**Millet: The Super Food for a Sustainable and Healthy Approach towards a Nutritious Lifestyle**

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ABSTRACT

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| Millets, a diverse category of diminutive-seeded grasses, have emerged as nutritional powerhouses with substantial potential to confront global food security challenges. Abundant in vital nutrients such as fiber, protein, vitamins, and minerals, millets contribute to a well-rounded diet, offering associated health advantages. The gluten-free attribute of millets renders them a versatile and inclusive option for individuals adhering to dietary restrictions. Diverse millet varieties, including pearl millet, finger millet, foxtail millet, proso millet, and more, are recognized for their nutritional richness in fiber, protein, vitamins, and minerals, making them a suitable grain choice for those with gluten sensitivity or celiac disease.  The United Nations declared 2023 as the International Year of Millets to raise awareness regarding the nutritional merits of millets and to advocate for their cultivation and consumption. This designation aims to underscore the significance of millets in global food security, biodiversity, and resilience to climate change. Throughout the International Year of Millets, various events, campaigns, and initiatives are orchestrated to stimulate millet production and consumption while endorsing sustainable agricultural practices.  This comprehensive review paper thoroughly examines the diverse applications and uses of millets. The paper initiates by providing a fundamental overview of millets and their nutritional composition, emphasizing their elevated content of fiber, protein, vitamins, and minerals. It explores the gluten-free nature of millets, making them an appealing choice for individuals with dietary restrictions.  Additionally, the review investigates the integration of millets into functional foods, underscoring their role in addressing malnutrition and promoting overall health. |

*Keywords: Millet, Millet protein, Sustainable option, Application of millet, Nutritious, Lifestyle*

**1. INTRODUCTION ON MILLET**

Millets, classified within the Poaceae family, are small-seeded cereals extensively cultivated in arid and tropical regions of Eurasia and Africa. These grains hold historical significance, being among the earliest crops domesticated, with evidence of millet consumption dating back to the Indus Valley Civilization (3000 BC) (Kheya et al., 2023). Millets rank as one of the most crucial cereal crops globally, following wheat, rice, maize, and barley. Compared to other cereals, millets exhibit heightened resistance to pests and diseases. While they were once essential food crops, millets are now recognized as vital foods for the future, given the detrimental effects of climate change, particularly in vulnerable ecosystems .

Millets, being small-seeded grasses thriving in arid and semi-arid tropical regions with nutrient-deficient soil and limited rainfall, have become a staple crop in developing countries due to their nutritional content, resilience, and adaptability to climate fluctuations (Khairuddin & Lasekan, 2021). India stands as the leading millet producer, with 26.6% of the global and 83% of Asia's millet cropping area. In Indian states like Odisha, Uttarakhand, Madhya Pradesh, Rajasthan, etc., millets are regularly consumed by tribal populations due to their cultural significance, nutritional richness (protein, dietary fiber, vitamins, minerals), and environmental benefits (drought-resistant crops, short growing time) (Chauhan et al., 2023a).

As a staple food, millets have gained global recognition for their exceptional nutritional advantages. Packed with dietary fiber, protein, essential vitamins, and minerals, millets contribute to a well-rounded and healthy diet. Their gluten-free characteristic enhances their appeal for individuals with gluten sensitivity or celiac disease, meeting the increasing demand for diverse and inclusive food options (Amadoubr & Le, 2013a).

**2. THE CULTURAL AND HISTORICAL IMPORTANCE OF MILLET**

The word "Millet" originated from the Latin word "Milum," which means grain. While millets have been cultivated for thousands of years, their origins are a mystery to most people. Millets are believed to have originated independently in multiple regions of the world and were among the earliest crops to be demons­trated. Recent archaeobotanical evidence suggests that foxtail millet (*Setaria italica*) and broom corn millet (*Panicum miliaceum*) were both farmed in northern China as early as 8000 cal BP. Millets were cultivated in Europe, the Middle East, and Africa at the same period (Paschapur et al., 2021).

Prior to the Indian Bronze Age (4500 BC), millet was commonly consumed in India, as shown by the discovery of foxtail millet (priyangava), barnyard millet (aanava), and black finger millet (shyaamaka) in some of the earliest Yajurveda texts. For thousands of years, millet has played a significant role in the customs and civilizations of several communities.   
Many cultures use millet in their religious ceremonies and rituals. In Hinduism, for example, millets are offered to gods and goddesses at festivals and other sacred rites. Additionally, millets are used in many traditional medicinal and therapeutic practice (Shukla et al., 2024).

