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Comprehensive Review on Barnyard and Kodo Millet: Nutritional composition & effect of Food processing

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Abstract

Cereals are staple foods that provide essential nutrients for human nutrition. However, their nutritional benefits are often hindered by antinutrients like trypsin inhibitors, polyphenols, and phytic acid. Given their resistance and nutritional value, millets like kodo millet (*Paspalum scrobiculatum*) and barnyard millet (*Echinochloa frumentacea*) are vital in semi-arid and tropical environments. This review explores the nutritional composition, health benefits and challenges attached to consuming millets, with a particular emphasis on barnyard millet (*Echinochloa frumentacea*) and kodo millet (*Paspalum scrobiculatum*). Packed with protein, dietary fiber, and vital minerals, millets are an excellent food option for avoiding and managing lifestyle-related disorders like diabetes. The review further discusses the potential of various processing techniques, such as fermentation and germination, which can effectively reduce antinutritional components and enhance the nutritional profile of millets. It also highlights the impact of fermented millets on the gut microbiome, contributing to better digestive health and metabolic regulation. Additionally, the role of millets in promoting sustainable agriculture is emphasized, as they contribute to achieving key Sustainable Development Goals (SDGs), including 'Zero Hunger' (SDG 2) and 'Climate Action' (SDG 13). By utilizing their potential as functional foods, such as low-glycemic, high-protein items, millets can support both global health efforts to control metabolic diseases.

Key words : Millet, gut microbiome, fermentation, Sustainable Development Goals.

Cereals hold significant importance in human nutrition. Utilizing various approaches in combination with cereals boosts the nutrient profile, including the quantity of various amino

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acids. Nevertheless, elevated levels of antinutrients such as phytic acid, polyphenols, and trypsin inhibitors pose a significant hindrance to the optimum biological use of cereals, legumes, or a combination of the two[12].

Millets, which encompass various cereal crops such as barnyard millet (Sanwa; *Echinochloa frumentacea*), kodo millet (Arikalu; *Paspalum scrobiculatum*), pearl millet (Bajra; *Pennisetum glaucum*), finger millet (Ragi; Eleusine coracana), foxtail millet (Kauni; *Setaria italica)*, and more are significant in semi-arid and tropical regions worldwide. They serve as a vital food source for millions of people, particularly those residing in arid and challenging environments. Flourishing in harsh weather conditions where many cereals struggle to thrive, millets exhibit resilience to drought. Their extended storage capability makes them crucial during times of extreme food scarcity[1]. People typically consume millets in their whole grain form, with the outer coating of the grain, known as the seed coat, is rich in minerals, phenolics, dietary fibers and vitamins that provide health and nutritional benefits[5]. Per 100g of millet approximately contains 6-12% protein, 60-70% carbohydrates, 1-5% lipids, 2-11% dietary fiber, and 10-350 mg % calcium[12].

The seed coat of millet is not only edible but also a valuable source of phytochemicals, including dietary fiber and polyphenols, ranging from 0.2% to 3.0% [17].

The fortification of diets with phenolic acid-rich foods has been shown to confer antiglycemic, antimutagenic, and antioxidative properties, as well as to be effective in preventing cancer initiation and in vitro development[15,26]. It is linked to higher levels of free radical scavenging action, lowering the risk of cardiovascular disease[34]. This research could be useful in the development of healthy food products.

Barnyard Millet :

Barnyard millet (*Echinochloa frumentacea*), a crucial type of millet, is widely cultivated across Asia and Africa, serving as a staple food for the populations in these developing regions. Hilly and tribal communities in Asia, especially in India, China, and Japan, cultivate it for both human consumption and fodder[15]. Barnyard millet is cultivated in various countries like India, China, Japan, and the United States[9]. Barnyard millet is grown in Uttarakhand, on hills under rainfed conditions and it has special adaptive properties to grow and flourish on eroded land, tolerate most abiotic strains, and grow in extreme climatic conditions. It comprises two main species: *Echinochloa esculenta*, known as Japanese Barnyard millet, and *Echinochloa frumentacea*, Indian Barnyard millet[68]. This self-pollinated crop is recognized for its nutritional richness, with about 10.1% protein, 3.9% fat, and a high total dietary fiber content of around 12.5% [47] (Table-1). Moreover, with its low carbohydrate content of 68.8%, low glycemic index, and slow-digestible carbohydrates, this minor millet has shown to have a beneficial impact on blood glucose levels[79]. Barnyard millet, due to its low glycemic index, is excellent for individuals suffering from diabetes. It can act as a replacement for rice, which causes a high rise in blood glucose levels. Research done by Kumari and Thayumanavan[41] indicated that rodents consuming a diet with untreated and processed starch from barnyard millet experienced notably reduced blood glucose, serum cholesterol, and triglyceride levels in comparison to those fed rice and other minor millets (Foxtail, Proso, and Little millet).

