Journal of
Food Chemistry & Nanotechnology

https://doi.org/10.17756/jfcn.2025-s2-009

Review Article

Open Access

Millets: A Nutritional Powerhouse for Food Security and Pharmaceutical Applications

Ishaan Garach[1], Pratik Vediya[1*], Udit Trivedi[1], Kaushik Kapuriya[2] and Hiral Kapuriya[3]

[1]*School of Pharmacy, RK University, Gujarat, India*
[2]*Pharmacist, Unit Hospital, Gujarat*
[3]*Faculty of Pharmacy, Marwadi University, Gujarat*

[*]Correspondence to:
Pratik Vediya
School of Pharmacy,
RK University,
Gujarat, India.
E-mail: pratikvedia@gmail.com

Received: May 06, 2025
Accepted: July 17, 2025
Published: July 23, 2025

Citation: Garach I, Vediya P, Trivedi U, Kapuriya K, Kapuriya H. 2025. Millets: A Nutritional Powerhouse for Food Security and Pharmaceutical Applications. *J Food Chem Nanotechnol* 11(S2): S77-S98.

Published by United Scientific Group

Abstract

Millets are highly nutritious and climate-resilient grains that play a vital role in enhancing food security and promoting overall health. Millets, abundant in proteins, dietary fiber, vitamins, and minerals, present a superior alternative to traditional cereals. With a low glycemic index (GI) and being naturally gluten-free, millets are especially beneficial for individuals with diabetes and gluten intolerance. Moreover, their high antioxidant content contributes to the prevention of lifestyle-related disorders, including cardiovascular diseases, obesity, and metabolic syndromes. Millets also contain bioactive compounds such as polyphenols and flavonoids, which exhibit anti-inflammatory and antimicrobial properties, adding to their therapeutic potential. These qualities make millets suitable candidates for use in functional foods and nutraceutical formulations. In addition to their health benefits, millets are well-suited to grow in harsh climatic conditions with minimal water and input requirements, making them an environmentally sustainable crop. This review emphasizes the nutritional, medicinal, and ecological benefits of millets, highlighting their growing importance in both the food and pharmaceutical sectors. It advocates for the increased integration of millets into daily diets and health products to support better health outcomes and strengthen global food system resilience in the face of climate change.

Keywords

Millets, Nutrition, Food security, Pharmaceuticals, Bioactive compounds, Health benefits

Introduction

Millets are a broad category of nutrient-dense grass crops that are grown for animal feed as well as human consumption. Within the grass family (Poaceae), these millet crops are members of several botanical tribes, each of which represents a different genus with distinctive traits and ecological adaptations. Panicum: This group includes species like proso millet, or *Panicum miliaceum*, which is commonly grown due to its short growth season and ability to withstand poor soil conditions. Setaria: It is well-known for its foxtail millet, or *Setaria italica*, which is among the earliest millets to grow and has exceptional drought tolerance. Echinochloa: This group includes *Echinochloa frumentacea*, sometimes known as barnyard millet, which is prized for its quick growth and adaptability to both human and animal consumption. Pennisetum: Known for its remarkable resistance to heat and drought, *Pennisetum glaucum*, also known as pearl millet, is a staple in many arid and semi-arid countries. Essential nutrients like proteins, carbs, good fats, minerals, vitamins, dietary fiber, and polyphenols are all abundant in millets. Four main forms of millet stand out among the various variants. The most extensively grown millet, pearl millet (*P. glaucum*), makes up

around 40% of the world's millet production. Other important varieties include finger millet (*Eleusine coracana*), proso millet or white millet (*P. miliaceum*), and foxtail millet (*S. italica*). Foxtail millet is particularly valuable as an economically important grain that is grown and consumed across regions such as India, China, North Africa, and the Americas. It is naturally gluten-free, very nutritious, and easy to digest, and it is often grown using organic farming practices. Millets have recently gained recognition for their exceptional nutritional composition, ecological sustainability, and many health benefits. These ancient grains are primarily grown in areas with limited water availability, making them crucial for global food security, and their capacity to grow with minimal agricultural inputs provides a viable substitute for traditional staples like rice and wheat. Additionally, millets are recognized as functional foods, offering potential health benefits and therapeutic properties. They are particularly beneficial in managing lifestyle-related disorders, including diabetes, cardiovascular diseases, and digestive issues, reinforcing their role as both a sustainable and health-promoting food source. Millets, alongside staple crops like wheat, rice, and maize, serve as a crucial food source for millions of people, particularly those living in hot and humid regions. These grains are primarily cultivated in marginal lands where conventional cereals struggle to produce substantial yields [1]. Their resilience to harsh climatic conditions, including limited rainfall, makes them an essential food in many developing nations. In arid regions, millets are a primary source of energy and protein, sustaining populations that rely on them for daily nutrition. Millets are ancient grains that have been growing for thousands of years and are now receiving global recognition for their impressive nutritional and health benefits. Their ability to thrive in drought-prone areas with poor soil fertility makes them vital for food security, especially in semi-arid and arid regions. Traditionally, millets have been a staple in Asian and African diets, but their significance has diminished over time with the widespread adoption of crops like rice and wheat. Millets have recently attracted more attention because of their high nutritional value. They are an excellent dietary choice since they are high in vitamins, minerals, vital amino acids, and dietary fiber [1-3]. Those with diabetes and those seeking healthier food options would especially benefit from their low GI and inherent gluten-free status. Furthermore, bioactive substances with antibacterial, anti-inflammatory, and antioxidant qualities, including flavonoids, tannins, and phenolics, are found in millets. These qualities have further established millets as a functional food with health and medical benefits, increasing their prospective uses in the pharmaceutical and nutraceutical sectors [4].

Types of millets

Major millet

Pearl millet (*P. glaucum*): Pearl millet, sometimes referred to as bajra, is a nutrient-dense grain that is high in iron, fiber, and protein. As such, it is a vital diet for preventing anemia and maintaining general health. The high fiber content promotes gut health, aids in digestion, and helps maintain healthy cholesterol levels. Additionally, by controlling blood sugar levels, its complex carbohydrate and magnesium content are essential for managing diabetes. Figure 1 shows the *P. glaucum* millets. Additionally, the presence of antioxidants supports cardiovascular health by lowering oxidative stress. Preventing anemia and maintaining blood health pearl millet is a great diet for controlling and preventing anemia since it is a great source of iron. Frequent ingestion can improve oxygen delivery in the body and raise hemoglobin levels. Additionally, the presence of folic acid supports red blood cell formation, which is essential for overall blood health. Heart health and cholesterol control the phytochemicals, fiber, and antioxidants in pearl millet help in reducing low-density lipoprotein (LDL) which is bad cholesterol and improving high-density lipoprotein (HDL) which is good cholesterol levels. This plays a significant role in preventing cardiovascular diseases such as hypertension, atherosclerosis, and strokes. Potassium's presence also promotes appropriate blood pressure regulation. The abundance of macronutrients and micronutrients in pearl millet contributes to its health-promoting qualities. The protein has a protein content of roughly 10 - 12%, which makes it a strong plant-based protein source, particularly for vegetarians. Rich in dietary fiber Its high fiber content supports gut health, facilitates digestion, and helps keep cholesterol levels within normal ranges [5, 6].

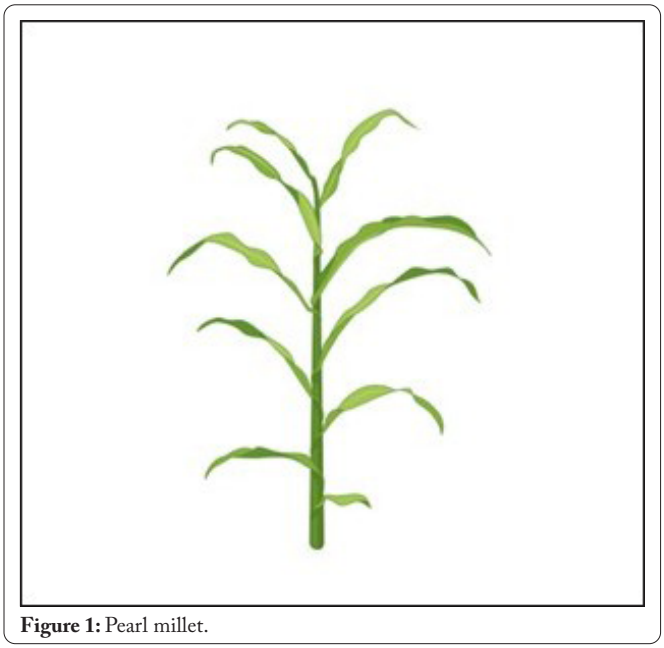

Figure 1: Pearl millet.

Finger millet (*E. coracana*): Finger millet, sometimes called ragi, is a popular grain that is recognized for having a high calcium content, which makes it a great food for maintaining healthy bones and preventing osteoporosis. Additionally, it contains a lot of vital amino acids that aid in the development and repair of muscles. Because it contains dietary fiber, it effectively regulates blood sugar levels, making it a fantastic option for diabetics. Ragi also has natural antioxidants and polyphenols that help with stress management, brain function, and anti-aging. Figure 2 shows the finger millets. A rich source of vital nutrients, finger millet contains dietary fiber, macronutrients, micronutrients, and bioactive substances. High level of calcium finger millet is the highest plant-based source of calcium, which is necessary for strong bones, the prevention of osteoporosis, and healthy muscular function. It has 344 mg of calcium per 100 g. About 7 - 9% of it is protein,

Figure 2: Finger millet.

including essential amino acids like cysteine, tryptophan, and methionine that are critical for immune system function, muscle growth, and tissue repair. Preventing osteoporosis and maintaining bone health ragi is one of the best foods for building and strengthening bones because it is a natural calcium powerhouse. In older people, the high phosphorus and magnesium concentration also promotes bone mineralization and inhibits bone deterioration. Osteoporosis prevention and bone density maintenance are especially advantageous for older adults, pregnant women, and youngsters. Controlling weight and obesity ragi is a great option for weight loss and obesity prevention because of its high fiber content and complex carbs, which help to increase fullness and control hunger cravings. Its slow digestion rate prevents excessive calorie intake and helps in maintaining a healthy metabolism [7].

Foxtail millet (*S. italica*): Foxtail millet is good for digestion and weight control because it's a wonderful source of dietary fiber and complex carbs. Because of its low GI, it helps regulate blood sugar and insulin sensitivity by ensuring a slow release of sugar into the bloodstream. Its rich mineral content, which includes magnesium and iron, lowers inflammation, improves cognitive function, and supports heart health. Due to its gluten-free status, foxtail millet is a good option for people who have gluten intolerance or celiac disease. Foxtail millet is unique due to its high fiber content and health-promoting qualities since it is rich in macronutrients, micronutrients, and bioactive substances. Figure 3 shows the foxtail millets. A diet high in complex carbs provides a steady flow of energy, lowering blood sugar spikes and improving metabolic health. Blood sugar regulation and diabetes management because of its low GI, foxtail millet is known to release glucose into the bloodstream gradually. In addition to improving insulin sensitivity, this gradual digestive process avoids abrupt blood sugar rises. Additionally, resistant starch and dietary fiber aid in the management of type 2 diabetes and the enhancement of metabolic health. The high protein and fiber content of foxtail millet assists with weight management and obesity control by reducing hunger cravings and promoting satiety. Overeating and snacking are avoided thanks to millet's slow-digesting carbs, which provide sustained energy levels [8-9].

Proso millet (*P. miliaceum*): Proso millet, also known as Barri or Chena, is a grain that improves memory, focus, and energy metabolism since it is rich in phosphorus, antioxidants, and B-complex vitamins. It is a fantastic choice for weight

Figure 3: Foxtail millet.

management and metabolic health because it contains fewer carbs than other grains. Essential minerals and phytochemicals boost neuron function, lower oxidative stress, and enhance cellular health in general. Furthermore, because it is gluten-free, it is perfect for those who have stomach issues or gluten allergies. Advantages for cardiovascular support, weight control, metabolic health, and cognitive function. Figure 4 shows the proso millets. Proso millet is a climate-resilient crop that requires little water and can be grown in drought-prone areas, making it a viable option for ensuring global food security. It is widely consumed in porridges, flatbreads, energy bars, and health supplements, contributing to both traditional and modern diets [10].

Minor millets

Kodo millet (*Paspalum scrobiculatum*): It is perfect for diabetes and weight loss because of its low GI. It is also high in fiber and antioxidants. Controlling weight and feeling full. Kodo millet is a grain that is perfect for obese patients because it is low in fat, high in protein, and rich in fiber. Because of its high fiber content, it reduces harmful appetites and encourages fullness. Complex carbohydrates that break down slowly help you feel fuller for longer and avoid overeating. It supports

Figure 4: Proso millet.

healthy body mass index maintenance and fat metabolism. Rich in potassium and magnesium, which help control blood pressure and prevent hypertension, kodo millet's heart-healthy minerals improve cardiovascular function. A high fiber diet raises HDL (good cholesterol) and lowers LDL (bad cholesterol). Antioxidants that lower inflammation and oxidative stress, such as flavonoids and polyphenols, protect the heart. Diabetes management, weight control, heart health, digestive wellness, and bone strength are just a few of the many health advantages that come with kodo millet (*P. scrobiculatum*), a grain that is both nutritionally excellent and environmentally sustainable [11, 12].