Millets are commonly used in traditional cuisines and have long been an important part of the local cuisine. For example, traditional Indian dishes like bhakri, dosa, idli, etc. are made with a variety of millet varieties. Historically, millets have been a major crop in a lot of farming areas. In many cultures, ceremonies and celebrations are held in connection with the planting, harvesting, and processing of millets. These rituals ask for the gods' blessings and guarantee an abundant harvest. Millets are well known for their resilience and ability to grow in unfavorable soil and environmental circumstances. Their low water and fertilizer requirements make them essential to sustainable agriculture (Wang et al., 2021)   
Around the world, millets constitute a staple meal and a significant source of income for many communities.

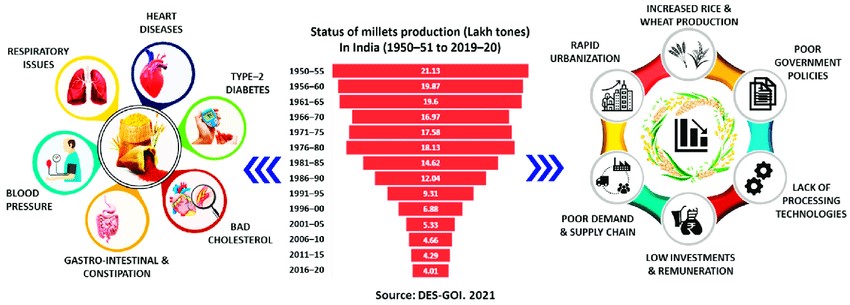


**Figure 1: Different types millets**

**3.BENEFIT OF MILLETS**

Millet emerges as a nutritional powerhouse, boasting a plethora of health benefits. Brimming with essential nutrients such as fiber, protein, vitamins, and minerals, millets make a significant contribution to overall well-being. Their gluten-free characteristic renders them an ideal option for individuals with dietary restrictions, while the substantial fiber content supports digestive health and aids in weight management. Millets also play a crucial role in cardiovascular health by potentially lowering cholesterol levels and regulating blood pressure. With a low glycemic index, millets assist in blood sugar control, making them suitable for individuals managing diabetes. Moreover, the antioxidant-rich profile of millets helps combat free radicals, reducing the risk of chronic diseases. Beyond their health benefits, millets stand out as environmentally sustainable, thriving in diverse conditions with minimal water requirements. Their versatility in the kitchen, offering a range of textures and flavors, positions millets as a valuable addition to a well-rounded and diverse diet.

Despite their nutritional advantages, the high fiber content and the presence of anti-nutritional factors such as phytates and tannins in millets can affect the bioavailability of minerals. Some studies in humans have suggested lower iron absorption from millets compared to rice or wheat (Karki et al., 2025). Millets are also rich in health-promoting phytochemicals, including polyphenols, lignans, phytosterols, phytoestrogens, and phytocyanins. These compounds function as antioxidants, immune modulators, and detoxifying agents, providing protection against age-related degenerative diseases such as cardiovascular diseases (CVD), diabetes, and cancer (Khan et al., 2025). Additionally, well-known nutrients like vitamins, minerals, and essential fatty acids offer preventive benefits against degenerative diseases, complementing their role in preventing nutritional deficiency diseases(R & Hema, 2021) .



**Figure 2. Millets: health benefits, production, and challenges in India** (Gowda et al., 2022; Priya et al., 2023)

**4.COMPOSITION AND CLASSIFICATION OF VARIOUS MILLETS**

* 1. **Classification and Health Benefits of millets**

Millets are categorized according to their botanical characteristics, geographical distribution, and traditional applications. Each variety of millet possesses distinctive nutritional qualities, thrives in specific growing conditions, and finds diverse culinary applications. This diversity adds resilience to global food systems. These millets are recognized by various names across different regions worldwide. In summary, millet serves as a preventive measure against a range of health issues, encompassing cardiovascular diseases, diabetes, gastrointestinal disorders, detoxification, cancer, obesity, celiac diseases, oxidative stress. It plays a crucial role in fortifying the body, providing strength, and enhancing overall immunity.

**4.2.Basic Composition of Millets**

The millet grain is composed of approximately 65% carbohydrates, with a significant portion being non-starchy polysaccharides and dietary fiber. These components contribute to the prevention of constipation, reduction of blood cholesterol, and the gradual release of glucose into the bloodstream during digestion. Regular consumption of millets is associated with a lower incidence of cardiovascular diseases, duodenal ulcer, and hyperglycemia (diabetes). Millet grains are also rich in essential vitamins, including Thiamine, Riboflavin, Folic Acid, and Niacin (R & Hema, 2021). They exhibit mineral richness comparable to rice and wheat, and in some cases, surpass them in fatty acids and minerals. The carbohydrate composition of millets varies, with amylose and amylopectin content ranging from 16-28% and 72-84%, respectively.