Table-1. Nutritional Composition of Barnyard Millet per 100g

Composition	Values %	Sources
Carbohydrates	51.5-68.8	Chandra *et al.* 2016;
Protein	11.2-12.7	Longvah 2017;
Fat	2.5-6.3	Himanshu et al. 2018; Serna-
Moisture	8.7-11.9	Saldivar &
Total Dietary Fiber	13.9-14.7	Espinosa Ramirez 2019

Sources: (Chandra et al. 2016; Longvah, 2017; Himanshu et al. 2018; Serna-Saldivar & Espinosa-Ramirez, 2019)

Kodo Millet :

Kodo millet (*Paspalum scrobiculatum*) is an underappreciated crop and a staple food in the Deccan plateau of India, found in regions like Uttar Pradesh, Karnataka, parts of Tamil Nadu, Odisha, Maharashtra, Rajasthan, West Bengal, Gujarat, and the Himalayas. It is traditionally eaten as a primary source of nutrition and energy in rural India[34].

Kodo millet is an annual grass species; this resilient and drought-resistant plant thrives in challenging conditions, making it a good choice for cultivation on soils that are often unsuitable for other crops[66]. Like Barnyard millet, Kodo millets are gluten-free, have low carbohydrate content, and a good substitute to wheat or rice. This makes them a feasible dietary option among individuals suffering from celiac disease or wheat allergies. Additionally, their rich composition of fiber, polyphenols, and proteins positions them as valuable contributors to the nutritional well-being of a considerable portion of the population[13]. Kodo millet grain is composed of 8.3% protein, 1.4% fat, 65.6% carbohydrate, and 9% dietary fiber, as compared to rice (0.2%), and wheat (1.2%)[20] (Table-2). Kodo millets contain a high concentration of antioxidants, phosphorus, tannins, and phytic acids. These chemicals, known as antinutrients, interact with critical micronutrients like iron, calcium, and zinc, producing complexes that reduce their solubility and availability for absorption in the body[85].

Table-2. Nutritional Composition of Kodo Millet per 100g

Composition	Values %	Sources
Carbohydrates	66.0-70.0	Chandra *et al.* 2016;
Protein	6.2-13.1	Longvah 2017;
Fat	3.2-4.9	Himanshu et al. 2018; Serna-
Moisture	11.6-14.2	Saldivar &
Total Dietary Fiber	8.4-11.0	Espinosa Ramirez 2019

Nutritional Composition

Carbohydrates and Dietary Fibers :

Depending on the species, variety, climatic conditions for growth, and crop management, millets can have a carbohydrate content between 50% to 88%. Starch (60–75%), non-starchy polysaccharides (NSPs) (15–20%), and free sugars (2-4%) make up millet's carbohydrate content[36]. According to Serna-Saldivar and Espinosa Ramirez[63], finger millet and kodo millet have a relatively greater starch content as compared to other millets. Barnyard millet has a relatively lower carbohydrate content (51.5 - 65.0%) than kodo millet (66.0 - 72.0%) [36].

In addition, non-starchy carbohydrates are regarded as dietary fiber in the form of cellulose, hemicellulose, arabinoxylans, lignin, and β-glucan[63]. When compared to other millets, barnyard millet has the highest content of dietary fiber and crude fiber, with 6.1–10.5% insoluble and 3.5–4.6% soluble dietary fiber[83]. Cellulose and lignin are the main insoluble dietary fiber components found in millet grains, whereas soluble fiber may comprise β-glucan, arabinoxylans, and specific hemicelluloses. Dietary fiber's health advantages are associated with lower blood sugar, cholesterol, and effective bowel movement. The majority of dietary fiber is insoluble, and this insoluble portion stimulates antioxidant activity because it contains specific polyphenolic compounds that help prevent degenerative diseases like cancer, neurological issues, and gastrointestinal disorders[39].