Little millet (*P. sumatrense*): A healthy source of fiber, iron, and protein that promotes metabolic and intestinal health. High protein content (7 - 9%) promotes metabolism, immunological response, and muscle building. Little millet is an ideal grain for those with diabetes and prediabetes because of its low GI (GI ~52 - 55). The slow-digesting carbs and rich fiber guarantee a steady release of glucose into the bloodstream, avoiding abrupt rises in blood sugar. Polyphenols and magnesium improve glucose metabolism and insulin sensitivity. According to studies, a small amount of millet can lower the incidence of type 2 diabetes. Little millet is a great grain for managing obesity and weight reduction because it is low in fat and high in fiber. The high fiber content promotes satiety, reducing frequent hunger pangs and overeating. Carbohydrates that digest slowly aid in sustaining energy levels over an extended period of time. It promotes a healthy body mass index and helps with fat metabolism. Diabetes management, weight control, heart health, digestive wellness, and bone strength are just a few of the many health advantages that come with little millet (*P. sumatrense*), a highly nutritious, gluten-free, and climate-resilient grain. It is a superfood for contemporary diets because of its high fiber content, low GI, and antioxidant-rich qualities. Climate-resilient and drought-resistant crops are crucial to climate-smart grain since they thrive in regions with little rainfall. It is a viable option for small-scale farmers because it requires little water and input and thrives in semi-arid areas. Quick and dependable harvests are guaranteed by the short growing cycle, which takes less than 100 days to mature. Enhances soil fertility grow well in rotation farming, improving soil health and preventing land degradation [13].

Importance of millets in food and pharma

Millets are more nutrient-denser than many conventional grains because they are higher in dietary fiber, proteins, essential amino acids, vitamins, and minerals like iron, calcium, magnesium, and phosphorus. Their high fiber content aids in digestion and promotes gut health, while their low GI makes them effective in treating diabetes and lowering lifestyle diseases including obesity and cardiovascular ailments. Millets are also naturally gluten-free, making them a fantastic dietary choice for those who have gluten intolerance or celiac disease. Millets have garnered attention for their utilitarian and medicinal applications in addition to their use as a staple grain. These comprise bioactive compounds such as flavonoids, tannins, and phenolics that possess strong antibacterial, anti-inflammatory, and antioxidant properties. These phytochemicals have potential uses in medicine and can prevent disease in managing metabolic disorders, cardiovascular diseases, and neurodegenerative conditions. Additionally, millet-based products, including flour, fermented foods, and nutraceutical supplements, are being explored for their health-promoting benefits, making them valuable in the pharmaceutical and functional food industries. Millets play a vital role in global food security, particularly in regions prone to drought and erratic rainfall. Their resilience and adaptability make them an excellent choice for farmers in developing countries. Rich in essential macronutrients, including complex carbohydrates, dietary fiber, and proteins, millets provide long-lasting energy and improve satiety levels, making them an ideal food source for both rural and urban populations. Furthermore, millets are rich in micronutrients that are necessary for many physiological processes, including iron, calcium, zinc, and magnesium. Millets are more nutritious than rice and wheat, especially when it comes to fiber and bioactive substances. Millets' high fiber content helps with digestion, blood sugar regulation, and gut microbiome health. They are the go-to option for people with diabetes because of their low GI. In order to increase their relevance in contemporary dietary practices, millets are also being added to value-added food products including energy bars, breakfast cereals, millet-based flours, and gluten-free substitutes. As consumers' concerns about their health have grown, millets have found a home in functional meals that cater to particular dietary and health requirements.

Pharmaceutical and therapeutic applications of millets

Millets are known for their medicinal potential in addition to their nutritional advantages since they contain bioactive substances such tannins, flavonoids, and phenolic acids. Because of these chemicals' potent antibacterial, anti-inflammatory, and antioxidant qualities, millets are useful for managing and preventing a number of chronic illnesses [14].

Diabetes management: Millets of high fiber content and low GI help to improve insulin sensitivity, lower postprandial glucose spikes, and regulate blood sugar. Some millet types, like barnyard and foxtail millet, have been researched for their potential to prevent diabetes.

Cardiovascular health: Heart-healthy minerals including potassium, magnesium, and unsaturated fatty acids are found in millets and can lower cholesterol and maintain blood pressure. Millets' phytochemical content helps to lower oxidative stress, which is a major contributing cause to heart disease.

Gut health and digestion: Millets' dietary fiber helps to maintain gut health by improving digestion, avoiding constipation, and encouraging the development of good gut flora. Their prebiotic qualities also help maintain a balanced gut microbiota, which enhances digestive function in general.

Anti-cancer properties: According to research, some of the phytochemicals in millets have anti-cancer effects by causing cancer cells to undergo apoptosis and preventing the growth of tumor cells. These bioactive substances lower the risk of diseases brought on by oxidative stress by acting as natural antioxidants.

Bone health and immunity: Bone health and the prevention of osteoporosis depend on calcium and phosphorus,

which are abundant in millets, especially finger millet (ragi). Their abundant vitamins and antioxidant content fortify the immune system, assisting the body in fending against infections and inflammatory conditions.

Historical and global perspective of millet

Millets have been a staple food for thousands of years in many cultures, especially in arid and semi-arid regions. These nutrient-dense grains were among the first crops to be domesticated, and historical evidence of their cultivation can be found in ancient civilizations in Africa, India, and China. Because they can withstand harsh environmental conditions and grow in nutrient-poor soils with little water, they are vital for maintaining population. Millets have traditionally been a fundamental part of diets worldwide, especially in Asia and Africa, where they are commonly used to make porridge, flatbreads, and fermented drinks. In India, they are often called "nutri-cereals" because of their rich nutritional content and are widely consumed in rural and tribal communities. Similarly, in Africa, millet-based meals such as porridge and flatbread continue to be a crucial part of daily nutrition. Despite their historical significance, millet consumption declined with the rise of high-yielding cereal crops like rice and wheat. However, because of its many health advantages, capacity to adapt to changing climates, and contribution to food security, millets have seen a global resurgence in popularity in recent years. Initiatives to promote millet production and consumption have been started by governments and international organizations, who highlight the grain's ability to fight malnutrition and advance sustainable agriculture. 2023 was designated as the "International Year of Millets" by the United Nations in an effort to increase awareness of their importance in global food systems and to further emphasize their use in contemporary agriculture and nutrition. Since ancient times, millets have been an essential part of civilizations' diets. According to archaeological findings, millet was widely grown more than 7,000 years ago in China, India, and several parts of Africa, and it was an essential component of traditional diets and cultural cuisine particles. However, with the advent of the Green Revolution and the introduction of high-yielding crops such as rice and wheat, millet consumption declined over time. In recent years, there has been renewed interest in millets due to increasing awareness of their health benefits and ability to thrive in challenging climatic conditions. Efforts are being made globally to revive millet production and encourage their inclusion in modern diets. Recognizing their significance in addressing food insecurity and malnutrition, several international organizations, including the Food and Agriculture Organization (FAO) and the United Nations, have actively promoted millets. In support of this initiative, the United Nations General Assembly designated 2023 as the International Year of Millets to enhance global awareness and encourage their cultivation and consumption. Governments, researchers, and industries are working together to integrate millets into modern food systems, encourage their use in functional foods, and explore their potential in pharmaceutical applications, the significance of millets in food security and pharmaceutical applications. It will explore their nutritional composition, health benefits, and industrial uses, shedding light on their potential to revolutionize global food systems and healthcare approaches. Since millet has the potential to alleviate malnutrition and food security issues, efforts are being made worldwide to encourage its planting. In order to guarantee food diversity and climatic resilience, the FAO and other organizations have underlined the necessity of sustainable agriculture techniques that incorporate millets. The potential of millets to improve human health and promote sustainable food systems is becoming more widely acknowledged. They are being thoroughly researched for their potential use in medicinal and functional food applications because of their high nutritional profile and bioactive components. The significance of millets in maintaining food security and their possible medical uses are thoroughly examined in this article. It explores their nutritional composition, health advantages and expanding industrial applications, emphasizing their growing significance in modern agriculture, nutrition, and healthcare.

Nutritional Composition of Millets

Grains rich in macro and micronutrients, millets are exceptionally nutrient-dense. They are an excellent source of complex carbohydrates, which provide you with a sustained energy boost, and they contain a significant quantity of dietary fiber, which supports gut health and digestion. Along with providing a balanced protein composition, these grains also include essential amino acids that promote muscle growth and overall health. In addition, millets are a good source of iron, calcium, magnesium, zinc, and B vitamins, which are vital for metabolism and overall health. Antioxidants and polyphenols are among their many bioactive components, which offer a host of health benefits, including reducing oxidative stress and improving immune function. Millets are a great complement to a balanced diet because of their distinct nutritional makeup. Millets are an excellent source of macronutrients, including carbohydrates, proteins, and fats, which play a crucial role in maintaining overall health and well-being. These grains provide a balanced composition of essential nutrients, making them a valuable addition to a healthy diet [15].

Macronutrients in millets: carbohydrates, proteins, and fats

Millets are highly nutritious grains that serve as a valuable source of macronutrients, including carbohydrates, proteins, and fats. These essential nutrients contribute to the overall health benefits of millets and make them an excellent dietary option for diverse populations [16, 17].

Carbohydrates

The main macronutrient in millets is carbohydrates, which offer a significant energy source. The complex carbohydrates and dietary fiber found in millets, as opposed to refined grains, help to slow down digestion and release glucose into the bloodstream gradually. Because of their low GI, millets are good for controlling blood sugar levels and avoiding diabetes. In addition to supporting gut health, the inclusion of soluble fiber and resistant starch enhances digestion and fosters a healthy gut flora. The high dietary fiber content of millet carbohydrates is one of their most significant features, as it is essential for digestive health. Different types of millets include varying amounts of fiber; finger millet, pearl millet, and foxtail

millet are very high sources. Soluble and insoluble fiber are two types of dietary fiber that offer different health advantages. While insoluble fiber promotes healthy gut microbiota, assists with digestion, and avoids constipation, soluble fiber lowers cholesterol and controls blood sugar. Additionally, fiber increases satiety, which lessens hunger pangs and aids weight management by avoiding overeating. Millets include fiber as well as resistant starch, a kind of carbohydrate that works similarly to dietary fiber in that it inhibits small intestine digestion. By feeding good gut bacteria and serving as a prebiotic, resistant starch improves gut health by encouraging the synthesis of short-chain fatty acids, which have anti-inflammatory and metabolic health benefits. The colon's fermentation of resistant starch promotes digestive health and lowers the risk of gastrointestinal diseases like colon cancer and irritable bowel syndrome (IBS). The function of millet carbohydrates in energy metabolism is another noteworthy characteristic. Athletes and those who perform physically demanding tasks favor millets as an energy source because of their complex carbohydrate structure, which releases glucose gradually and steadily. Unlike refined grains, which cause quick energy bursts and then crashes, meals made from millet offer sustained energy and improve metabolic efficiency. Those who follow low GI diets and are looking to improve their blood sugar control may especially benefit from this characteristic. Millets are a more nutritious grain than refined cereals because of their carbohydrate content. They are the perfect option for controlling diabetes, enhancing gut health, encouraging weight loss, and guaranteeing maintained energy levels because of their special combination of complex carbs, dietary fiber, resistant starch, and bioactive substances. By preventing chronic diseases, including millets in the daily diet not only improves nutrient intake overall but also promotes long-term health and wellness.

Proteins

Millets are a significant dietary component, especially for those on vegetarian or vegan diets, because they are a good source of plant-based protein. Varied types of millets have varied amounts of protein; foxtail, pearl, and finger millets have comparatively higher amounts. Although millets are a good source of essential amino acids, their lysine content is generally lower. They can, however, contribute to a more balanced protein intake when taken with dairy or legumes. Millets' protein is essential for tissue healing, muscle growth, and general metabolic processes. Depending on the variety, millets can have a protein level of 7 - 14%. They are especially high in critical amino acids including tryptophan, lysine, and methionine. These amino acids, often lacking in other staple grains like rice and wheat, make millets a superior protein source. Finger millet and pearl millet, in particular, contain higher amounts of lysine, an essential amino acid required for protein synthesis, muscle growth, enzyme production, and immune system function. The protein in millets also helps prevent muscle deterioration, supports tissue regeneration, and enhances metabolic efficiency, making them a valuable food choice for vegetarians, vegans, and individuals at risk of protein-energy malnutrition. Beyond being a high-quality protein source, the amino acid profile of millets enhances their digestibility and bioavailability, making them suitable for all age groups, including children, pregnant women, and the elderly. Among millet varieties, finger millet, pearl millet, and foxtail millet stand out for their high protein content, making them excellent options for improving dietary protein intake. Additionally, methionine, a sulphur-containing amino acid abundantly found in millets, plays a vital role in liver detoxification, fat metabolism, and antioxidant defense. It also supports the synthesis of cysteine and glutathione, which help protect the body against oxidative stress. Millets, especially finger millet, contain notable amounts of lysine, an essential amino acid that is often deficient in most cereal grains. Lysine is vital for collagen synthesis, calcium absorption, immune function, and the production of hormones and enzymes. This makes millets particularly beneficial for individuals suffering from protein-energy malnutrition, as well as for those seeking to improve muscle strength and promote tissue repair. Additionally, millets' high protein content is important for controlling hunger and weight. By promoting the production of satiety hormones like glucagon-like peptide-1 and peptide YY, which lessen food cravings and discourage overeating, foods high in protein help regulate appetite. Because they offer vital nutrients and encourage a balanced calorie intake, millets are therefore a perfect complement to diets aimed at reducing body weight. Apart from their nutritional advantages, millets are increasingly being used in the nutraceutical and pharmaceutical sectors. Protein hydrolysates produced from millet are being researched for possible use in functional foods, protein supplements, and pharmaceutical formulations because of their antibacterial, anti-inflammatory, and antioxidant qualities. These bioactive proteins have demonstrated potential in the treatment of metabolic conditions such as diabetes, heart disease, and neurodegenerative conditions by reducing inflammation, enhancing insulin sensitivity, and improving lipid metabolism.