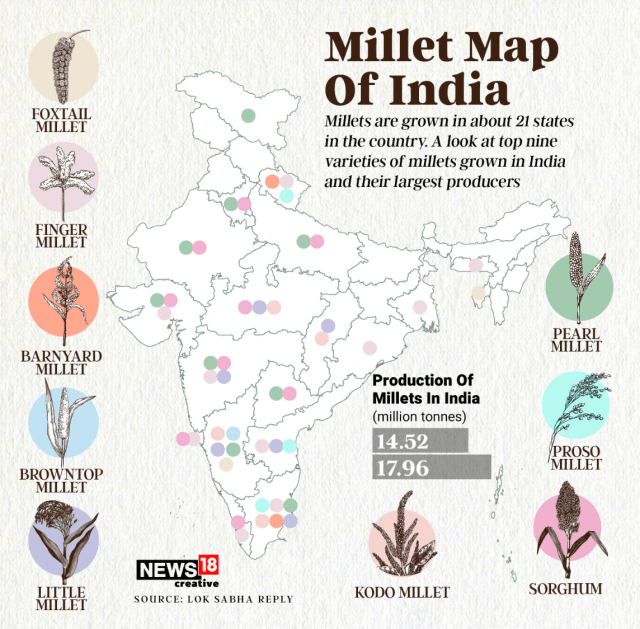
The nutrient composition of millet grains reveals them as a valuable source of energy, protein, vitamins, and minerals, including trace elements. The edible part of the millet kernel is rich in phytochemicals such as dietary fiber and polyphenols (0.2-0.3%) (Jacob et al., 2024). Millets contribute to antioxidant activity through the presence of phytates, polyphenols, and tannins, playing a vital role in aging and metabolic diseases (Shukla et al., 2024). Finger millet boasts the highest calcium content among cereals (344 mg/100g) and is also rich in phytates (0.48g/100g), polyphenols, and tannins (0.61%) (Devi et al., 2014). Millets emerge as a superfood, offering a reservoir of calcium (10–348 mg/100 g), iron (2.2–17.7 mg/100 g), zinc (32.7–60.6 mg/100 g), phosphorus (200–339 mg/100 g), as well as vitamins such as thiamin (0.15–0.60 mg/100 g), niacin (0.09–1.11 mg/100 g), and riboflavin (0.28–1.65 mg/100 g) . Millets are particularly beneficial for diabetic individuals due to their low carbohydrate content (60%–70%), mainly consisting of non-starchy polysaccharides, and gluten-free properties (Chauhan et al., 2023b). They are notably high in lipids, with millet oil serving as a source of linoleic acid, oleic acid, palmitic acid, and tocopherols, known for their immune system and defense mechanism roles in the human body (Kittur et al., 2024). Various millet types exhibit richness in specific nutrients, such as foxtail millet, barnyard millet, and proso millet in protein (>10%), finger millet grains in calcium (>350 mg/100 g), foxtail millet and little millet in crude fiber (6.7%–13.6%), and barnyard millet and little millet in fat (>4.0%). Additionally, barnyard millet and little millet have high iron content (9.3–18.6 mg/100 g) compared to major grains like rice, wheat, barley, sorghum, and maize (Kam et al., 2016; Mohapatra et al., 2024).

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| **Table 1:** Vernacular names and benefits of major millets consumed in India | | | |
| **Kinds of Millet** | **Local name** | **Benefits** | **Reference** |
| Foxtail | Kangni, kakum | Absorbs excessive fluids, normal formation of feces and enchances digestion, dries up excessive moisture, fracture healing. | (Ardie et al., 2025; Zhang et al., 2025) |
| Barnyard | Sarwa, Jhangon | Dries up the tissues, fights against skin problems, cancer and celiac diseases. | (Bhatt et al., 2023; Sharma et al., 2016) |
| Kodo | Kodon | Sweet-bitter in taste, anti-poisonous, Antaphrodisiac. | (Jenipher et al., 2024) |
| Proso | Barre | Contains high lecithin, which supports the neural health  [https://doi.org/10.3390/agriculture9030064] | (Karmakar et al., 2025) |
| Finger | Mandua, Ragi | Promotes strength, helps in managing diabetes, regulation of glucose homeostasis, and prevention of dylipideamia. | (K et al., 2024) |
| Sorghum | Jowar | Enchances taste perception, pacifies excessive thirst, pacifies excessive moisture content. | (Drub et al., 2021) |
| Pearl | Bajra | Strength, stamina and immunity promoter, difficult to digest and beneficial for heart. | (Choudhary et al., 2025) |

**5.Distribution of Different Millets across India**

The distribution of millets in India is intricately tied to the diverse agro-climatic conditions across different states. The varied distribution of millets underscores their resilience and ability to thrive in different climatic zones, contributing significantly to India's agricultural diversity (Banerjee et al., 2025).