Protein :

Agronomic factors, such as the growth environment and soil nitrogen level, have a major impact on protein content. Millets are good options for the development of value-added food items for malnourished and targeted groups due to their high protein content. Barnyard millet has around 11.2–12.7% of protein, whereas kodo millet has a larger range between 6.2–13.1% [36]. The majority of cereals lack lysine, whereas millets, finger millet, and kodo millet have 2.2–5.5g of lysine per 100 g of proteins; the inclusion of albumin, glutelin, or globulin accounts for the high lysine concentration[8]. The range of millet proteins' digestibility is 95 - 99.3, with common millet having the highest and foxtail and barnyard millets having the lowest[29].

Fat :

Millets have a 1-6% fat content; they are not as prevalent as proteins or carbohydrates[36]. The majority of the fat in millets is found in the bran and endosperm section, which is removed during decortication, the lower lipid content of millets contributes to their longer shelf life.

Minerals :

Mineral deficiencies are cause for concern due as they have a significant impact on tissue structure and metabolic processes, which can lead to serious and long-lasting illnesses[72]. Minerals are used by plants as building blocks for proteins and carbohydrates, as well as organic molecules for metabolism (such as phosphorus in ATP and magnesium in chlorophyll), enzyme activators like potassium, and osmotic balance maintenance. Calcium is essential for the formation and stability of cell walls, the maintenance of membrane structure and permeability, the activation of certain enzymes, and the regulation of numerous cell responses to stimuli. It is strongly linked to the preservation of the firmness of fruits (Olaiya, 2006). Phosphorus is essential for the production of ATP, the cell's energy currency, and is abundant in millets. According to Saldivar[59], the majority of phosphorus is found in phosphate groups such as phytate and phytic acid, which lowers its bioavailability. Several processing techniques, including germination and fermentation, lower the amount of phytic acid by releasing the chelated minerals and enhancing intestine absorption.

Antinutritional factors :

Millets consist of different anti nutrient elements that limit their nutritional value. Antinutritional components are organic compounds in food that interfere with minerals, proteins, and carbohydrates and limit their digestion and absorption.

The primary antinutrients present are phytic acid, tannins, and enzyme inhibitors, such as amylase and trypsin inhibitors, these chelate with metals and inhibit enzyme activity. Cereals possess copious amounts of minerals; however, their bioavailability is typically low due to antinutritional substances such phytate and polyphenols[81]. Minerals serve as crucial components to preserving optimal wellness. Calcium for instance, is necessary for bone production, while zinc is vital for protein and nucleic acid synthesis, digestion of carbohydrates, and healthy pregnancy (slightly helps reduce preterm births), delivery, and fetal growth. Phytic acid has been shown to have a profound influence on newborns, pregnant women, and breastfeeding women when large amounts of cereal-based foods are consumed.

Phytic Acid :

Phytates store 1-5% of the phosphorus by weight in cereals, legumes, and nuts[82]. Furthermore, plants absorb 50-85% of their phosphorus from outside sources[56]. Barnyard millet contains 3.37-3.70 mg/g of phytic acid. Kodo millet have lower levels of phytic acid and tannin, with concentrations ranging from 1.2 to 1.4 and 1.0 to 1.2 mg/g [69]. Phytic acid, and other nutrients required for plant growth is found within a spherical crystalline structure called a globoid. Negatively charged phytate structures attract positively charged minerals like Ca, Zn, and Mg resulting in insoluble complexes that cannot be digested or absorbed. Phytic acid interacts with negatively charged proteins via positively charged mineral ions, making them partially indigestible, therefore reducing its bioavailability[76].