Fats

Although millets have relatively low-fat content, they are rich in beneficial unsaturated fatty acids that support heart health. These grains contain essential fatty acids such as linoleic acid, which plays a key role in reducing inflammation and maintaining proper cellular function. Moreover, millets are naturally packed with antioxidants, which help prevent fat oxidation, further enhancing their nutritional value. Typically, millet fat content ranges from 1 - 5%, yet it includes healthy unsaturated fatty acids that contribute to cardiovascular health and brain function. The presence of omega-3 and omega-6 fatty acids aids in reducing inflammation, improving cognitive abilities, and promoting heart health by lowering harmful cholesterol levels. Additionally, millets contain bioactive lipids, phospholipids, and sterols that support cellular activities and neurological well-being. Unlike refined grains, millets naturally contain antioxidants that prevent lipid oxidation, extending their shelf life and preserving their nutritional quality. The combination of healthy fats and dietary fiber in millets also supports satiety regulation, helping prevent excessive calorie consumption and assisting in weight management. The monounsaturated and polyunsaturated fatty acids (PUFA) found in millet fats are a major benefit because they help regulate cholesterol levels by raising HDL ("good cholesterol") and lowering LDL ("bad cholesterol"). In order to reduce the risk of cardiovascular diseases like hypertension, atherosclerosis, and stroke, this cholesterol management is essential. Because

they have higher quantities of PUFAs than other millet kinds, pearl millet and foxtail millet are particularly good for heart health. Additionally, millets are a good source of omega-3 and omega-6 fatty acids, which are vital because the body is unable to produce them on its own. Omega-3 fatty acids play a significant role in reducing inflammation, enhancing brain function, supporting neurological health, and promoting cognitive development. These properties make them particularly beneficial for individuals at risk of neurodegenerative diseases like Alzheimer's and Parkinson's. Meanwhile, omega-6 fatty acids contribute to immune system function, skin health, and hormone regulation. Maintaining a balanced intake of omega-3 and omega-6 from natural sources such as millets can help prevent chronic inflammation and metabolic disorders. Another essential feature of millet fat is their ability to prevent oxidative damage, thanks to their antioxidant content, which includes polyphenols, flavonoids, and tocopherols (vitamin E). These antioxidants help combat oxidative stress, inflammation, and age-related degenerative diseases, promoting overall well-being. Despite their modest fat content, millets contribute to long-lasting energy release and weight control. Millet fats are a great nutritional choice for athletes, those with physically demanding lifestyles, and people trying to control their weight because their delayed digestion guarantees a constant energy source. All things considered, millets' lipid profile provides a host of health advantages, from enhanced metabolic efficiency and anti-inflammatory qualities to cardiovascular protection and cognitive support. They are a better substitute for processed grains due to their special blend of unsaturated fatty acids, essential fatty acids, phospholipids, and antioxidants, which promotes long-term illness prevention and general well-being. Millets are a great dietary option for supporting long-lasting energy, metabolic stability, and general health because of their well-balanced macronutrient content.

Micronutrients: vitamins and minerals in millets

Millets are a rich source of essential micronutrients, including various vitamins and minerals, which play a crucial role in maintaining overall health. These nutrients contribute to several physiological functions, such as immune support, bone strength, and enzymatic activities.

Vitamins in millets: Millets are a great source of B-complex vitamins, such as thiamine (B1), riboflavin (B2), niacin (B3), pyridoxine (B6), and folic acid (B9), all of which are necessary for many physiological processes. Thiamine (B1) is essential for the metabolism of carbohydrates, assisting in the conversion of glucose into energy to maintain bodily functions; it also plays a critical role in nerve function, muscle coordination, and brain activity by supporting the production of neurotransmitters, especially acetylcholine; a thiamine deficiency can result in beriberi, a condition marked by muscle weakness, nerve damage, cardiovascular problems, and cognitive impairment; regular consumption of millet-based foods helps maintain adequate thiamine levels, promoting cognitive health and preventing neurological disorders. It acts as a coenzyme in redox reactions, aiding in the breakdown of proteins, fats, and carbohydrates for energy. Additionally, riboflavin contributes to healthy skin, proper eye function, and red blood cell formation, reducing the risk of anemia and oxidative stress-related diseases. A deficiency in riboflavin can lead to cracked lips, skin disorders, sore throat, and light sensitivity, but including millets in the diet can help prevent such deficiencies. Niacin (B3) plays a crucial role in DNA repair, cellular signaling, and metabolism. It aids in reducing inflammation, lowering cholesterol levels, and supporting digestion. Pyridoxine (B6) is important for protein metabolism and neurotransmitter synthesis, contributing to brain health and cognitive development. Folic acid (B9) is especially important for pregnant women as it helps prevent neural tube defects in newborns and supports fetal development. Millets also include trace levels of vitamin K to improve bone health and vitamin E as antioxidant, both of which have unique health advantages. As a potent antioxidant, vitamin E lowers the risk of chronic illnesses like cancer, heart disease, and neurological disorders by scavenging free radicals. In order to maintain healthy bones and avoid osteoporosis and excessive bleeding, vitamin K is necessary for blood coagulation. Millets are not a significant source of vitamin C but eating them with meals high in vitamin C improves the absorption of non-heme iron, which is important for avoiding fatigue and anemia. Millets are a great complement to a balanced diet because of their high vitamin content, which supports energy metabolism, cognitive function, red blood cell synthesis, and general well-being.

Minerals in millets: Millets are an excellent source of vital minerals such as iron, calcium, magnesium, phosphorus, zinc, potassium, and copper, all of which contribute to overall growth, development, and disease prevention. Among these, iron is particularly crucial for hemoglobin synthesis, oxygen transport, and immune support. Finger millet (ragi) is especially rich in iron, making it a beneficial dietary choice for individuals susceptible to iron-deficiency anemia. Although phytates and polyphenols in millets may slightly reduce iron absorption, consuming them alongside vitamin C-rich foods can significantly enhance their bioavailability. Calcium is another essential mineral found in large amounts in millets, especially in finger millet, which contains even more calcium than milk. This makes it particularly beneficial for maintaining bone health, supporting muscle function, and preventing osteoporosis. The combination of calcium, phosphorus, and magnesium in millets strengthens bones, aids nerve signaling, and helps prevent bone-related conditions such as osteopenia and arthritis. Magnesium further contributes to muscle relaxation, nerve function, and blood pressure regulation, thereby reducing the risk of hypertension, cardiovascular diseases, and type 2 diabetes. Zinc, another important mineral in millets, supports immune function, wound healing, and enzyme activities. It also plays a key role in DNA synthesis, growth, and development, making millets a valuable dietary addition for children, pregnant women, and individuals recovering from illnesses. Potassium is essential for maintaining electrolyte balance, nerve function, and muscle contraction, thereby reducing the risk of hypertension and stroke. Additionally, copper plays a significant role in red blood cell production, iron metabolism, and immune function, helping lower the risk of cardiovascular and neurological disorders.

Millets are an excellent source of essential minerals, including selenium and manganese, which act as antioxidants, shielding cells from oxidative stress while promoting thyroid

function, metabolism, and reproductive health. Selenium plays a key role in regulating thyroid hormones, while manganese supports bone formation and enzyme activation. Although required in small quantities, these trace minerals are vital for preventing chronic diseases, enhancing metabolic health, and promoting longevity. Beyond these, millets are rich in iron, calcium, magnesium, phosphorus, zinc, potassium, and copper, all of which contribute to overall growth, development, and disease prevention. Iron is particularly essential for hemoglobin production, oxygen transport, and immune support. Finger millet (ragi) is especially high in iron, making it an ideal dietary option for individuals at risk of iron-deficiency anemia. Although phytates and polyphenols in millets may slightly hinder iron absorption, consuming them with vitamin C-rich foods can greatly enhance bioavailability. Calcium is another vital mineral found abundantly in millets, particularly in finger millet, which contains more calcium than milk. This makes it highly beneficial for maintaining bone health, supporting muscle function, and preventing osteoporosis. The combination of calcium, phosphorus, and magnesium in millet strengthens bones, supports nerve signaling, and helps prevent bone-related conditions such as osteopenia and arthritis. Additionally, magnesium is essential for nerve function, blood pressure regulation, and muscle relaxation, all of which reduce the risk of cardiovascular disease, type 2 diabetes, and hypertension. Another crucial mineral found in millets is zinc, which is necessary for wound healing, immune system function, and enzyme activity. Because of its important function in DNA synthesis, growth, and development, millets are especially good for kids, expectant mothers, and people recuperating from illnesses. Potassium lowers the risk of hypertension and strokes by supporting nerve and muscle function, electrolyte balance, and muscle contraction. Copper lowers the risk of neurological and cardiovascular diseases by supporting immune system function, iron metabolism, and red blood cell synthesis.

Bioactive compounds and antioxidants in millet

Millets' remarkable health benefits are a result of their high content of bioactive chemicals. These substances, which have anti-inflammatory, antioxidant, and medicinal qualities, include phenolic acids, flavonoids, tannins, phytosterols, and lignans. Their presence improves millets' capacity to scavenge dangerous free radicals, which lowers oxidative stress and the risk of chronic illnesses like diabetes, heart disease, and some types of cancer. Phenolic acids and flavonoids, two of the main antioxidants found in millets, are essential for scavenging free radicals and averting cellular damage. Furthermore, millets' high fiber content encourages a gradual release of carbohydrates, which supports improved metabolic control. The presence of phytochemicals further enhances millet's function as a health-promoting food, making them valuable for both dietary and pharmaceutical applications. The antioxidant properties of millets can vary based on the type of millet and the processing methods used. Whole millets generally retain higher antioxidant activity than refined products, as processing may result in the loss of some bioactive compounds. Research indicates that regularly including millets in the diet can help strengthen the body's defense system against oxidative damage, thereby promoting overall health.

Phenolic compounds - powerful antioxidants

Millets have high levels of phenolic acids, which have strong antibacterial, anti-inflammatory, and antioxidant properties. These acids include gallic acid, caffeic acid, ferulic acid, and chlorogenic acid. These compounds reduce the risk of diseases like cancer, heart disease, and neurological disorders that are linked to oxidative stress by aiding in the neutralization of free radicals. Phenolic acids also promote gut health by changing the gut flora and encouraging better digestion. Flavonoids are heart protective and anti-cancer properties.

Millets also contain flavonoids, a significant class of bioactive substances with anti-aging, anti-cancer, and cardioprotective qualities. These substances, which include kaempferol, apigenin, quercetin, and catechins, aid in lowering inflammation, enhancing blood flow, and fortifying the immune system. Additionally, flavonoids can lessen the incidence of heart attacks and strokes by lowering LDL (bad cholesterol), raising HDL (good cholesterol), and avoiding plaque accumulation in arteries. Their anti-cancer qualities also aid in halting the growth of tumors, avoiding DNA damage, and causing cancerous cells to undergo apoptosis, or programmed cell death.

Tannins: natural anti-diabetic agents

Some millet types contain tannins, which are polyphenolic chemicals that give them an astringent flavor and antioxidant properties. Because of these substances' well-known capacity to control blood sugar, millets are an excellent choice for managing diabetes. By blocking the enzymes that break down carbohydrates, tannins assist to slow down the absorption of glucose and avoid blood sugar increases after meals. They also support gut and mouth health because of their antibacterial and antifungal qualities.

Lignans - hormonal balance and cancer prevention

The phytoestrogenic qualities of lignans, another class of bioactive substances found in millets, are well-known for promoting hormonal balance, particularly in women. By acting as natural estrogen regulators, these substances lower the incidence of malignancies linked to hormones, including prostate and breast cancer. Additionally, lignans promote heart health by lowering cholesterol and blood pressure, which lowers the risk of cardiovascular disease and hypertension.

Phytosterols - cholesterol-lowering and anti-inflammatory benefits

Millets include phytosterols, which are sterols obtained from plants that decrease cholesterol. These substances lower total cholesterol levels and lower the risk of atherosclerosis, stroke, and heart disease by preventing the intestinal absorption of cholesterol. Additionally, phytosterols have anti-inflammatory qualities that help to prevent arthritis, lessen joint pain, and boost immunity.