* Foxtail millet, thriving in both dry and moist conditions, is extensively cultivated in Tamil Nadu, Andhra Pradesh, Karnataka, Odisha, and Maharashtra, where varying climates exist.
* Barnyard millet, well-suited for diverse climates, finds favor in Uttar Pradesh, Bihar, Karnataka, Andhra Pradesh, and Tamil Nadu.
* Finger millet, or ragi, is a resilient crop flourishing in hilly areas and is a staple in Karnataka, Tamil Nadu, Andhra Pradesh, Telangana, Maharashtra, and Odisha.
* Kodo millet, known for its adaptability, is commonly grown in Karnataka, Tamil Nadu, Andhra Pradesh, Odisha, and Maharashtra, displaying versatility in agro-climatic preferences.
* Proso millet, adaptable to various climates, is cultivated in Uttar Pradesh, Maharashtra, Karnataka, and Haryana, reflecting its flexibility.
* Sorghum, another millet variant, has a wide distribution across Maharashtra, Karnataka, Andhra Pradesh, Telangana, and Rajasthan, indicating its adaptability to diverse climates.
* Pearl millet, well-suited for arid conditions, dominates in states like Rajasthan, Gujarat, Haryana, Uttar Pradesh, and Maharashtra, showcasing its preference for hot and dry climates



**[Fig.3 : Distribution of some millets, across various regions of India]**

**6.MILLET AS A SUSTAINABLE OPTION**Top of Form

Globally, billions of people rely on rice, wheat, maize, and, to a lesser extent, millet as their primary food sources. The growth patterns of these crops are influenced by temperature and water availability. Wheat is predominantly cultivated in regions with limited water resources and suitable temperatures, while rice and maize thrive in areas with abundant water supply. Millets, on the other hand, are cultivated in regions with limited water supplies, particularly in semi-arid and dry areas due to their resistance to various stressors and high yield on low-quality soil with minimal maintenance (Awika, 2011). Millets, described as an ancient crop with a sustainable future, exhibit adaptability to dry and semi-arid climates, performing well in areas with scarce rainfall. The germination and sprouting of millet seeds require a mild, temperate atmosphere, as they are susceptible to damage from cold weather and frosts. Notably, millets are 70% more water-efficient than rice and can withstand temperatures as high as 42°C. This resilience to high temperatures positions millets as an excellent choice for tropical countries seeking drought-resistant food solutions. The International Crops Research Institute for the Semi-arid Tropics emphasizes that millets are often "the last crops standing in droughts" (Saxena et al., 2018).

Millets demonstrate a notable return on investment while proving resilient to climate change. Their climate-resilient characteristics contribute to sustainable agriculture without the need for chemical fertilizer (Thilakarathna & Raizada, 2015). The cultivation of millets is anticipated to support environmentally friendly farming practices, mitigating potential harm to the environment resulting from the careless application of fertilizers and pesticides. As a result, millets are often referred to as "miracle crops" due to their diverse advantages, including their use as food and value-added food products, forage, contribution to agro-diversity, low nutrient requirements, significant C sequestration (C4 plants), erosion prevention in arid regions, and ensuring an adequate food and nutrition supply for smallholders in harsh environmental conditions (Amadoubr & Le, 2013b). Furthermore, millets are deemed ideal for health-conscious individuals as they are gluten-free.

In summary, millet and millet-based products present themselves as a sustainable option compared to other staple food products (Punia Bangar et al., 2021).

**7.SUSTAINABLE DEVELOPMENT GOALS**

Sustainable development is of paramount importance as it embodies a comprehensive and forward-looking strategy to fulfill present needs without jeopardizing the ability of future generations to meet their own requirements. It acknowledges the intricate interdependencies among economic, social, and environmental dimensions, underscoring the imperative of achieving equilibrium and resilience. Sustainable development seeks to address global challenges, including poverty, inequality, climate change, and environmental degradation, by integrating economic prosperity, social inclusion, and environmental stewardship, thereby striving for enduring solutions. Increasingly, sustainability is being woven into decision- and policy-making processes. This is exemplified by the formulation of the Sustainable Development Goals (SDGs), unanimously adopted by all Member States of the United Nations (UN) in 2015. Comprising 17 goals accompanied by 169 targets, the SDGs articulate a 2030 development agenda aimed at fostering sustainable societies (Laurent et al., 2020).