Tannins and Phenols :

The primary purpose of tannins is to shield grains against decay. According to Dykes and Rooney[22], tannins have anticarcinogenic, anti-ulcerogenic, cholesterol-lowering, and gastro-protective qualities. However, tannins are not suited for consumption by humans. It can form compounds with proteins or occasionally attach to minerals, which can disrupt digestion[54]. There are two types of tannins: hydrolysable and condensed. Hydrolysable tannins may undergo hydrolysis during digestion and produce harmful compounds, while condensed tannins are not hydrolyzable and do not get absorbed throughout the course of digestion. They additionally inhibit the effects of digestive enzymes such α-amylase, chymotrypsin, trypsin, and lipase. Protein digestibility is decreased by the inefficient use of other amino acids, which occurs when pancreatic hyperplasia caused by protease inhibitors, such as trypsin inhibitors, impacts sulfur metabolism[65]. Presence of tannins in food results in decreased food utilization and diminished development[60].

Because of their antibacterial, antioxidant, and anticarcinogenic properties, phenolic compounds like lignans and phenolic acids have the potential to be bioactive substances[53]. As free radical scavengers, inhibitors of LDL (low density lipoprotein), cholesterol oxidation, and DNA breakage, polyphenolic compounds are an important class of secondary metabolites[64]. However, they can also form complexes with vitamins, like B12, minerals, proteins, and carbohydrates, which lowers their bioavailability.

Enzyme Inhibitors :

Almost all cereal grains and cereal-based diets contain inhibitors that impact the activities of both trypsin and α-amylase. According to Salas *et al.*[58], proteases refer to enzymes that catalyze cleavage of proteins at peptide bonds generating smaller peptides and are essential for boosting the general nutritional and functional qualities of various protein molecules.

Plant serpins, which are a widely distributed family of protease inhibitors that block an enzyme's most active site through conformational changes, are the main component of cereal grains[42]. This inhibits the activities of trypsin, chymotrypsin, and other intestinal proteases. It also interferes with digestion, resulting in pancreatic hypertrophy and metabolic disturbances related to the consumption of amino acids and sulfur[55].

The primary regulator of the conversion of complex carbs into simpler ones is α-amylase, inhibition of α-amylase delays the digestion and absorption of carbohydrates. A longer period spent digesting carbohydrates lowers the rate at which glucose is absorbed, which has an immediate impact on the typical postprandial (after a meal) blood glucose level[2].

Effect on processing on Kodo and Barnyard millet :

Various techniques and combinations of methods are recognized for reducing the levels of antinutrients, leading to increased availability of amino acids and minerals, elevating protein content, and improving protein and starch digestibility. Among these, germination and fermentation are considered the most critical and widely adopted processes, significantly changing and improving the overall nutritional composition of coarse cereals and other grains. According to Ohanenye *et al.*[51], processing is necessary to increase protein availability and accessibility. Eliminating phytic acid improves the meal's nutritional value by increasing the bioavailability of several cations[49].

Germination :

Germination is regarded as an effective technique in which significant alterations in the biochemical, nutritional, and sensory elements take place due to the activation of dormant enzymes. It is a process which involves seeds to recover from its dormant stage, restore its structural integrity, resume its metabolic processes to allow growth of an embryo; it utilizes the natural enzymes within the seed to release polypeptides and bioactive peptides[77]. As a result of germination, the concentration of certain anti-nutrients, including tannins and phytic acid, is lowered. Temperature and germination duration are the two key variables to watch during the procedure. The nutritional enhancement of cereal grains is significantly influenced by these two parameters[62].

Gibberellin, a plant hormone, is vital in controlling germination. It has been proven that it triggers the release of a variety of ions as well as increases the production and distribution of enzymes, particularly alpha-amylase[57]. Hydrolytic enzymes begin to alter the different components found in grains when they are hydrated in optimal settings; specifically, they alter the soluble sugars, protein, and enzyme activity. In response to the increased water intake via germinating seeds, and longer germination and fermentation times, resulted in increased amylase production and correlated with higher soluble sugar content, indicating an increase in carbohydrate metabolism[40]. It additionally triggers the release of phytase, an enzyme that lowers phytate and phytic acid levels. This immediately raises the body's ability to absorb different minerals, improving the nutritional content of food products[50]. When millets underwent germination, the antinutrient content decreased the most when compared to other procedures including soaking, fermenting, and milling.