Antioxidant activity and health benefits

Millets include bioactive substances that have antioxidant action, which helps to improve immune function, prevent chronic diseases, and postpone aging. The body's natural defenses are strengthened, oxidative stress is lessened, and cells are shielded from harm by these antioxidants. According to

studies, eating foods made from millet on a daily basis can strengthen liver function, lower the risk of metabolic illnesses, and increase longevity. Millets contain phenolic acids, flavonoids, tannins, lignans, and phytosterols, which are antioxidants that help shield organs, tissues, and cells from the harm that reactive oxygen species can do. Include foods high in antioxidants, like millets, to preserve overall health and longevity because oxidative stress is connected to cellular aging, neurological diseases (like Alzheimer's and Parkinson's), cardiovascular disorders, diabetes, and even cancer.

Role of Millets in Food Security

Millets play a crucial role in ensuring food security due to their resilience, nutritional benefits, and adaptability to diverse climatic conditions. As climate change threatens global food production, these hardy grains offer a sustainable alternative to conventional staple crops [18, 19].

Climate resilience and sustainability

Millets play a crucial role in ensuring food security, particularly in regions facing climate change, water scarcity, and declining soil fertility. These resilient grains are a sustainable substitute for water-intensive crops like rice and wheat because they thrive in semi-arid, drought-prone, and resource-constrained regions. They are a perfect crop for climate-resilient agriculture because of their capacity to flourish in hot, dry climates with poor soil conditions. Millets' low water requirement they use 30 - 70% less water than traditional cereals-is one of its main benefits. Because of this feature, they are especially advantageous for areas that are suffering from desertification and irregular rainfall. Furthermore, millets have a strong resistance to heat, pests, and diseases, which lessens the need for artificial fertilizers and pesticides and encourages environmentally friendly and sustainable farming methods. The deep-rooted system of millet crops helps in soil conservation and erosion control, improving soil structure and fertility. Unlike monoculture crops that deplete soil nutrients, millet-based intercropping systems enhance biodiversity, restore soil health, and promote carbon sequestration, contributing to climate change mitigation. Moreover, their shorter growing cycles enable multiple harvests per year, ensuring continuous food production and income generation for small-scale farmers. Millets also support agroecological balance by requiring minimal external inputs such as synthetic fertilizers and pesticides. Their production promotes organic farming methods, which lower greenhouse gas emissions and protect the environment. Additionally, millet farming strengthens community food sovereignty while preserving local knowledge, biodiversity, and cultural legacy through its seamless integration with traditional and indigenous agricultural systems. Governments and policymakers may improve rural lives, increase food security, and lessen reliance on climate change-vulnerable staple crops by encouraging the cultivation and use of millet. They are an essential part of future food systems because of their resilience, sustainability, and nutritional value, which guarantee long-term food availability, environmental preservation, and economic stability in a climate that is changing quickly. Millets are renowned for their capacity to flourish in a variety of challenging environmental circumstances, such as semi-arid and drought-prone areas.

Contribution to global food supply

Millets play a significant role in strengthening the global food supply by providing a nutrient-rich, climate-resilient, and economically viable food source.

Traditional and modern millet-based foods

Since ancient times, millets have been a mainstay of traditional diets, especially in Asia, Africa, and some regions of Europe, where they have been essential to maintaining nutritional balance and food security. Porridges, flatbreads, fermented dishes, and drinks are examples of traditional millet-based foods that have a long history in many nations' culinary traditions. For instance, in India, bajra (pearl millet) is frequently used to make rotis (flatbreads) and khichdi (a savory porridge), while ragi (finger millet) is used to make ragi mudde (dumplings), dosa (fermented pancakes), and malted drinks. Millets are necessary in Africa to make traditional brews, ugali (a thick porridge), and injera (a fermented flatbread). These food are not only provide sustained energy and essential nutrients but also support local economies and indigenous food systems with the growing awareness of health, sustainability, and gluten-free diets, millets have found their place in modern food innovations, expanding beyond traditional uses into commercially processed. As the global population continues to rise and climate change threatens agricultural productivity, millets present a sustainable solution for ensuring food security and nutritional stability. Unlike staple crops such as rice, wheat, and maize, which are highly susceptible to drought, unpredictable weather patterns, and soil degradation, millets can flourish in arid and semi-arid regions with minimal water and external inputs. This resilience makes them an ideal crop for sustaining food production in areas prone to climate-related food shortages.

Millets have essential role in diversifying the global food system, reducing dependence on a few staple crops while enhancing dietary diversity. Their widespread cultivation across Asia, Africa, and parts of South America helps bridge the food gap, particularly in developing nations where malnutrition and food insecurity remain pressing concerns. Countries like India, Nigeria, China, and Ethiopia are among the top producers of millets, incorporating them into both traditional and modern diets. Beyond their adaptability, millets have high yield potential, making them a highly efficient grain for mass cultivation. With advancements in agricultural practices and policy support, millet farming can be scaled up to improve global food availability. Additionally, their long life ensures food security, as they can be stored for extended periods without significant loss of nutrients, making them an ideal grain for emergency food supplies and crisis management. The increasing demand for nutritious and functional foods has also boosted the popularity of millets in mainstream markets. With growing concerns over gluten intolerance, diabetes, and lifestyle-related diseases, millets are increasingly recognized as superfood, leading to their incorporation into processed foods, baked goods, and health-conscious diets. This shift in consumer preferences strengthens their role in global food systems while

promoting sustainable agriculture and economic resilience. Investing in millet cultivation, research, and value chain development can help nations build a stable and resilient food supply capable of withstanding climate challenges, economic fluctuations, and nutritional deficiencies. Their exceptional nutritional profile, ecological benefits, and adaptability make them a vital component of future food security strategies, contributing to a more diverse, sustainable, and resilient global food system. Millets provide a reliable source of essential nutrients, particularly in developing countries, as they are rich in carbohydrates, proteins, dietary fiber, vitamins, and minerals like iron, calcium, and magnesium. Their high nutritional value helps combat malnutrition and micronutrient deficiencies, especially among vulnerable populations and value-added products. The food industry has embraced millets in ready-to-eat cereals, pasta, bakery products, snacks, and plant-based dairy alternatives, making them more accessible to urban populations. Millet-based breakfast cereals, granola bars, noodles, cookies, and gluten-free bread are gaining popularity as healthy, high-fiber alternatives to refined grains. Additionally, the emergence of millet-based plant-based milk and fermented probiotic drinks highlights their potential in functional and health-promoting foods. Millets' adaptability to both traditional and modern food systems make them a key player in enhancing food security, reducing dependence on wheat and rice, and promoting dietary diversity. As governments and global organizations advocate sustainable food choices, millets are being reintroduced into mainstream diets through public awareness campaigns, research on improved processing techniques, and policy support for millet farming. By integrating traditional knowledge with modern food technologies, millet-based foods can contribute to nutritional security, economic growth, and sustainable food production, ensuring a resilient food system for future generations. By integrating millets into mainstream agriculture and food systems, they can play a pivotal role in addressing food security challenges while promoting sustainable and nutritious diets worldwide.

Production of millets in India

India's agricultural and nutritional environment is greatly influenced by millets, a type of small-seeded grasses that have been grown there for thousands of years. With main kinds including jowar (sorghum), bajra (pearl millet), and ragi (finger millet) as well as a number of smaller millets like foxtail, barnyard, and kodo millet, India is the world's largest producer of millets. Because of their resistance to dryness and unfavorable soil conditions, these crops are primarily produced in arid and semi-arid locations. States that contribute significantly to millet farming include Tamil Nadu, Karnataka, Maharashtra, Rajasthan, and Andhra Pradesh. Because of their high nutritional content and climate-resilient qualities, millets have seen a resurgence in popularity in recent years. Through programs like the United Nations designation of 2023 as the International Year of Millets, which India proposed, the Indian government has aggressively encouraged the production and consumption of millets. As a result, millet farmers now have more market options, regulatory assistance, and knowledge, which has improved both domestic consumption and export potential. Millets are frequently referred to as "nutri-cereals" because of their high protein, dietary fiber, vitamin (particularly B-complex), and vital mineral content, which includes calcium, magnesium, and iron. Millets, in contrast to rice and wheat, have a low GI, which makes them perfect for heart health promotion and diabetes management. They used to be a mainstay of many Indian homes, particularly in rural regions, but as the green revolution focused on high-yielding rice and wheat types, their use fell. However, there has been a resurgence of interest in millet cultivation due to the negative impacts of climate change and growing health consciousness. The Indian government provides incentives for the production, processing, and marketing of millets and has incorporated them into the National Food Security Mission. To guarantee greater accessibility, millets are also being incorporated into public distribution networks and midday meal programs. In order to close the gap between traditional nutrition and modern consumption patterns, research institutions and start-ups are also developing millet-based food products to suit modern tastes. In India, millets are becoming a sustainable answer for food and nutritional security as a result of this all-encompassing approach. India is the world's biggest producer of millet, making a substantial contribution to global millet output. Rajasthan, Karnataka, Maharashtra, Uttar Pradesh, Haryana, Gujarat, Madhya Pradesh, Tamil Nadu, Andhra Pradesh, and Uttarakhand are the main states that produce millet. According to the 2nd advance estimates, these ten states collectively will produce about 98% of India's millet in 2023 - 2024. Among these states, Rajasthan stands out as the leading producer, contributing 31.3% of the total millet production in India. Together, Uttar Pradesh, Karnataka, Maharashtra, Madhya Pradesh, and Haryana contribute significantly to the nation's millet production, which exceeds 79.6%. The cultivation of millet has been aggressively promoted by the Indian government. For example, the government of Rajasthan launched the Rajasthan Millet Promotion Mission in 2022 and set aside Rs 40 million to build 100 primary processing facilities. Furthermore, as a Center of Excellence, the Indian Institute of Millet Research in Hyderabad is receiving financing to exchange research, technology, and best practices globally. India produces more millets than any other country in the world, and each state makes a substantial contribution to the total amount produced. Figure 5 show the millets production in India during 2023

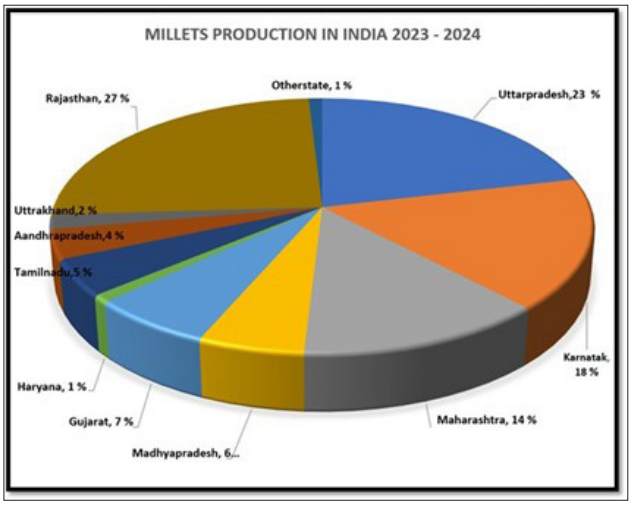

Figure 5: Millet's production in India.

- 2024. As per the 2023 - 2024 estimates, Rajasthan is the leading millet-producing state, accounting for about 31.3% of the country's total output. Other major contributors include Uttar Pradesh, Karnataka, Maharashtra, Madhya Pradesh, and Haryana, with these states collectively producing nearly 80% of India's millets. About 98% of India's millet production is produced in ten key states: Rajasthan, Karnataka, Maharashtra, Uttar Pradesh, Haryana, Gujarat, Madhya Pradesh, Tamil Nadu, Andhra Pradesh, and Uttarakhand. The most common millets grown in India are jowar (sorghum), bajra (pearl millet), ragi (finger millet), and several small millets like foxtail, barnyard, kodo, and little millet. Andhra Pradesh is the most productive state, with an outstanding average yield of 2,363 kg/ha for all millets and 3,166 kg/ha for jowar, while Gujarat comes in second with 2,310 kg/ha (Table 1).

Health Benefits of Millets

Millets are known to be a very nutrient-dense grain with several health advantages. They are a great complement to a balanced diet because they are high in vitamins, minerals, dietary fiber, and vital amino acids. Their richness of bioactive substances and low GI provide a number of health benefits [20, 21].

Diabetes management and glycemic control

Millets avoid abrupt rises in blood sugar levels by releasing glucose into the bloodstream gradually due to their naturally low GI. Because of this, they are a great dietary option for anyone who already has diabetes or is at risk of getting it. They are useful for preserving stable blood sugar levels because of their high fiber content, which also improves insulin sensitivity and helps control the metabolism of carbohydrates. Millets are very helpful for managing diabetes because of their low GI, high fiber content, and complex carbohydrate content. Millets ensure a continuous flow of glucose into the bloodstream because they digest more slowly than refined grains like rice and wheat, which induce quick increases in blood glucose. This slow digestion process is primarily attributed to their high fiber and resistant starch content, which slows carbohydrate breakdown and promotes better glycemic control. Research indicates that regular consumption of millets can help lower fasting blood sugar levels, reduce HbA1c levels (a key indicator of long-term blood sugar control), and enhance pancreatic function. Additionally, millets contain bioactive compounds such as polyphenols, tannins, and flavonoids, which exhibit antidiabetic properties and aid in improving glucose metabolism. Essential minerals like magnesium also play a vital role in enhancing insulin function and reducing the likelihood of developing type 2 diabetes. Millets contribute to gut health, which is closely linked to blood sugar regulation. Better digestion and general metabolic health are encouraged by their prebiotic fiber, which feeds good gut bacteria. Additionally, adding millets to the diet might reduce blood sugar increases after meals, which makes them a good grain for people with prediabetes or diabetes. Foods made from millet, such as porridge, rotis, dosas, and snacks, provide a healthy substitute for refined grains and aid in the treatment of diabetes while enhancing general health. People with diabetes can improve blood sugar control, maintain longer-lasting energy levels, and possibly lessen their need for medication by including millets in a balanced diet. Millets are becoming more widely acknowledged as a useful superfood in the fight against diabetes and metabolic diseases due to its rich nutritional makeup and practical advantages.