Millet significantly advances several Sustainable Development Goals, acting as a catalyst for Zero Hunger (Goal 2) through its nutrient-rich composition and resilience in challenging agro-climatic conditions. As a source of diverse and balanced nutrition, millet contributes to Good Health and Well-being (Goal 3), preventing diseases and enhancing overall well-being. Additionally, millet aligns with Responsible Consumption and Production (Goal 12) by requiring fewer resources in cultivation and presenting a low environmental impact, fostering sustainable agriculture. Its extended shelf life also aids in reducing food waste, aligning with responsible consumption patterns. In essence, millet emerges as a sustainable option that addresses hunger, promotes health, and encourages responsible consumption and production practices, embodying the principles of the Sustainable Development Goals (Vijayakumar T & Beryl Mohankumar, 2009).



**Fig. 4: The 17 Sustainable development goals [Image source:** Department of Economic and Social Affairs, Sustainable Development, United Nations.]

**8. APPLICATIONS OF MILLETS:**

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| **Table 2: Different application of millet** | | |
| **Types of Millets** | **Application** | **Reference** |
| Foxtail Millet | Uses for making porridge, biofuel, starch gel formation, animal feed | (Abedin et al., 2025; Huchchannanavar et al., 2019) |
| Barnyard Millet | Uses as fermented drink, preparation of muffins | (Goswami et al., 2015; Joseph et al., 2025) |
| Kodo Millet | Uses for making porridge, other traditional food products, food packaging films, functional beverage | (Arya & Shakya, 2021; Suryavanshi et al., 2025) |
| Proso Millet | Production of waxy and non-waxy starch, parched rice, gluten-free rice cookies | (S. Kumari et al., 2023; Ren et al., 2025; Zhu et al., 2023) |
| Finger Millet | Use for preparation of flat bread, porridge, alcoholic beverage preparation, pasta | (Devi et al., 2014; M. Kumari et al., 2023; Selladurai et al., 2023) |
| Sorghum Millet | Production of bioethanol, composite bread, gluten-free whole-grain yeast rolls | (Compaore-Sereme et al., 2023; Drub et al., 2021; Mgeni et al., 2025) |
| Pearl Millet | Production of whole grain cake, gluten- free bread, probiotic beverage | (Costa et al., 2024; Theodoro et al., 2024) |

***Millet Based Packaging :***

Food Packaging is one of the most crucial part of food processing industry. It helps in maintaining the quality and safety of food by prevention of Contamination, protection from foreign matters and mechanical damage and also accelerating the promotional and advertising domains for profitability. Plastic based packaging has several applications in the food as well as in the other sectors. But due to the adverse effects it has on the environment, including their long term accumulation due to their less biodegradable nature. Plastic pollution is a global concern. In concern of the issue, shift towards a biodegradable and sustainable packaging which serves to minimised waste production, has been in trend and under study. The biodegradable packaging includes natural biopolymers out of which starch is the most suitable one due to its abundant availability and biodegradation and the ease of modification for the betterment of the characteristics and features.

Millets can withstand and adapt to dry and infertile soils, to a better extent than other crops, and can be cultivated under exceedingly severe conditions – for example, high temperatures, low and unpredictable Precipitation , short growing seasons and acidic and sterile soils with poor water-holding capacity and high productivity (Pooja Saklani et al., 2019)

From different millets the starch can be extracted and utilised to produce edible films and coatings. There was an attempt to prepare a starch based film from Barnyard millet and characterization was performed (transparency, swelling power, sealing property, solubility, etc.). The results indicated the possibility of the films as an alternative LDPE and HDPE plastic bags(Deshpande & Nishad, 2021). There was another attempt of preparation of millet based film and incorporation of clove essential oil thus increasing the antioxidant and antimicrobial activity therefore concluding it’s benefits to be used as a method of preservation . Another experiment exhibited the use of Proso millet starch in the edible film. The films can be modified with flavours ,pigments (Sandhu et al., 2020).

The key benefits of edible films and coatings include, they are an integral part of the food and can be eaten along with the food without unpacking causing less wastage of packing material. The wrappings prevent moisture loss, aromas of gases and movement of solutes out of the food material and also being selectively permeable for the exchange of essential gases involved. The applications of the film and the coatings not only enhance the shelf life of the food product but also provide economic efficiency. Edible films are separately prepared and applied on the food surface while the coatings are directly formed on the surfaces.

