc*.	2. Good source of diabetic people. iron, zinc,iodine, *etc.* 3. Low maintenance. 4. Value addition can gains lead to economic.

(Chandraseara *et al*., 2012). The main use of millet is its fibrous and thick husk, astringent taste, color pigments and poor shelf life. Hammer mills or roller mills are generally used for grinding grains, but hammer mill flour contains coarse particles and is not homogeneous; thus, it is impractical to prepare fine, solid porridges with rough textures or steamed flour-baked oatmeal (Birania *et al*., 2020). According to one study, milling modifies the chemical makeup of raw millet (Liang and Liang, 2019). Furthermore, during the process of making chapatti, milling and heat treatment lower the quantities of polyphenols and phytic acid while greatly enhancing the protein and starch's digestibility (Tanwar *et al*., 2025).

Malting

Grain germination with regulated moisture conditions is known as malt. Following these procedures, abrasives are used to remove the vegetative growth from the beans and they are dried in an oven (Adebiyi *et al*., 2018). This technique increases the digestibility of millet in terms of starch and protein content and the increase in yield is much greater during germination than during balancing (Mahajan *et al*., 2024; Dagadkhair *et al*., 2025). The digestibility of millet protein is enhanced by the above malting steps and helps reduce nutrients such as tannins, phytic acids and polyphenols that interact with protein-forming complexes (Rathore *et al*., 2016). Malting has many advantages that can be combined with malt to fortify grains, allowing us to produce healthy and nutritious products such as baby food, food mixes and dietary supplements (Amadou, 2022).

Fermentation

Due to food storage problems, fermentation is widely used. Enzymes found in the grains break down starch and soluble sugars as fermentation progresses (Hassan *et al*., 2021). Pearl millet was fermented for nine hours, which decreased the amount of phytic acid by 27-30% and the number of polyphenols by 10-12% (Mahajan *et al*., 2024). These grains are soaked before sprouting and fermentation. A longer germination and fermentation time leads to increased amylase production and increased levels of soluble sugars (Birania *et al*., 2020). According to the literature, hydrolysis and enzymatic fermentation, either alone or in combination, are very promising for obtaining foods with high nutritional value (Kumar *et al*., 2021).

Soaking and cooking

Grain soaking is a useful method that is often used to minimize non-nutrient content and increase mineral bioavailability (Suman and Chandra, 2025). After the maceration process, studies on leaching and phytate degradation were carried out to determine the activity and concentration of zinc and iron in flours, peels and whole seeds. However, soaking flour in water does not usually increase phytate breakdown (Rathore *et al*., 2019; Hassan *et al*., 2021). Millet is husked, soaking and subsequent cooking reduce the nutrient content, improve the bioavailability of the mineral and improve protein digestibility in vitro (Dekka *et al.,* 2023). Thus, soaking and heating can be used as a pre-treatment to improve the nutrient bioavailability and nutritional quality of millet products when ideal conditions for lowering antinutrient in millet occur (Liang and Liang 2019).

Millet-based products

Composite flour

Although millet has a greater nutritional value than grain, it can be increased by mixing it with wheat flour, although its use has not increased much (Dekka *et al*., 2023) and from this mixture, nutritional, physical, chemical and functional changes occur (Fig 3). Extruded products such as macaroons, spaghetti, *etc.,* made from extruded millet and cowpea mash (pressure-dried) have greater nutritional value and acceptable properties for weaning foods (Poornakala, 2022). Instead of corn and wheat flour, millet, buckwheat and amaranth are used to make extruded snacks (Liang and Liang, 2019).