Cardiovascular health

Millets' high antioxidants, polyphenol, and dietary fiber content has been linked to improved heart health when consumed regularly. These nutrients help maintain or even raise good cholesterol levels (HDL) while reducing bad cholesterol (LDL). Furthermore, the presence of vital minerals like potassium and magnesium lowers the risk of cardiovascular disease and hypertension by regulating blood pressure. Additionally, millets have anti-inflammatory qualities that assist heart health by reducing oxidative stress and inflammation-related problems. One of the key benefits of millets for cardiovascular wellness is their high fiber content, which aids in lowering LDL cholesterol while preserving healthy HDL cholesterol levels. The soluble fiber in millets binds with excess cholesterol, facilitating its removal from the body and preventing arterial plaque buildup, which can lead to atherosclerosis (hardening of the arteries). Furthermore, natural compounds such as phytosterols and polyphenols found in millets act as cholesterol-lowering agents, offering additional protection against heart-related conditions. Millets are also an excellent source of magnesium and potassium, both of which play an essential role in blood pressure regulation. Magnesium helps relax blood vessels, enhance circulation and prevent hypertension, while potassium counterbalances sodium levels in the body, reducing water retention and sudden blood pressure spikes. Studies suggest that incorporating millets into the diet can lower the risk of stroke and heart failure, making them par-

Table 1: Types of millets and uses.

Millet name	Brand name (Examples)	Common uses
Jowar (Sorghum)	24 Mantra, Organic India, and Tata Soul	Rotis, porridge, snacks, upma, and dosa
Bajra (Pearl millet)	Slurp Farm, Nutriorg, and Pro Nature	Rotis, khichdi, ladoos, and porridge
Ragi (Finger millet)	24 Mantra, Manna, and Slurp Farm	Porridge, rotis, idli, dosa, and baby food
Foxtail millet	Organic Tattva and Jiwa	Pulav, khichdi, salads, and upma
Barnyard millet	Praakritik and True elements	Fasting recipes, upma, pulao, and kheer
Kodo millet	Organic Gyaan and Millet Amma	Pulao, upma, idli, and dosa
Little millet	Just Organic and Bhoomi Naturals	Pongal, khichdi, idli, and dosa
Proso millet	Organic Roots and Nutriwish	Breakfast cereals, energy bars, and baking

ticularly beneficial for individuals with high blood pressure or a family history of cardiovascular diseases. Furthermore, millets include a wealth of antioxidants like flavonoids, tannins, and phenolic acids that help scavenge dangerous free radicals and lessen oxidative stress, a significant cause of heart disease. These antioxidants lessen blood vessel inflammation, shield heart tissues from harm, and enhance heart health in general. Another significant way millet support cardiovascular health is by aiding in the management of diabetes and metabolic syndrome, both of which are major risk factors for heart disease. Their low GI and high fiber content help regulate blood sugar levels and enhance insulin sensitivity, reducing the chances of diabetes-related heart complications. Including millets in daily meals-through options like millet-based rotis, porridge, soups, or salads-can greatly lower the risk of cardiovascular diseases, improve heart function, and contribute to overall well-being. Their naturally heart-protective nutrients make them an essential part of a heart-healthy diet, promoting long-term cardiovascular wellness and longevity.

Gut health and digestive benefits

Millets are a fantastic source of dietary fiber, which makes them excellent for digestive health. Because they contain fiber, which facilitates easy bowel movements, they help prevent constipation and other gastrointestinal issues. Additionally, millets include prebiotic properties that promote the growth of beneficial gut bacteria and maintain healthy gut microbiota. This promotes better digestion, more nutrient absorption, and general gastrointestinal well-being. Because millets are high in soluble and insoluble fiber, they help keep the digestive tract healthy and control bowel motions. Soluble fiber gives the stool a gel-like consistency that helps with digestion and enhances the absorption of nutrients, while insoluble fiber adds weight to the stool, making it easier for the stool to pass through the tract. Regular consumption of millets has been linked to a lower prevalence of digestive issues such bloating, acid reflux, and IBS. Furthermore, millets serve as natural prebiotics, promoting a balanced gut flora and gut microbiome. Improving digestion, reducing inflammation in the gastrointestinal tract, and increasing immunity all depend on healthy gut flora. Millets' resistant starch further encourages the growth of probiotic bacteria, improving metabolism, avoiding stomach infections, and promoting gut health. Millets are especially helpful for people with gastritis, acid reflux disease, and other digestive issues because of their alkaline nature, which helps neutralize excess stomach acid. Their easy digestibility and gut-friendly properties make them an excellent addition to a diet focused on promoting digestive wellness and overall health.

Antioxidant and anti-inflammatory properties

Antioxidants such phenolic chemicals, flavonoids, and tannins, which are found in millets naturally, aid in preventing oxidative stress brought on by free radicals. These antioxidants are essential for lowering the risk of neurological diseases, cancer, and early aging, among other chronic illnesses. Additionally, millets possess strong anti-inflammatory properties that aid in managing conditions like arthritis, metabolic disorders, and inflammatory bowel diseases by minimizing inflammation at the cellular level. Oxidative stress is a key contributor to several diseases, including cancer, cardiovascular conditions, neurodegenerative disorders like Alzheimer's and Parkinson's, and metabolic syndromes. The antioxidants in millets help neutralize free radicals, protecting the body from cellular damage and reducing the risk of these conditions. Beyond their antioxidant potential, millets also serve as powerful anti-inflammatory agents, helping to lower chronic inflammation, which is often associated with arthritis, diabetes, obesity, and autoimmune disorders. Millets contain bioactive compounds such as ferulic acid, catechins, and quercetin, which regulate inflammatory pathways, reduce swelling, and prevent tissue damage. They are a good food option for people with inflammatory diseases like arthritis and inflammatory bowel disorders because of their anti-inflammatory qualities. A natural and efficient method to defend the body against oxidative stress, fight inflammation, and reduce the risk of chronic diseases is to incorporate millet into regular meals, whether they are consumed as rotis, cereal, salads, or fermented foods. Their potent antioxidant and anti-inflammatory properties make them a valuable functional food for enhancing immunity, supporting longevity, and promoting overall health. By integrating millets into both traditional and modern diets, individuals can improve their long-term health and well-being.

Weight management

Millets are an excellent choice for weight management due to their high fiber content, low GI, and rich nutritional profile. They support healthy weight loss, help maintain an ideal body mass, and enhance metabolism. Unlike refined grains, millets are complex carbohydrates that take longer to digest, keeping you full for extended periods. This prolonged satiety reduces frequent hunger cravings and prevents overeating, which is essential for managing calorie intake and sustaining a healthy weight. Additionally, millets are packed with proteins and essential amino acids that aid in preserving lean muscle mass and boosting metabolic function. A higher metabolism enables the body to burn calories more efficiently, supporting fat loss while maintaining muscle health. The presence of bioactive compounds and antioxidants in millets also plays a role in enhancing fat metabolism and reducing inflammation, which is often associated with obesity and weight-related health issues. Another benefit of millets in weight control is their ability to minimize bloating and water retention. Since they are gluten-free and easy to digest, they do not cause digestive discomfort, unlike wheat and other refined grains, making them a suitable choice for individuals with gluten sensitivities or digestive concerns. Furthermore, their high magnesium and potassium levels help regulate fluid balance in the body, preventing unnecessary weight gain caused by excess water retention. By incorporating millets into a balanced diet, individuals can effectively manage their weight in a healthy and sustainable way.

Boosting immunity

The immune system is strengthened by the necessary micronutrients included in millets, such as vitamins, zinc, and iron. Frequent ingestion preserves general health and strengthens the body's defenses against illnesses. They are quite helpful at boosting immune function because of their remarkable nutritional profile and antioxidant qualities, which supply essential elements that support the body's natural defenses. Iron,

zinc, magnesium, and selenium are among the vital minerals found in millets, which are important for the development and function of immune cells. This is one of the main reasons millets increase immunity. The formation and operation of white blood cells, which are crucial for infection defense, are significantly influenced by zinc. Iron aids in hemoglobin production, ensuring efficient oxygen transport throughout the body, which supports immune cell function. Magnesium and selenium serve as immune-enhancing nutrients by protecting cells from oxidative stress and reducing inflammation, which can otherwise weaken the immune response. By incorporating millets into a balanced diet, individuals can naturally strengthen their immune system, improve resistance to infections, and promote long-term health.

Bone health

Calcium, magnesium, and phosphorus are among the vital minerals found in millets, and they are important for strong bones and lowering the risk of osteoporosis. These nutrients are vital for bone formation, repair, and overall skeletal health. Calcium is the most important mineral for bone strength and development, and certain millets, such as finger millet (ragi), are exceptionally high in calcium-containing nearly three times more calcium than milk. This makes them an excellent dietary option for individuals who require higher calcium intake, such as children, pregnant women, and the elderly. Adequate calcium consumption supports bone density, minimizes the risk of osteoporosis, and helps prevent bone deterioration with age. Beyond calcium, millets provide significant amounts of magnesium, phosphorus, and potassium, all of which are essential for bone mineralization and structural integrity. Magnesium is particularly important as it aids in calcium absorption and proper utilization, ensuring that calcium is directed to the bones rather than accumulating in soft tissues. Phosphorus works in tandem with calcium to build strong bones and maintain skeletal health, while potassium helps neutralize acids that can deplete calcium from bones, thereby preserving bone strength. Additionally, millets contain silicon, a trace mineral that contributes to bone regeneration and collagen formation, which enhances joint flexibility and bone resilience. This makes them especially beneficial for individuals dealing with joint pain, arthritis, or age-related bone issues. Millets are an excellent dietary supplement for those with osteoporosis, arthritis, or other bone-related disorders because of their inherent anti-inflammatory qualities, which also help reduce joint stiffness and irritation.

Millets in Pharmaceutical Applications

Millets have gained increasing attention in pharmaceutical and nutraceutical research due to their rich profile of bioactive compounds, which exhibit various therapeutic properties. These small-seeded grains contain phytochemicals, antioxidants, and essential nutrients that contribute to disease prevention and overall health improvement. Their role in pharmaceuticals extends beyond basic nutrition, offering potential applications in disease management and functional food development [22-24].

Bioactive compounds for therapeutic use

The bioactive substances found in millets, including phenolic acids, flavonoids, tannins, lignans, and dietary fibers, have strong antibacterial, anti-inflammatory, and antioxidant properties. By decreasing oxidative stress and minimizing cellular damage, these substances aid in the neutralization of dangerous free radicals.

Phenolic compounds: Millets' capacity to fend off chronic illnesses like cardiovascular disease and neurological diseases is increased by the presence of phenolic acids and flavonoids. These substances have been shown to enhance vascular health, lower lipid peroxidation, and alter metabolic pathways. Phenolic acids and flavonoids, which are abundant in millets, have demonstrated encouraging promise in the prevention and treatment of chronic illnesses like diabetes, cardiovascular disease, and neurodegenerative diseases. As potent antioxidants, these bioactive substances aid in the body's defense against free radicals, oxidative stress, and inflammation. Phenolic compounds in millets have been found to modulate metabolic pathways, it helps reduce lipid peroxidation, a major contributor to the development of atherosclerosis and other heart-related disorders, improve insulin sensitivity, and control cholesterol levels. Furthermore, by improving blood circulation, fortifying blood vessels, and lowering the risk of hypertension, these substances promote vascular health and lessen the likelihood of heart attacks and strokes. Their neuroprotective properties also significantly lower the risk of neurodegenerative diseases like Parkinson's and Alzheimer's by postponing the beginning of cognitive decline.

Phytosterols: Millets are a natural source of phytosterols, plant-derived compounds that share a structural resemblance to cholesterol and are recognized for their ability to lower cholesterol levels. These phytosterols help reduce cholesterol absorption in the intestines, effectively decreasing overall cholesterol levels and minimizing the risk of cardiovascular conditions such as atherosclerosis, hypertension, and stroke. Including millet-based foods in the diet has been linked to a reduction in LDL (bad cholesterol) while maintaining or even boosting HDL (good cholesterol), thereby promoting heart health and preventing hypercholesterolemia. Beyond their cardiovascular benefits, phytosterols also exhibit anti-inflammatory and immune-enhancing properties, contributing to improved overall health and well-being.

Tannins and saponins: Millets are good for gut health and immunological support because of the bioactive chemicals that give them their antibacterial and anti-inflammatory qualities. Because of their astringent properties, tannins reduce the risk of infections and support a healthy digestive tract by preventing the growth of bacteria. By serving as organic growth inhibitors of tumor cells and shielding DNA from harm, they also help prevent cancer. Another class of bioactive substances found in millets, saponins, are known to improve immune function by promoting the activity of immune cells. Their anti-inflammatory qualities aid in reducing the symptoms of long-term inflammatory diseases include metabolic syndromes, gastrointestinal issues, and arthritis. Moreover, saponins contribute to heart health by aiding in cholesterol reduction

and supporting overall metabolic balance, making millets a valuable addition to a health-conscious diet.