***Processed Food Products:***

Millets are considered to be “future crops” as they are resistant to most of the pests and diseases and adapt well to the harsh environment of the arid and semi-arid regions of Asia and Africa.Millets have great utility in the food sectors due to the wide range of benefits it provides. Some of the processed millet food products have been discussed below

***Millet Flour:***

Millet grains undergoes milling process to produce Millet flour which can be itself used or can be blended with wheat flour in a definite ratio to enhance the nutritional and functional properties and change the physicochemical properties of products. An experiment was conducted where kodo and barnyard millet flour was blended with whole wheat flour. The addition of a blend of millet flour enhanced the composite flour’s quality by raising its nutrient density, decreasing its viscosity, and raising syneresis levels, which may enhance the resistant starch content during storage (Irigoytia et al., 2025)

***Flaked , Puffed and Extruded Products:***

Starch is the major constituent of millet grains. High temperature for short time is applied through air blowing puffing machines to produce Flaked and Puffed Products. Finger millet is used to make flat breads (roti ) and is consumed in North West Himalayan region. Compared to wheat rotis, finger millet rotis do not have the capability to puff and swell due to absence of Gluten, therefore is not preferable by consumers due to the hard texture. Hence to make the flat breads soft, there is a traditional method of addition of dried bark of tree (Boehmeria rugulosa), known as gethi, and that helps in production of soft rotis very similar to that of wheat rotis.

An experiment was conducted using the high temperature short time (HTST) puffing method, barnyard millet was transformed into a ready-to-eat (RTE) puffed product (JAYBHAYE & SRIVASTAV, 2015). Steam cooking and hot air puffing were used to make cold extruded dough sheet pieces, which were made from barnyard millet flour, potato mash, and tapioca powder in a definite ratio. Another experiment was conducted where Millet based complementary foods were developed using the millet sorghum (Sorghum vulgare), rice (Oryza Sativa), besan (Cicer arietinum;), legume mix (Green gram and roasted Bengal gram; Phaseolus aureus Roxb and Cicer arietinum) and soybean (Glycine max Merr) with a lab scale twin screw extruder (Lakshmi Devi et al., 2014; Meherunnahar et al., 2023)

***Noodles and Pasta:***

Noodles and Pastas are one of the most loved and popular food items made from wheat flour. The worldwide acceptance and popularity of the food items is due to the convenience , ease of preparation and cost. Incorporation of millets into noodles and pasta stands out to be a sustainable and healthier way of consuming the same(M. Kumari et al., 2023). A research has developed a nutri rich instant noodles using Foxtail millet flour mixed with wheat flour, mushroom and rice bran flower to improve the contents of protein, nutrients and making it economical commercially.

Another research deals with the preparation of ready to eat pasta made from Kodo millet flour, wheat flour and Semolina along with the nutritional quality of the product. One research evaluated the quality changes in pearl millet pasta during storage in flexible packaging (Kirti Jalgaonkar et al., 2017).

***Bakery Products :***

Bakery industry is one of the fastest growing sector of the food industry. Therefore, incorporating millet in this industry will be profitable and economical. A multi millet bread was made with wheat flour, sorghum and pearl millet flour, which was found to have better and rich amount of nutrients, proteins, fiber, calcium , etc. as compared to that of normal bread, therefore pointing out the benefits over the normal bread used.

Another attempt of making of pizza base with Proso millet flour and refined flour showed the sensory evaluations such as texture, taste, crust colour and other attributes to be significantly relatable to the control pizza base made from refined flour(Kirti Jalgaonkar et al., 2017). People who all are gluten intolerant or with celiac disease need an alternative to the regular gluten containing biscuits available in the market. An attempt was made to produce gluten-free rice cookies with the mixture of malted buckwheat, foxtail and proso millet flour (S. Kumari et al., 2023).

***Fermented food products:***

A study presents the nutritional, physicochemical, and sensory characterization of a functional fermented African finger millet-based beverage, which used a co-culture containing an exopolysaccharide-producer strain and probiotic strain which was organoleptically acceptable, providing a high nutritional value , and promising potential for targeting international markets. There are different fermented millet products showed promising results with various health benefits. Synbiotic barnyard millet fermented health beverage fermented *with Lactobacillus rhamnosus* and *Saccharomyces cerevisiae* yields higher total polyphenolic content and anti-microbial activity (Joseph et al., 2025). Fermented skim milk product fortified with pearl millet decreased levels of antinutrients, as well as improved protein digestibility, micronutrient bioavailability, and other technofunctional properties (Samtiya et al., 2024).

**9.APPLICATIONS OF MILLET PROTEINS**

***Pharmaceutical Applications-***

Numerous studies have demonstrated the significant health benefits of consuming millet protein, indicating its potential applications in medicinal products and therapeutic diets. Research has shown that millet protein concentrate has positive effects in mice models, particularly in the prevention of metabolic disorders, hyperglycemia, cardiovascular issues, liver damage, and gastric issues. The concentrated protein from proso and foxtail millet has been recommended for individuals with diabetes and heart conditions, as it helps regulate glucose, insulin, and cholesterol levels by affecting adiponectin levels. However, further in vivo studies are needed to fully understand how millet protein works on a molecular level in order to effectively prevent and treat diseases. Millet proteins or peptides, whether obtained naturally or through enzymatic hydrolysis, have shown significant biological functions in laboratory settings. As such, they mayhave potential as nutraceutical or pharmaceutical ingredients with bioactive properties, such as anti-viral or antibacterial effects (Moreno-Camacho et al., 2019).