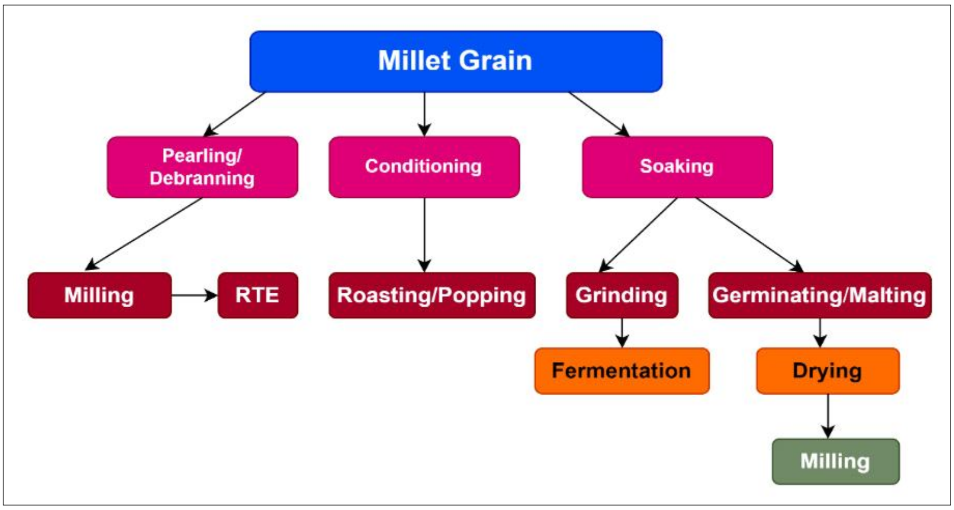

Fig 2: Schematic diagram of the processing of millets (Bora *et al*., 2019).

Baked products

Baked goods are gaining increasing popularity around the world due to their varied taste, inexpensive price and lean texture, as well as attractive packaging and long shelf life that suits marketing (Poornakala, 2022). Similarly to Millets Proso, foxtail and sorghum can be used in baking, but this approach is not applicable for pearls millet because there is no gluten in the pearl millet, resulting in poor consistency of the dough, so it is not regarded as a suitable raw ingredient for baking bread (Sharma *et al*., 2023). However, after processing, the pearl millet flour, i.e., hydrating, drying and supplementing with unrefined soy lectin, yielded better results and the spreadable biscuit dough was comparable to soft wheat flour biscuits (Bora, 2013).

Extruded products

Ready-to-eat items are being made with extrusion more frequently. For a brief period of time, cereals are cooked at an elevated temperature (Liang and Liang, 2019). There are many benefits to using this technology, including increased productivity, adaptability, excellent quality and improved in vitro protein digestibility (Mahajan *et al*., 2021). Premium-quality millet-based extruded snacks can be made with the combination of a 70/30 blend of millet and cowpea; a mixture of millet, such as pearl millet and sorghum, or a mixture of soy, ragi and rice can produce good, extruded products, such as noodles and vermicelli (Dekka *et al*., 2023).

Fermented products

The most common fermented South Indian foods in India are Idly and Dosa. The chemical nature of millet grains is altered during the fermentation process, making the food that results more nutrient-dense (Hassan *et al*., 2021). This process also helps to reduce the level of anti-nutritional components and increases the digestibility of proteins *in vitro* (Mahajan *et al*., 2024).

Flakes and pops

The CFTRI Mysore carried out research on sorghum peeling using a number of standardized factors, including temperature, wet heat, soaking time and dry heat treatment conditions (Poornakala, 2022). Moisture-balanced soaked kernels are roasted to a level when the starch has completely gelatinized and dried, bagged, shelled and finally rolled into flakes over time (Sharma *et al*., 2023). During cleavage and swelling, structural alterations take place in the starch or protein matrix (Deevi *et al*., 2024). Preconditioned millet or dough starch causes grains or dough pieces to swell upon puffing, resulting in a puffed product with high crispness and other textural characteristics (Liang and Liang, 2019).

Difficulties in the production of millet

Reduction in the area used for millet farming

Historically, millets grew on 35 million hectares of land. (Joshi *et al*., 2025). The 2019-20 fiscal years saw 54 million tons of grains supplied through school lunches, the Public Distribution System (PDS) and the Integrated Child Development Scheme (ICDS). To replace 20% of wheat and rice, the state would need to buy 10.8 million tons of millet (Kumari *et al*., 2025).

Low productivity

Over the last ten years, there has been a decrease in the production of sorghum, a plateau in the output of pearl millet and a stagnation or drop in the production of other millet including finger millet (Ceasar *et al*., 2024; Vinoba *et al*., 2025).