Dietary fibers and prebiotics: Millets are rich in dietary fiber, which plays a key role in improving digestive health, supporting gut microbiota, and lowering the risk of colon-related diseases. The soluble fiber in millets aids in maintaining healthy digestion by promoting smooth bowel movements, preventing constipation, and reducing the likelihood of digestive issues such as IBS and diverticulitis. Additionally, millets exhibit a prebiotic effect, fostering the growth of beneficial gut bacteria that contribute to immune regulation, efficient nutrient absorption, and overall gastrointestinal health. A well-balanced gut microbiome strengthens immunity by combating harmful pathogens, reducing inflammation, and enhancing metabolic functions. Furthermore, the high fiber content in millets supports weight management and cardiovascular health by increasing satiety, curbing overeating, and assisting in cholesterol regulation.

Anti-cancer and immunomodulatory properties

Recent research highlights the potential of millets in cancer prevention due to their high antioxidant content and immune-modulating capabilities. The phytochemicals present in millets act as natural inhibitors of carcinogenesis by interfering with tumor cell proliferation and inducing apoptosis (programmed cell death) in malignant cells.

Cancer prevention: Since millets are rich in polyphenols, such as flavonoids, phenolic acids, and tannins, which have been shown to have anti-proliferative effects on a variety of cell types, they are becoming more and more known for their possible anti-cancer qualities. By limiting tumor growth, altering cell signaling pathways, and reducing oxidative DNA damage, these bioactive substances aid in the fight against cancer. Free radicals and oxidative stress are major causes of cancer because they cause DNA mutations that can result in unchecked cell division. Millets' strong antioxidants reduce the risk of cancer development and genetic damage by neutralizing these dangerous chemicals. Furthermore, studies indicate that by promoting gut health, lowering chronic inflammation, and improving liver detoxification processes, including millets in the diet may lower the risk of diseases like colorectal, breast, and liver cancer. Additionally, millets' high fiber content is essential for removing toxins and carcinogens from the digestive tract, which reduces the risk of colorectal cancer. Millets help to prevent cancer and improve general digestive health by encouraging bowel regularity and reducing the development of dangerous colon polyps.

Modulation of inflammatory responses: Chronic inflammation plays a significant role in the onset of various diseases, including cancer, autoimmune disorders, and metabolic conditions. Millets are rich in bioactive compounds with potent anti-inflammatory properties that help regulate immune responses and reduce prolonged inflammation. These compounds function by inhibiting the production of pro-inflammatory cytokines molecules that drive and sustain inflammation. Elevated cytokine levels can contribute to tissue damage, genetic mutations, and an increased risk of cancer. By mitigating inflammation, millets help protect healthy cells, lower the chances of tumor development, and support immune system balance. Additionally, key compounds found in millets, such as ferulic acid, catechins, and flavonoids, have demonstrated strong anti-inflammatory effects. These properties make millets beneficial in managing conditions like arthritis, cardiovascular diseases, and metabolic disorders, further reducing the risk of inflammation-associated cancers.

Boosting immune function: Essential micronutrients including iron, zinc, and selenium, which are abundant in millets, are critical for enhancing immune function. By supporting the development and activation of immune cells, these nutrients improve the body's defenses against infections, long-term conditions, and aberrant cell division. Selenium is a potent antioxidant that protects cells from oxidative stress and DNA damage, while zinc is essential for immunological response, wound healing, and lessening the severity of infections. Iron promotes the production of red blood cells and the movement of oxygen, which guarantees the best possible immune cell function. Additionally, millets contain bioactive peptides that help modulate the immune system and fortify the body's defenses against infections and harmful substances. A balanced immune system, a decreased risk of infection, and protection against immune-related illnesses like cancer can all be achieved by including millets in the diet.

Role in functional foods and nutraceuticals

Millets are increasingly being incorporated into functional foods and nutraceuticals due to their health benefits and medicinal properties. Functional foods derived from millets not only provide essential nutrients but also offer therapeutic advantages that help in preventing and managing various health disorders.

Gluten-free and digestive health benefits: People with wheat allergies, gluten intolerance, or celiac disease can benefit greatly from millets as a gluten-free substitute. Millets, as opposed to gluten-containing grains, promote easy digestion, lessen bloating, and lessen gut inflammation. Their high fiber content promotes balanced gut microbiota, helps control bowel motions, and avoids constipation. Furthermore, the growth of advantageous gut bacteria is promoted by millets' prebiotic qualities, which are critical for immunological and nutritional absorption. For those seeking to enhance digestive health while avoiding gluten, incorporating millet-based meals such probiotic millet beverages, gluten-free bread, and porridges offer a healthy and safe alternative.

Diabetes management: Millet-based functional foods have a low GI, making them a beneficial choice for individuals with diabetes and those prone to insulin resistance. Unlike refined grains, millets are rich in complex carbohydrates and resistant starch, which break down slowly, leading to a gradual release of glucose into the bloodstream. This controlled digestion helps maintain steady blood sugar levels, prevent sudden glucose spikes, and enhance insulin sensitivity. Additionally, the dietary fiber and polyphenols in millets support better glucose metabolism, making millet-based products like diabetic-friendly flours, breakfast cereals, and sugar-free snacks a valuable addition to diabetes management plans.

Cardiovascular health: Millets support cardiovascular health due to their high content of bioactive peptides, antioxidants, and polyphenols, which help combat oxidative stress, lower cholesterol levels, and enhance blood circulation. The presence of phytosterols and dietary fiber in millets inhibit cholesterol absorption in the intestines, thereby reducing LDL (bad cholesterol) and preventing plaque build-up in the arteries. These heart-protective properties make millets effective in lowering the risk of hypertension, atherosclerosis, and other cardiovascular diseases. Researchers are exploring millet-based nutraceuticals for their potential in promoting vascular health and regulating blood pressure. Additionally, millet-enriched heart-healthy foods, such as whole grain millet bread, cholesterol-lowering health bars, and antioxidant-rich millet beverages, are gaining popularity as functional foods that help prevent heart-related disorders and promote overall wellness.

Incorporation into fortified foods: Millets are becoming a key ingredient in fortified and value-added food products due to their exceptional nutrient profile and numerous health benefits. Their abundance of essential vitamins, minerals, amino acids, and bioactive compounds makes them a valuable component in fortified cereals, energy bars, health beverages, and dietary supplements. These millet-based products cater to health-conscious individuals, those with specific dietary needs, and consumers looking for functional nutrition. Additionally, fortifying millets with essential micronutrients like iron, calcium, and vitamins enhances their nutritional value, making them an effective solution for addressing malnutrition, supporting metabolic health, and boosting overall well-being. The growing interest in millet-based functional foods and nutraceuticals underscores their potential in creating innovative and health-enhancing dietary options for modern consumers.

Processing and Value Addition in Millets

Millets' high nutritional content, tolerance to climate change, and health advantages are making them an increasingly important food source. However, to enhance their usability, shelf life, and consumer appeal, various processing and value addition techniques have been developed. These methods can be broadly classified into traditional and modern processing techniques, followed by the production of fortified millet products and their role in functional foods and beverages [25-27].

Traditional vs modern processing techniques

Traditional processing techniques

Traditional processing methods for millets have been practiced for centuries in rural and indigenous communities. These methods are typically labor-intensive but help retain the nutritional integrity of the grains. Some of the common traditional processing techniques include:

Dehusking and polishing: Traditional dehusking methods, such as using stone grinders or wooden pounders, are commonly practiced removing the outer husk while preserving the nutrient-dense bran layer. This process helps retain essential fiber and micronutrients, making it a healthier alternative to modern mechanical polishing. However, excessive polishing can result in significant nutrient loss by stripping away vital fibers, vitamins, and minerals. Compared to industrial processing, manual dehusking ensures minimal nutrient depletion, maintaining the natural goodness of millets.

Soaking and fermentation: Soaking millets in water for several hours helps break down anti-nutritional compounds such as phytic acid and tannins, improving their digestibility and enhancing the absorption of essential minerals. This process makes nutrients more bioavailable and softens the grain for easier consumption. Fermentation further boosts their nutritional profile by introducing beneficial probiotics, which support digestion and promote healthier gut microbiome.

Milling and grinding: Traditional hand milling and stone grinding are widely used to produce millet flour, which serves as a key ingredient in porridges, flatbreads, and other staple foods. These methods help retain essential nutrients and dietary fiber, unlike modern roller milling, which often results in nutrient loss. By preserving the natural goodness of millets, traditional milling ensures a more wholesome and nutritious final product.

Germination (Sprouting): Sprouting millet stimulates enzymatic activity, breaking down complex compounds and enhancing nutrient absorption. This process boosts the bioavailability of essential minerals like iron while increasing levels of vitamin C and folate. Additionally, sprouting improves digestibility, making millets a more nutritious and easily absorbed dietary choice.

Modern processing techniques

With advancements in food technology, modern processing techniques have been developed to improve millet utilization, reduce cooking time, and enhance product consistency. Some of these techniques include:

Mechanical dehulling and polishing: Modern automated machines streamline the dehulling process, increasing efficiency, yield, and reduce manual labor. These technologies enable large-scale millet processing with improved uniformity and speed. However, over-processing can lead to the loss of vital nutrients such as fiber, vitamins, and minerals, highlighting the need for optimized techniques that preserve millet's nutritional value while ensuring efficiency.

Extrusion cooking: The extrusion process involves subjecting millet flour or whole grains to high temperature and pressure, transforming them into convenient ready-to-eat products such as breakfast cereals, snack bars, and puffed millet snacks. This method enhances digestibility by breaking down complex carbohydrates and proteins while preserving essential nutrients. Additionally, extrusion improves the texture, flavor, and shelf life of millet-based products, making them more suitable for large-scale food production and consumer appeal.

Microwave and infrared processing: Advanced heating methods improve processing efficiency while preserving essential nutrients. Unlike conventional heat treatments, techniques such as microwave and infrared processing distribute heat evenly, effectively reducing anti-nutritional factors like

phytic acid while maintaining bioactive compounds, including antioxidants and essential amino acids. These innovative approaches enhance both the functional and nutritional value of millet-based foods.

Encapsulation technology: Encapsulation is a cutting-edge method for producing functional millet-based goods that guarantees improved stability and regulated nutrient release. Bioactive substances including polyphenols, flavonoids, and omega-3 fatty acids are shielded against oxidation and destruction by techniques like spray drying and nano-encapsulation. This procedure increases the bioavailability of vital minerals and prolongs shelf life, increasing the health advantages of millet-based meals.

Fortified millet products

Fortification is a key approach to improving the nutritional value of millet-based foods. Since millets are naturally rich in fiber, minerals, and antioxidants, they serve as an excellent base for fortified products. Some examples of fortified millet products include:

Millet flours fortified with iron and zinc: Iron and zinc-fortified millet flour play a vital role in combating micronutrient deficiencies that contribute to anemia, weakened immunity, and impaired cognitive development. Iron is crucial for red blood cell formation and oxygen transport, while zinc supports immune function, wound healing, and enzymatic processes. Enriching millet flour with bioavailable iron sources like ferrous sulfate, ferrous fumarate, or micronized ferric pyrophosphate enhances iron absorption, helping to prevent iron-deficiency anemia, especially in women and children. Similarly, zinc fortification boosts immunity, promotes growth, and reduces the severity of infections. These fortified flours serve as a cost-effective and sustainable nutritional intervention, particularly in malnourished regions. Additionally, fortification does not significantly impact the taste or texture of millet-based foods, making them easy to incorporate into daily diets. Regular consumption of iron and zinc-fortified millet products supports cognitive function, energy levels, and overall health, making them an essential component of global nutrition initiatives.

Protein-enriched millet blends: Enhanced amino acid profile while millets contain a moderate amount of protein, they are often low in certain essential amino acids like lysine. Blending them with protein-rich sources such as legumes (e.g., chickpeas and lentils), dairy proteins (e.g., whey and casein), or plant-based proteins (e.g., soy and pea protein) creates a more balanced amino acid profile, improving overall protein quality. Muscle growth and recovery in protein-enriched millet blends are highly beneficial for athletes and individuals with high protein requirements. The combination of millets with complementary protein sources provides essential amino acids needed for muscle repair, growth, and overall strength.

Satiety and weight management: These blends enhance satiety, reduce hunger and support weight management. The slow-digesting nature of millet, combined with high-quality proteins, helps maintain steady energy levels and prevents overeating.

Improved Digestibility and Absorption: Sprouting, fermenting, or hydrolyzing the protein-enriched blends can further enhance digestibility and nutrient absorption. These processes reduce anti-nutritional factors, making proteins more bioavailable and easier to digest, particularly for individuals with digestive sensitivities.