After 35.82 hours, the protein content of the germinated Kodo millet flour increased significantly from 6.7% to 7.9%, minerals from 232.82 to 251.73 mg/100 g, and dietary fiber from 35.30 to 38.34 g/100 g. On the other hand, the tannin and phytate contents decreased from 1.603 to 0.234 mg/100 g and 1.344 to 0.997 mol/kg, respectively[67].

Natural bioactive peptides have several health benefits, specifically in preventing diseases and infections. This interest stems from the adverse reactions caused by synthetic peptides found in medications in the treatment and prevention of several illnesses.

Germinated seeds or sprouts have enhanced nutritional value compared to their original form, which includes elevated nutrient levels, reduced antinutrient content, and improved digestibility of proteins and starches[48].

Fermentation :

Fermentation is an ancient and cost-effective method of food preservation and it additionally enhances the texture, flavor, and scent of the finished product. Traditional fermented foods made from staple cereals such as rice, wheat, corn, or sorghum are widely recognized and enjoyed in various parts of the world. India and several other nations in central and southern Africa are major consumers of fermented cereal products. Consumption of such a food would benefit all age groups, including children and senior citizens, particularly the vegetarian populations in developing countries.

The process of fermentation modifies

the grains' biochemical composition, which includes protein, ash, moisture, fat, and fiber. During the process, organisms responsible for fermentation, maybe naturally occurring microflora on the substrate, or they can be added as starter cultures[32], multiply and engage in their metabolic activities within the food. This not only boosts the nutritional content of the food but also enhances its digestibility[10]. The fermentation method is utilized in millets to improve the digestion of protein and starch while lowering the content of antinutrients[33]. The partial breakdown of complex storage proteins into simpler substances like peptides and amino acids improves protein digestibility. Coulibaly *et al.*[18] reported that when millet is fermented for 12 or 24 hours, almost all antinutrients - trypsin, amylase inhibitor, and phytic acid - are greatly reduced by fermentation, with the exception of tannins.

Compared to other popular cereal grain, finger millet, also known as ragi in India, is a source of carbohydrates, protein, and minerals, however, due to presence of antinutrients like phytate and tannin, there is a decrease the bioavailability of nutrients. In comparison to germination, finger millet underwent a substantial amount of biochemical alterations during fermentation.

According to Sripriya *et al.*[74], there was a 60% decrease in phytate contents accompanied by a 47% increase in extractable minerals, such as calcium, iron, phosphorus, and zinc, and a decrease in antinutrient levels.

Gut Microbiome & Probiotic Fermentation:

The human microbiome is a complex ecosystem of species. It is composed of bacterial, fungal, archaeal, and viral species, with the gut microbiome often regarded as a vital "organ" playing a crucial role in immune homeostasis, providing nutrients, regulating development of the intestinal epithelial lining, and regulating various physiological pathways[24,37]. These pathways are linked to chronic diseases, including the initiation of various cancers, obesity, and inflammatory bowel diseases, such as ulcerative colitis[25,43,78].

Studies conducted on a small number of unrelated, healthy adults have exhibited a distinctive and significant variation in their gut microbiome, which was determined by assessing specific sequences in 16S ribosomal RNA genes[24,45]. The composition of the gut microbiome is influenced by various factors, including age, gender, immunity, childhood factors, medication, diet, and exercise. These factors contribute to the diversity and functionality of the microbiota[43].

Research indicates obesity is not solely caused by an excessive caloric intake, but can also be impacted by imbalances or reduction in gut microbial diversity, which play a role in how an individual, predisposed to obesity, may harvest and store more energy from food as compared to lean individuals[45,78]. A recent study conducted by Yang *et al*. (2024) examined the effects of fermented and unfermented millet bran on obese mice, which was induced by a high-fat diet fed over a course of 10 weeks. Fermented millets proved to be more effective in preventing obesity by reducing fat synthesis, enhancing fat breakdown and regulating cholesterol levels through modifications at the gene level, such as reducing expression of 3-hydroxy-3-methyl-glutaryl-CoA (HMGCoA) reductase and increasing expression of cholesterol 7α-hydroxylase, both of which leads to an overall decrease in cholesterol levels.