When given to infants between the ages of six and eighteen months, millets, which are as old as rice, can be a useful supplementary feeding strategy to combat malnutrition. Widely hydrolyzed rice protein formulae have been identified as a viable substitute for cow milk-based formulae in terms of allergy response, nutritional sufficiency, palatability, and affordability . For healthy and malnourished populations as well as those with food-based protein allergies and sensory issues, hydrolyzed formulae based on millet proteins may be investigated as novel, affordable, hypoallergenic, sustainable, and alternative protein sources, opening the door for millet protein-based products. Researcher mentioned about pearl millet seed extracted starch which showed same physicochemical characteristics as maize and potato starch and can be used as alternative source for pharmaceutical use (Osman et al., 2021).

***Protein Nanoparticles for Film Formation and Encapsulation-***

Recently, there has been increased interest in using cereal protein to create food-grade delivery systems, such as biofilms or nanoparticle-based pickering emulsions. Designing delivery systems with cereal proteins necessitates investigating protein extraction techniques, the connection between structure and function, and the potential for modification. Cereal protein nanoparticles are typically made by a low-cost, readily scalable process known as antisolvent precipitation, in which the protein solution’s quality is altered to produce controlled aggregation and the creation of a dispersion of uniformly distributed nanoparticles. These include the use of organic solvents (ethanol-water system), adjusting the pH, or dissolving in acetic acid solution—all of which were covered in the section above. Electro-spraying/electrospinning, spray drying, and nano-spray drying are further methods used in the production of nanomaterials(Shukla et al., 2024) . To distribute β-sitosterol, prolamin-pectin nanoparticles made from foxtail millet were created (Li et al., 2025). These microscopic structural features are caused by the formation of a continuous phase of polymeric matrix and strong molecular interactions between tef starch, agar, and glycerol. The compacted structure of the composite film, which has greater structural solidity than the stated film formed of pearl millet starch, may be the cause of its good mechanical properties, particularly its tensile strength (Tafa et al., 2023). Curcumin was encapsulated in proso protein that was prepared by wet milling and ethanol extraction, with sodium caseinate serving as a stabilizer. Better solubility and a higher surface hydrophobicity value (So) for proso protein extracted from ethanol suggested that it would be a suitable encapsulant for lipophilic material. The curcumin-encapsulating sodium caseinate stabilized protein particles exhibited a narrow polydispersibility index (<0.3), as well as a negative μ potential (<-30 mv), with an average mean particle size of 240–336 nm. Protein extracted from ethanol showed higher stability and encapsulation efficiency (78.9 percent). The antioxidant activity of curcumin was found to benefit from encapsulation, indicating that millet protein is an appropriate carrier for lipophilic compounds (Kaur et al., 2024)

***Stabilized emulsion-***

Protein particles derived from cereals can be utilized to shield delicate nutrients, like fatty acids, lipophilic vitamins, pigments, and flavors, from environmental deterioration while being processed. The bioactive ingredients encapsulated in cereal protein matrices are inexpensive, easily assimilated by enzymes, stable, miscible in food products, able to withstand processing, and release the compound in a controlled manner while maintaining it’s gut bioavailability .Pickering emulsions, or stabilizing agents in food systems, can be achieved by using cereal protein nanoparticles in their native or modified form. These nanoparticles have varying degrees of hydrophobicity and a tendency to reduce interfacial tension at the oil–water or water in oil interface . Through the “pickering” mechanism, a stabilized emulsion type delivery system (food, supplement, pharmaceutical, or cosmetic product) is established. Millet proteins are typically modified by physical, chemical, or enzymatic treatment to improve interfacial properties for the purpose of designing emulsion-based delivery systems because of their high hydrophobicity and poor solubility in their native form. The efficiency of millet protein concentrate (MPC) made from different types of millet (proso, pearl, and foxtail) for encapsulating millet oil (MO) was assessed in this study. Millet is a rich source of protein and unsaturated fatty acids (Roustaazad et al., 2025). Compared to regularly consumed staple grains, millet protein provides a great source of important amino acids. The functionality of millet protein in both food and non-food applications is greatly influenced by processing techniques and operating settings. Protein secondary structure and disulphide linkage synthesis are two examples of how heat processing changes a protein's structural and functional characteristics. A new avenue of study is the non-thermal processing of millet proteins employing methods including cold plasma, high pressure, pulsed electric fields, and ultrasound (Suri et al., 2024). Biomolecule-derived polymers, especially those derived from hydrophobic proteins, are showing promise as a superior substitute for artificial polymers in the targeted transportation of drugs and vaccines across biological barriers to their target molecular sites of action. Because of their availability, affordability, biocompatibility, and environmental sustainability, millet-based proteins can be a valuable drug release system (Kaur et al., 2024).