Probiotic millet-based foods: Fermented millet-based foods enriched with probiotics such as Lactobacillus strains support gut health and improve digestion. These include millet-based yogurt, kefir, and probiotic beverages. Probiotic millet-based foods are an innovative approach to enhancing gut health by combining the nutritional benefits of millets with the digestive advantages of probiotics. Millets, being rich in dietary fiber, act as a prebiotic, fostering the growth of beneficial gut bacteria. When fermented with probiotic strains such as Lactobacillus and Bifidobacterium, these foods promote better digestion, improve nutrient absorption, and support a balanced gut microbiome. Fermentation also helps break down anti-nutritional factors like phytic acid, enhance the bioavailability of essential minerals such as iron, calcium, and zinc. Popular probiotic millet-based products include millet-based yogurt, kefir, fermented porridge, and probiotic beverages, which serve as excellent alternatives to dairy-based probiotics for lactose-intolerant individuals. These fortified foods are very helpful for those with digestive disorders including IBS or constipation because they can help increase immunity, lower inflammation, and enhance overall gut function. Probiotic millet meals are also more palatable for commercial manufacturing and consumption due to their improved sensory qualities and longer shelf life. Frequent use of these functional meals improves general wellbeing, energy levels, and digestive health.

Vitamin-enhanced millet products: The nutritional content of millet-based weaning foods and staple items is increased through fortification with vital vitamins like vitamin A, vitamin B complex, and vitamin D. A major nutritional breakthrough, vitamin-enhanced millet products enrich millets with vital vitamins like vitamin A, vitamin B-complex, and vitamin D, treating inadequacies and enhancing general health. Although millets are naturally high in fiber, minerals, and antioxidants, fortification can increase their vitamin content and improve their nutritional value, especially in staple items and weaning foods. Fortification with vitamin A helps avoid deficiencies that might result in night blindness and impaired immunity. Vitamin A is essential for preserving skin health, vision, and immune function. Energy metabolism, brain function, and the production of red blood cells all depend on the B-complex vitamins, which include B1 (thiamine), B2 (riboflavin), B6 (pyridoxine), and B12 (cobalamin). These vitamins can be added to millet-based diets to promote cognitive development and lower the risk of neurological illnesses and anemia. A lack of vitamin D can cause osteoporosis in adults and rickets in youngsters, making it especially crucial for people with little exposure to the sun. Vitamin D is essential for calcium absorption and bone health. For vulnerable populations, such as children, pregnant women, and the elderly, fortified millet products such as vitamin-enriched flours, porridges, energy bars, and ready to eat snacks offer a practical

and efficient means of providing vital nutrients. By promoting energy generation, bone strength, and immune function, these items not only aid in the fight against malnutrition but also improve general health. Consuming vitamin-fortified millet meals on a regular basis can help address micronutrient deficiencies in a sustainable and convenient way, especially in areas with limited dietary diversity.

Omega-3 and fiber-enriched millet snacks: The inclusion of flaxseeds, chia seeds, or other omega-3 sources in millet-based snacks improves their cardiovascular benefits while adding functional properties. Omega-3 and fiber-enriched millet snacks offer a powerful combination of heart-healthy fats and digestive benefits, making them a functional and nutritious alternative to conventional processed snacks. The inclusion of omega-3-rich ingredients such as flaxseeds, chia seeds, walnuts, and hemp seeds enhance the cardiovascular benefits of millet-based snacks by reducing inflammation, LDL, and supporting brain function. Omega-3 fatty acids, particularly alpha-linolenic acid, play a crucial role in maintaining heart health, reducing the risk of cardiovascular diseases, and promoting cognitive well-being. Additionally, fiber enrichment through natural sources like psyllium husk, oats, and prebiotic fibers improves digestive health by regulating bowel movements, supporting gut microbiota, and stabilizing blood sugar levels. Since millets are already a good source of dietary fiber, their combination with additional fiber-rich ingredients further enhances satiety, making these snacks ideal for weight management and appetite control. To satisfy health-conscious consumers, omega-3 and fiber-enriched millet snacks are available in a variety of forms, such as energy bars, granola clusters, crackers, and roasted millet puffs. These fortified snacks provide a nutrient-dense substitute for highly processed foods, making them especially advantageous for people with diabetes, high cholesterol, or stomach problems. Omega-3 and fiber-enriched millet snacks are becoming more and more well-liked as a sustainable and practical choice that promotes general well-being and provides vital nutrients in a tasty and convenient way, thanks to the rising demand from consumers for functional foods.

Role in functional foods and beverages

Millets have gained popularity in the functional food sector due to their impressive nutritional profile. They are widely used in:

Bakery and confectionery free of gluten: Millets play a crucial role in the development of gluten-free bakery and confectionery products, offering a nutritious and versatile alternative to wheat-based products for individuals with celiac disease, gluten intolerance, and those opting for gluten-free diets. Millet flour, derived from grains like sorghum, finger millet, pearl millet, and foxtail millet, is rich in dietary fiber, essential minerals (iron, calcium, and magnesium), and antioxidants, making it a healthier choice compared to refined wheat flour. Due to its natural gluten-free nature, millet flour is widely used in the production of gluten-free bread, cookies, cakes, pastries, and pasta, providing a safe and wholesome option for those who need to avoid gluten. Additionally, millets contribute to improved texture, flavor, and shelf life when combined with binding agents such as xanthan gum or guar gum, which help mimic the elasticity and structure provided by gluten. The incorporation of millet flour enhances the nutritional profile of bakery products, increasing their protein, fiber, and micronutrient content while also supporting better digestion and gut health. As consumer demand for gluten-free and functional foods continues to grow, millet-based bakery and confectionery products are gaining popularity, offering sustainable, nutrient-dense, and delicious alternatives to conventional wheat-based items.

Healthy breakfast cereals and granola bars: Millets serve as a highly nutritious and functional ingredient in healthy breakfast cereals and granola bars, offering a fiber-rich, vitamin-packed, and mineral-dense alternative to conventional grain-based products. Puffed or extruded millet-based cereals provide a light, crispy texture while retaining essential nutrients like iron, calcium, magnesium, and B-complex vitamins, which are crucial for energy metabolism and overall health. These cereals are ideal for individuals seeking gluten-free, whole-grain, and high-fiber breakfast options, making them beneficial for digestive health, weight management, and sustained energy release. Granola bars made with millet flakes, puffed millets, or millet flour serve as nutrient-dense, on-the-go snack options, catering to health-conscious consumers, athletes, and busy individuals. When combined with nuts, seeds, dried fruits, and natural sweeteners like honey or dates, these bars provide a balanced mix of proteins, healthy fats, and complex carbohydrates, making them a sustained energy source for active lifestyles. The inclusion of functional ingredients such as flaxseeds, chia seeds, or probiotics further enhances the health benefits of these products by promoting heart health, gut health, and immune support.

Millet-based plant-based milk alternatives: Millet milk is particularly beneficial for individuals with lactose intolerance, dairy allergies, or those following vegan diets, offering a cholesterol-free and easily digestible alternative to cow's milk. It is also a low GI beverage, making it suitable for people with diabetes or blood sugar concerns. The presence of antioxidants and bioactive compounds in millets supports heart health, immune function, and gut microbiota balance, further enhancing its functional properties. Commercially available millet-based milk alternatives are often fortified with calcium, vitamin D, and vitamin B12 to match the nutritional profile of dairy milk. It can be used in smoothies, cereals, baking, coffee, and other beverages, making it a versatile option for both home and commercial food applications. Additionally, as consumers seek more sustainable and climate-friendly food choices, millet milk stands out due to the low water and resource requirements of millet cultivation, making it an environmentally responsible dairy alternative. With its impressive nutritional benefits and growing market demand, millet milk is poised to become a mainstream plant-based beverage option in the functional food industry.

Fermented millet beverages: Fermented millet beverages are gaining popularity due to their digestive health benefits, probiotic content, and rich nutritional profile. These beverages, which include traditional millet beers, probiotic smoothies, and non-alcoholic fermented drinks, have been consumed for centuries in various cultures and are now being modernized

for wider commercial appeal. Fermentation enhances the bioavailability of essential nutrients, including B vitamins, amino acids, and minerals like iron and zinc, while also breaking down anti-nutritional factors such as phytic acid and tannins, making millets easier to digest. Traditional millet-based fermented drinks, such as Kunu (West Africa), Tongba (Nepal), and Boza (Middle East and Balkans), are made through natural fermentation processes, which encourage the growth of beneficial probiotic bacteria like Lactobacillus and Bifidobacterium. These probiotics help maintain a healthy gut microbiome, improve digestion, and boost immunity. Modern variations, such as fermented millet probiotic smoothies and non-alcoholic probiotic beverages, are being developed as functional drinks aimed at health-conscious consumers. These beverages provide a refreshing, nutrient-dense alternative to sugary carbonated drinks while supporting gut health, metabolism, and overall well-being.

Instant millet-based soups and ready to eat meals: The growing demand for convenient, nutrient-dense, and quick-to-prepare meals has led to the rise of instant millet-based soups, noodles, and porridge mixes, which provide a healthy alternative to conventional processed foods. These ready-to-eat products are designed to retain high fiber, protein, and essential micronutrients, making them a wholesome option for busy individuals, health-conscious consumers, and those seeking balanced meals. Millets such as finger millet (ragi), pearl millet (bajra), sorghum (jowar), and foxtail millet serve as excellent base ingredients due to their low GI, gluten-free nature, and rich antioxidant content. Instant millet soups are fortified with vegetables, herbs, and plant-based proteins like lentils or soy to enhance their flavor, texture, and nutritional profile. They provide gut-friendly fiber, support weight management, and help stabilize blood sugar levels, making them ideal for individuals with diabetes, digestive issues, or heart health concerns. Millet-based porridge mixes, often enriched with nuts, seeds, and dried fruits, offer a quick breakfast or meal replacement option that delivers long-lasting energy. Additionally, millet noodles and pasta, formulated without refined wheat, provide a healthier alternative to conventional instant noodles while ensuring better digestion and satiety.

Challenges and Future Prospects

Market potential and consumer acceptance: Millets are often considered "coarse grains" and are overshadowed by staple cereals like rice and wheat. Although they are nutritionally superior, their market potential is underutilized due to factors such as low consumer awareness, limited availability, and lack of processing infrastructure [28].

Consumer awareness and perception: One of the major challenges in promoting millets as a staple food is limited consumer awareness and perception. Despite their high nutritional value, climate resilience, and health benefits, millets are often perceived as a "poor man's food" or as an ancient grain with limited appeal compared to modern refined cereals like rice and wheat. This perception stems from historical dietary shifts, urbanization, and changing food preferences influenced by globalization and industrialized agriculture. Many consumers lack knowledge about the health benefits, culinary versatility, and environmental sustainability of millets, leading to their underutilization in daily diets. Furthermore, availability and accessibility issues play a role in limiting millet consumption. Unlike widely marketed grains, millets are often found in limited quantities in supermarkets, and their higher price due to lower production and processing costs can deter consumers. Additionally, lack of awareness regarding cooking methods and misconceptions about millet taste and texture prevent many people from adopting them into their diets. To overcome these challenges, government policies, public health campaigns, and market-driven strategies are essential. Awareness programs through social media, educational institutions, and food industry collaborations can help reshape public perception and highlight the nutritional, environmental, and economic benefits of millets. Additionally, integrating millets into modern food products like ready-to-eat meals, bakery items, snacks, and fortified foods can make them more appealing to younger generations. With increased consumer education, better availability, and innovative millet-based food options, millets have the potential to become a mainstream superfood, contributing to global food security, health, and sustainability [29].

Availability and affordability: One of the significant challenges in promoting millets as a staple food is their limited availability and affordability in comparison to widely consumed cereals like rice and wheat. The green revolution prioritized high-yielding crops such as rice and wheat, leading to a decline in millet production and consumption. As a result, millets are now cultivated on a smaller scale, making them less accessible in mainstream markets. The lack of structured supply chains, inadequate storage facilities, and inefficient processing techniques further restrict their widespread distribution. Affordability is another major concern. Although millets are drought-resistant and require fewer resources for cultivation, their market price is often higher due to low production volumes, limited government subsidies, and high processing costs. Unlike wheat and rice, which receive strong financial and policy support, millets are not widely promoted through minimum support prices (MSP) and large-scale procurement programs, making them less attractive to both farmers and consumers. The cost of millet-based processed foods is also relatively high due to specialized processing requirements, further limiting their affordability for low-income populations. To enhance the availability and affordability of millets, policy interventions are necessary. Governments and agricultural organizations should focus on incentivizing millet cultivation through subsidies, improved infrastructure, and research in high-yield millet varieties. Additionally, integrating millets into public distribution systems (PDS), midday meal programs, and food aid initiatives can increase access for economically disadvantaged populations. Strengthening processing technologies and value chain development will also help reduce costs, making millet-based products more economically competitive and widely available. By addressing these challenges, millets can play a crucial role in enhancing food security, promoting sustainable agriculture, and improving global nutrition [30].