A similar study performed by Li *et al.*[46] examined how consuming millets affects liver fat metabolism in rats on a high-fat diet. The researchers analyzed liver RNA and markers of liver function, focusing on three key genes: sterol regulatory element-binding protein 1 (SREBP-1); fatty acid synthase (FAS); 3-hydroxy-3-methylglutaryl-coenzyme A reductase (HMGCR); these genes play a crucial role in fatty acid and cholesterol synthesis in the liver. The high-fat diet caused a significant upregulation in the expression of the key genes, however, when rats were fed with millets, it caused a remarkable downregulation of these genes.

SREMPs, a family of transcription factors, regulate the expression of FAS and HMGCR, which play a crucial role in fatty acid and cholesterol synthesis[23]. The FAS gene, associated with lipogenic synthesis, stores energy as fat in the liver and adipocytes (fat cells) and HMGCR directly influences cholesterol production in the liver[38]. The researchers concluded that consuming millets helps prevent liver fat accumulation by reducing the expression of these genes, particularly FAS[61]. This leads to decreased cholesterol and triglyceride production, suggesting that millet could help prevent diet-induced metabolic disorders.

Additionally, another research, Chen *et al.*[16] linked the intake of millets to an increase in the relative abundance of beneficial bacteria within the gut, particularly Bifidobacteria and Lactobacilli, which are known for their probiotic properties[71]. In the colon, gut bacteria ferment millet fibers and resistant starches to produce short-chain fatty acids (SCFAs)[30,70]. These SCFAs play a crucial role in stimulating contractions within the colon[73] and enhancing the intestinal barrier, thereby preventing an exchange of harmful bacteria and toxins into the bloodstream and reducing the risk of inflammation and metabolic disorders.

Furthermore, millet consumption influences the secretion of anorectic gut hormones, including glucagon-like peptide-1 (GLP-1) and peptide YY (PYY), which are important in enhancing satiety, regulating appetite, and improving balance of glucose levels. GLP-1 stimulates insulin secretion and lowers blood glucose level by suppressing glucagon secretion from the pancreas, this mechanism can aid in alleviating diabetes[70].

The prevalent rise of obesity and its associated health risks have led to extensive research into identifying mechanisms that regulate appetite. While drug-based GLP-1 receptor agonists, like semaglutide or liraglutide, are available to enhance GLP-1 levels, improve glycemic control in type 2 diabetic patients, and promote weight loss in overweight patients, these treatments involve synthetic compounds and require subcutaneous administration[19,28,86]. In contrast, millets offer a natural, dietary approach to enhancing GLP-1 levels, providing similar benefits without the need for additional medications.

Probiotics, defined as "substances or live microbial feed that beneficially affect the host animal by improving its microbial balance"[27], offer specific advantages when used in fermentation. Most commonly recommended probiotics are bacterial, especially the *Lactobacillus* and *Bifidobacteria* species. Examples include L. *plantarum,* L. *bulgaricus, Bacillus subtilis, and Streptococcus lactis*. Apart from enhancing the food's nutritional quality, probiotic organisms accelerate metabolism, relieve constipation, lower blood cholesterol levels, and increase tolerance to phenols[3] (Table-3).

Millets can be fermented using microbial cultures, such as *Lactobacillus brevis*, *Lactobacillus fermentum*, *Saccharomyces cerevisiae*, and *Saccharomyces boulardii* (a probiotic yeast variant of *Saccharomyces cerevisiae* with distinct differences in traits, making it more resilient in the gut environment, such as greater tolerance to acid and heat). Yeast are capable of preserving their stability and viability even during different food processing conditions[52]. They can withstand an extensive range of salt concentrations, oxygen activity, and pH levels[7,11].

Table-3. Key Probiotic Strains and their Fermentation Effects in Food

Probiotic Strain	Effect on Fermentation	Source
Lb. brevis	Higher fiber solubility Increased peptides and free amino acids content Increased in vitro protein digestibility	Verni *et al.* 2019
Lb. plantarum	Decreased anti nutritional factors Increased protein and mineral bioavailability Higher antioxidant activity	
Lb. bulgaricus	Higher fiber solubility Decreased phytic acid content	
S. cerevisiae	Folic acid fortification Higher protein and antioxidant activity Anti-stress and anti-fatigue	

Millet protein and starch digestibility could be improved further by combining lactobacilli and yeast. When lactic acid is used to ferment pearl millets, the amount of antinutritional phytate activity is decreased[21]. While ash, crude fiber, and carbohydrate content decreased, likely as a result of soluble inorganic salt leaching and the enzymatic degradation of fiber during fermentation, the amount of protein and crude fat in pearl millet increased, possibly as a result of protein synthesis through fermentation[4].