Prolamins are known to have moderate barrier qualities (water and oxygen permeability) when cast as films because of their amphiphilic nature. The hydrophobic core’s adsorptive qualities and surface-active characteristics make it an ideal colloidal delivery system for encasing substances. Due to its hydrophobicity and high cysteine content, which causes a tendency for crosslinking, the proteins of wheat, barley, and sorghum are the most studied when it comes to lipophilic compound encapsulation in nanoparticles and film-forming ability . Commercialization requires a connection between producers of millet, producers of biopolymers, and processors of those products. Investigations into small millet prolamins are being conducted for the same purpose. Millets are low-cost, easy to cultivate, and nutrient-rich crop produced globally in sufficient quantity, thus it’s effective utilization and value addition

***Biodegradable packaging-***

Additionally, the problem of plastic generation in the food industry and biomedical systems may be addressed, and the climate impact may be lessened, by using biofilms from a sustainable and renewable source, like millet proteins, in packaging. This is an additional intriguing potential use for millet protein particles, wherein films are created using a wet process called “solvent casting” or a dry method that involves compression, molding, and extrusion to create a thermoplastic. A variety of techniques, such as the use of plasticizers, heat-induced cross-linking, aldehydes, acid/alkaline treatment, enzyme or physical treatment, and the creation of composite films using various polymers, can be used to improve structure and functionality. These films’ biodegradability, strong mechanical qualities, and good aroma barrier qualities make them potential packaging materials (Calva-Estrada et al., 2019; Sachdev et al., 2023). Three distinct plasticizers were used in the study to examine the film cast made from the protein genistein found in pearl millet: glycerol, glycerol/citric acid (glycerol/CA) mixture, and glycerol/lactic acid/polyethylene glycol 400 (glycerol/LA/PEG) mixture. Good material properties were obtained from the glycerol/CA film. The film had a smooth texture, was transparent, had minimal moisture content, was extensible, and had the lowest permeability of water vapor and oxygen. Both the dense microstructure of the formed film and the crosslinking effect of citric acid were proposed as the causes of these properties.

***Fertilizers-***

Particles of millet protein may be used to prevent environmental deterioration of plant fertilizing agents like urea. The substance created with protein particles is more efficient and releases nutrients in accordance with the needs of the plant . The molecular properties of millet protein, such as charge, mass, flexibility, thermal stability, length of protein chains, distribution of amino acids, and sum of interactions among protein chains, determine how best to apply the protein to create an appropriate delivery system. Beside structural attributes, functional attributes such as solubility and wetting characteristics are also of huge importance. The millet seed’s prolamin protein may be a structurally appropriate raw material for making a variety of micro- and nanomaterials, fibers, and particles (Kaur et al., 2024; Sachdev et al., 2023).

**10. CONCLUSION**

Millet is truly described to be a super grain and food due to its richness in nutrition and paving a way towards the sustainable development. Millet has been an underutilised crop for a long period of time but there has been a surge of recent interest in the crop for its benefits in the field of food processing sector. However, millets' culinary adaptability is arguably their greatest asset. Various food products like millet flour, flaked and puffed extruded, fermented products are prepared from different millets. Millet proteins are extensively used formation of biofilm, as stabilised emulsion, biodegradable packaging material and as fertilizer. They can be used as a foundation for salads, stirfries, or grain bowls by cooking them similarly to rice or quinoa. In addition, they can be crushed into flour and added to baked items like bread and muffins. Millet flour is really a common component in glutenfree baking since it has a somewhat sweet flavour and a light, fluffy texture. Millets have been a mainstay of many cultures' diets for many years. They are a vital crop for smallscale farmers since they can be cultivated in a range of regions and are resistant to drought. The International Year of Millets seeks to promote smallscale millets growers and increase public knowledge of the nutritional and environmental benefits of these superfoods by encouraging millets' use.To sum up, millets are a real superfood that need to be acknowledged and enjoyed by more people. They are a vital crop for smallscale producers and a plentiful source of nutrients and culinary versatility. You can support a more sustainable food system for everyone and enhance your own health by include millets in your diet. For encouraging and enhancing the production of millets keeping in mind the package of benefits it provides, government has taken several measures that will foster the growth and cultivation of millet in India. It would be advantageous for both our farmers and the environment with the benefits of millet

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