Product development and innovation: One of the key challenges in increasing the adoption of millets is limited

product development and innovation in comparison to mainstream grains like wheat, rice, and corn. Traditional millet-based foods, such as porridge and flatbreads, are well known in certain regions, but there is a lack of diverse, ready-to-eat, and value-added millet products that cater to modern consumer preferences. Unlike wheat and rice, which have been extensively used in bakery items, snacks, and processed foods, millets require specialized processing techniques due to their small grain size, harder outer husk, and distinct texture. This has led to technological and industrial challenges in developing commercially viable millet-based products that are both nutrient-rich and appealing to consumers. Another challenge in product innovation is the lack of research and investment in millet-based food technology. The food industry has historically focused on refining and fortifying wheat- and rice-based products, leaving millets underexplored in areas such as extrusion technology (for snacks and breakfast cereals), fermentation (for probiotic-rich foods), and functional ingredient development (for nutraceuticals and supplements). Additionally, the short shelf life of certain millet flours and the difficulty in achieving the desired taste, texture, and consistency pose further obstacles to widespread acceptance. To address these challenges, there is a need for greater investment in millet research and processing innovations. Food scientists and industries must develop novel millet-based products such as gluten-free baked goods, millet-based pasta, energy bars, instant mixes, plant-based dairy alternatives, and fermented foods. Advances in processing technologies, including milling, puffing, and extrusion, can help create millet products that are nutritionally superior, convenient, and appeal to a global audience [31].

Competition with other grains: One of the major challenges facing the widespread adoption of millets is their competition with other staple grains like rice, wheat, and maize, which dominate global food production and consumption. These grains have been extensively cultivated, processed, and marketed for decades, making them more accessible, affordable, and familiar to consumers. The green revolution further reinforced the dominance of wheat and rice by promoting high-yielding varieties, large-scale subsidies, and mechanized farming, which led to a decline in millet production. As a result, millets are often perceived as secondary or traditional grains, limiting their integration into mainstream diets. Another factor contributing to this competition is consumer preference and convenience. Rice and wheat-based products such as bread, pasta, and noodles have become staples in many households due to their soft texture, ease of cooking, and longer shelf life. In contrast, millets require longer cooking times and specific processing techniques to improve their taste and texture. Additionally, due to limited awareness about millet-based diets and their health benefits, many consumers prefer the more readily available and well-marketed alternatives. To overcome this challenge, policy support, marketing strategies, and product diversification are essential. Governments can promote millet cultivation through subsidies, incentives, and inclusion in food security programs, ensuring farmers have the necessary resources to grow these climate-resilient crops. The food industry must also focus on developing innovative millet-based products such as millet pasta, bread, snacks, and ready-to-eat meals, making them as convenient and appealing as wheat and rice alternatives. Additionally, awareness campaigns, nutritional labelling, and millet-based recipes can help shift consumer perception and position millets as a modern superfood rather than just a traditional grain. By creating a competitive market presence, millets can coexist with other grains, offering consumers a nutrient-rich, sustainable alternative that contributes to global food security [32].

Policy interventions and government initiatives

Governments and international organizations recognize the importance of millets in addressing food security and nutrition challenges. Several initiatives have been launched to promote millet cultivation, processing, and consumption.

Incentives for millet farmers: Governments in many countries are offering subsidies, MSP, and incentives to encourage farmers to cultivate millets. To promote millet cultivation and ensure its role in food security and nutrition, governments have introduced various incentives for millet farmers to encourage large-scale production and improve economic viability. Due to the historical shift towards high-yielding cereals like rice and wheat, millet farming was neglected, leading to low production, limited market access, and inadequate financial support for farmers. Recognizing the potential of millets as climate-resilient, nutrient-rich crops, policymakers have started implementing financial incentives, subsidies, and technical assistance to boost millet farming. One of the key incentives is MSP for millet crops, ensuring that farmers receive fair prices and are encouraged to cultivate these grains. Additionally, some governments provide direct financial assistance, input subsidies for seeds, fertilizers, and irrigation facilities, making millet farming cost-effective and profitable. Agricultural extension programs and research initiatives also focus on developing high-yielding millet varieties, improving pest resistance, and optimizing farming techniques to enhance productivity. To further support millet farmers, governments are integrating millets into PDS, school meal programs, and food security initiatives, ensuring a stable demand and market for these crops. International efforts, such as the United Nations declaring 2023 as the International Year of Millets, have also contributed to policy advancements, increased funding, and global awareness about the benefits of millet farming. By expanding market linkages, facilitating farmer cooperatives, and promoting millet-based agro-industries, these incentives aim to revitalize millet production, improve farmer incomes, and enhance global food sustainability.

Integration into PDS: To enhance food security, nutritional diversity, and agricultural sustainability, governments have begun integrating millets into PDS and other social welfare programs. Traditionally, rice and wheat have dominated PDS allocations, leaving nutrient-rich but underutilized grains like millets out of mainstream food supply chains. However, recognizing the health benefits, climate resilience, and lower resource requirements of millets, policymakers are now focusing on reintroducing and promoting these grains through subsidized food programs. Many countries, especially in millet-growing regions, have included millets in government-

supported meal programs, such as midday meals in schools, ration schemes for low-income families, and food security initiatives for vulnerable populations. This ensures wider accessibility to millets while supporting small-scale farmers by creating stable market demand. Additionally, initiatives like the National Food Security Act in India have paved the way for the distribution of coarse cereals, including millets, at subsidized rates, making them more affordable and appealing to consumers. To further strengthen millet integration into PDS, governments are investing in procurement, storage, and supply chain improvements to ensure millet grains reach the beneficiaries in good quality and adequate quantities. Awareness campaigns, nutritional education, and millet-based product innovations such as fortified millet flour, millet-based ready-to-eat foods, and millet meal kits are also being promoted to increase acceptance and consumption among the general public.

International recognition and promotion: Global awareness of millets' critical role in tackling malnutrition, food security, and climate resilience has resulted in substantial worldwide promotion and policy actions. 2023 has been proclaimed the "International Year of Millets" by the United Nations, emphasizing the significance of these grains for biodiversity, hunger alleviation, and sustainable agriculture. The goals of this worldwide effort were to promote the use of millets in international food systems, boost production, and enhance awareness. A number of international organizations have highlighted the importance of millets in supplying vital nutrients, assisting small-scale farmers, and enhancing agricultural sustainability. These organizations include the FAO, World Health Organization, and International Fund for Agricultural Development. To ensure their greater accessibility and acceptance, numerous nations have begun integrating millets into their national dietary recommendations, school meal programs, and food security strategies. Additionally, millet production and consumption have increased due to international trade policy and research partnerships. Countries are increasing the efficiency of their supply chains, promoting cross-border commerce in millet grains and goods, and investing in millet-based value-added products. In order to increase production and market viability, millet cultivation, research funding, and technological developments are being promoted by international food summits and agricultural forums.

Research Gaps and Future Directions

Despite significant progress, several research gaps remain in understanding and utilizing millets to their full potential. Addressing these gaps can drive future innovations in the food and pharmaceutical sectors [33, 34].

Nutritional and pharmacological studies: Despite the growing recognition of millets as a superfood, there are still significant research gaps in fully understanding their nutritional and pharmacological potential. While millets are known to be rich in essential macronutrients (carbohydrates, proteins, and fats), micronutrients (vitamins and minerals), dietary fiber, and bioactive compounds, more in-depth clinical and biochemical studies are needed to explore their precise health benefits, bioavailability, and disease-preventive properties. One of the key areas requiring further investigation is the role of millets in chronic disease management, particularly in conditions like diabetes, cardiovascular diseases, obesity, and neurodegenerative disorders. Although studies have shown that millets have a low GI, antioxidant properties, and cholesterol-lowering effects, more controlled human trials and pharmacokinetic studies are needed to establish standardized recommendations for their therapeutic use.

Processing and storage technologies: One of the major challenges limiting the widespread adoption and commercialization of millets is the lack of advanced processing and storage technologies. Unlike common cereals like rice and wheat, millets have a hard-outer husk and small grain size, which makes their dehulling, milling, and processing more complex and labor-intensive. Research is needed to develop efficient, cost-effective, and scalable processing methods that can retain the nutritional integrity of millets while enhancing their texture, taste, and shelf life. Traditional processing techniques such as soaking, germination, and fermentation are known to improve nutrient bioavailability and digestibility; however, more studies are required to optimize these methods for large-scale industrial applications. Additionally, advancements in extrusion technology, micronization, and fortification can help create value-added millet products such as ready-to-eat cereals, gluten-free flour blends, and nutraceutical formulations, making them more appealing to modern consumers. Storage remains another significant challenge due to millets' susceptibility to moisture absorption, fungal contamination, and pest infestation. Research on improved post-harvest handling, packaging innovations, and preservation techniques is crucial to extend the shelf life of millet grains and flour without compromising their nutritional quality and safety. Developing eco-friendly and cost-efficient storage solutions can also benefit small-scale farmers and rural communities, reduce post-harvest losses and ensure year-round millet availability.

Breeding and genetic improvement: Despite their resilience to harsh environmental conditions, millet productivity and yield potential remain relatively low compared to other staple crops like wheat and rice. Enhancing millet cultivars to increase grain output, disease resistance, drought tolerance, and nutritional quality requires breeding and genetic enhancement initiatives. Comparing this field to other important crops, however, research is still scarce and unexplored. High-yielding and stress-resistant millet cultivars have been created through traditional breeding techniques, but in order to speed up genetic advancements, more sophisticated biotechnological techniques are required, such as genome editing (Clustered regularly interspaced short palindromic repeats (CRISPR) associated protein 9 (CRISPR-Cas 9)), marker-assisted selection, and genomic selection. These technologies can help identify and modify specific genes responsible for higher protein content, enhanced micronutrient density (iron, zinc, and calcium), and improved resistance to pests, diseases, and environmental stressors. Another critical area of research is the preservation and utilization of millet genetic diversity. Millets have a rich genetic pool, but many traditional landraces and wild relatives remain underutilized in breeding programs. Strengthening

genetic resource conservation and developing hybrid millet varieties with superior agronomic traits can significantly boost productivity, farmer profitability, and food security.

Sustainable agriculture and climate resilience: Millets are recognized for their exceptional adaptability to harsh environmental conditions, making them a vital crop for sustainable agriculture and climate resilience. Unlike water-intensive cereals like rice and wheat, millets thrive in drought-prone, arid, and semi-arid regions, requiring minimal water, chemical fertilizers, and pesticides. However, more scientific research and policy interventions are needed to fully harness their potential in mitigating the impacts of climate change and ensuring global food security. One of the key research gaps in this area is the need for agronomic optimization to improve millet cultivation techniques. Studies should focus on enhancing soil fertility, optimizing water-use efficiency, and implementing climate-smart agricultural practices to maximize millet yields while maintaining ecological balance. The development of sustainable intercropping and crop rotation systems involving millets can also help restore soil health, enhance biodiversity, and reduce dependency on chemical inputs.

Commercialization of millet-based products: The expansion of millet-based products is essential for boosting their market presence, increasing consumer awareness, and ensuring economic sustainability. Despite their significant nutritional benefits and environmental advantages, millets remain underutilized in mainstream food markets due to limited awareness, insufficient processing technologies, and a lack of diverse value-added products. Enhancing research and innovation in this sector can bridge the gap between traditional millet consumption and modern dietary preferences, making them more appealing and accessible to a wider audience. One of the key challenges in millet commercialization is the limited shelf life of millet-based products, as they are prone to rancidity and degradation under poor storage conditions. Advancing processing techniques-such as extrusion, fermentation, micronization, and fortification-can improve product stability, texture, and flavor. Additionally, better packaging and preservation methods are needed to extend shelf life while maintaining nutritional quality. Another important aspect is product diversification. Unlike widely consumed staples like wheat and rice, millets have yet to be fully explored in the convenience food sector, including ready-to-eat meals, bakery products, energy bars, plant-based dairy alternatives, and gluten-free formulations. Investing in research and development for millet-based functional foods, nutraceuticals, and health supplements can help meet the increasing consumer demand for nutritious, organic, and sustainable food choices. Effective marketing and branding strategies are also vital for millet commercialization. Understanding consumer preferences, taste expectations, and pricing strategies can help position millets as a premium, health-conscious option in the global food industry. Additionally, strengthening supply chain infrastructure, establishing millet processing centers, and providing financial support to millet-based enterprises can improve market reach and affordability.

Conclusion

Millets are showing great health advantages and are becoming an increasingly important part of the world's food security. They are a great substitute for traditional staple grains like rice and wheat because of their high nutritional content, which includes fiber, proteins, vitamins, and vital minerals. Millets' importance in sustainable agriculture, which helps fight climate change and food scarcity, is highlighted by their capacity to flourish in dry and semi-arid environments with little water and inputs. Millets have promise uses in medicine and illness prevention in addition to their significance in food security. Their bioactive substances have been connected to health advantages like better heart health, better digestion, and diabetes control. Millets may be used to prevent chronic diseases like obesity, heart disease, and even some types of cancer since they contain antioxidants and polyphenols. Because of their limited market availability, processing difficulties, and lack of knowledge, millets continue to be neglected in popular diets despite their many advantages. To promote millets, governments, researchers, and the food sector must work together to improve processing methods, boost value addition, and raise consumer knowledge. Their popularity can be increased even more by including millets into regular diets through creative culinary products and medicinal uses. To sum up, millets represent a wholesome and sustainable response to contemporary issues with food security and health. Their resilience to harsh climatic conditions, combined with their immense health benefits, makes them an indispensable component of future food systems. With increased investment in research, policy support, and consumer education, millets can reclaim their place as a staple food, promoting both environmental sustainability and human well-being.

Acknowledgements

None.

Conflict of Interest

None.

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