Shelf-life hurdles

Millets foods offer numerous health benefits and nutrients-rich that making them excellent choice for balance diet (Kumari *et al*., 2025). Additionally, moisture and water activity can further degrade the quality of millet goods. Therefore, various pre-treatments and storage settings have a

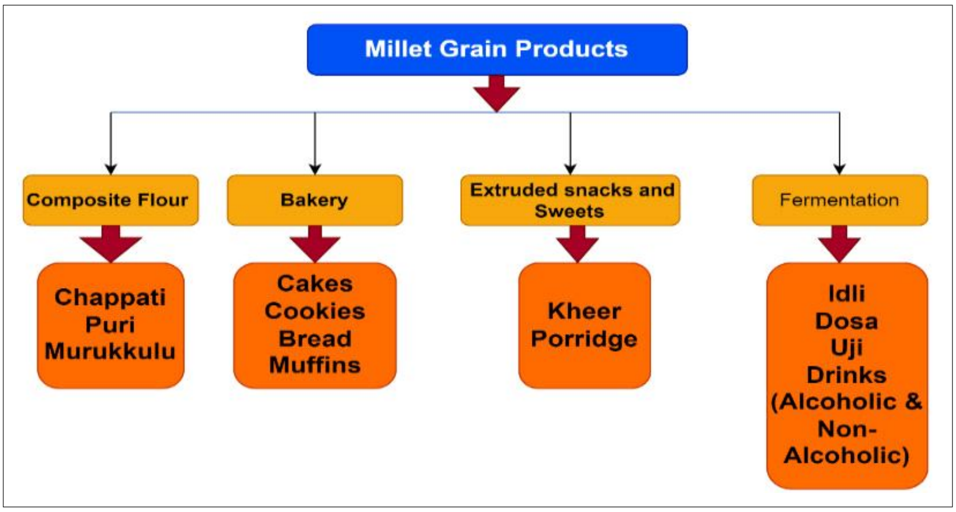

Fig 3: Diagrammatic representation of making composite foods based on millet (Bora *et al*., 2019).

significant impact on guaranteeing the quality assurance of millet goods (Kaur *et al*., 2024; Jiang *et al*., 2023).

Promising potentials of millets

Climate-resilient crop

Millets offer an effective, sustainable solution for food security in regions facing climate change, especially those prone to drought (Dixit and Ravichandran, 2024).

Nutrients rich

Millets are a highly nutritious, whole grain that provides essential vitamins, minerals, fiber and protein (Chandrasekara *et al*., 2012).

Absence of gluten

Millets are naturally gluten-free, making them an excellent alternative for people who have celiac disease or are gluten sensitive (Ramashia *et al*., 2025).

Adaptable

Because millets may be cultivated in a range of soil types and climates, they provide farmers with a flexible crop alternative (Jaybhaye *et al*., 2014).

Sustainable

Traditional agricultural practices that are environmentally benign and sustainable are frequently used to raise millets and India offers an extensive selection of hybrids and varieties (Yi *et al*., 2022).

Research and innovation

Worldwide, truly little research has been conducted on millets to improve yield qualities and plant variety resilience to biotic and abiotic stress (Du *et al*., 2024; Maharajan *et al*., 2024; Aliveni *et al*., 2025). The project involves a network of 13 research centers, distributed across 22 cooperative centers, the Indian Council of Agricultural Research (ICAR) institutes and State Agricultural Universities (SAUs). Planning, organizing and conducting research projects to raise the yield and productivity of all millets, large and tiny, fall under the purview of AICRP-tiny Millet (Bangar *et al*., 2022; Harish *et al*., 2024; Sharma *et al*., 2025). The project's research focus is on creating agricultural production technologies that are suitable for regional and national demands in order to enhance productivity (Sabuz *et al*., 2023). Higher returns were achieved by using institutions tiny millet, which produced high-yield cultivars that were resistant to blast disease, had superior nutrition, were early and mid-maturing, had white and bright-seeded finger millet, were resistant to collaring and reluctance in domestic millet and were resistant to shoot flies in proso and tiny millets. So far, India has released six small millets, containing 250 varieties (Gebreyohannes *et al*., 2024).

CONCLUSION

Millets are nutrient-rich, gluten-free cereals with significant potential for commercial food products. This overview highlights millet types, regional availability, processing methods and their role in product development. Advanced processing enhances both micro- and macronutrient content, making millets suitable for diverse dietary needs, including celiac disease. Their affordability, climate resilience and health benefits support their use in combating malnutrition and food insecurity. Increased public awareness, research into high-yield varieties and supportive policies can further promote millet consumption and boost rural economies.

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Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

Conflict of Interest

The authors declare no conflict of interest.

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