Role of Millets in Sustainable development goals :

The United Nations designated 2023 the International Year of Millets (IYM2023), emphasizing the importance of millets and their role in improving food security.

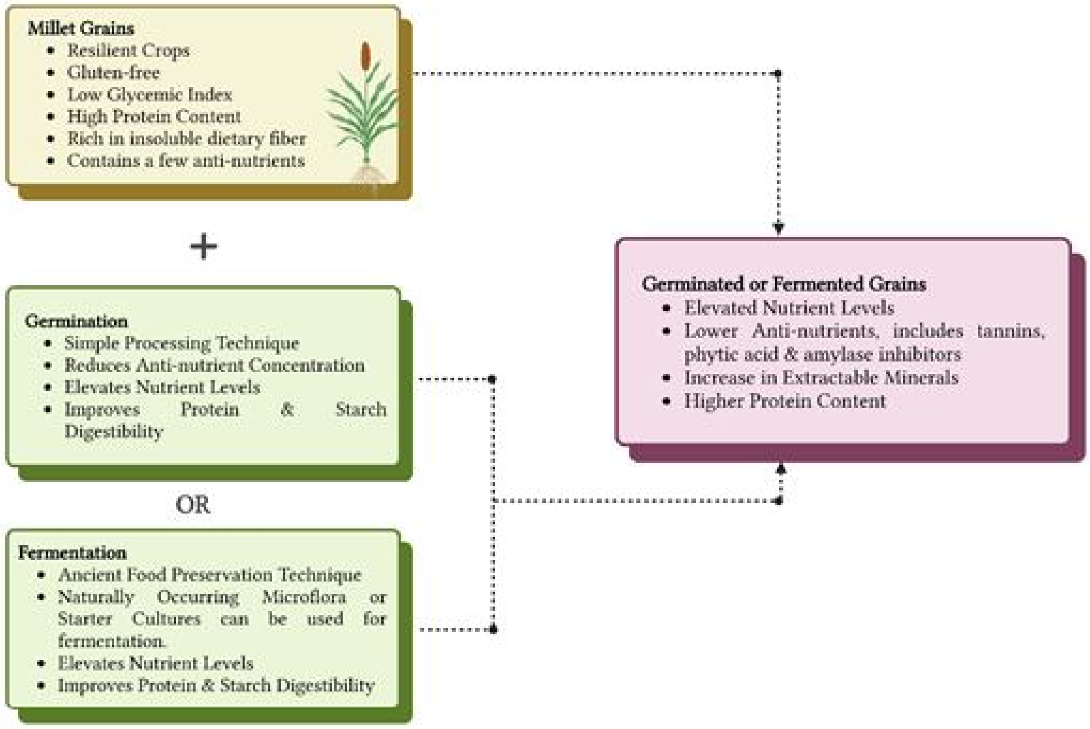

Figure 1.

Millets, valued for their exceptional nutritional value and benefits, are playing a crucial role in advancing six of the seventeen Sustainable Development Goals (SDGs) for 2030.

One of the SDGs (Goal 2) is 'Zero Hunger'. The objective of this goal is to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture[80]. Millets consist of an array of vitamins and minerals, which are typically deficient in the diets of low-income people, and they offer long-lasting satiety, which makes them an economical dietary option. It helps promote 'Good Health and Well-being' (SDG 3); encouraging individuals to shift their dietary preferences is vital for promoting greater millet consumption among consumers. Millets are packed with essential minerals and vitamins, have a low glycemic index, and contain no gluten, which can help avoid chronic diseases such as diabetes, heart disease, and cancer[6]. Moreover, millets are rich in antioxidants, which can boost immunity against oxidative stress[31]. Millets' ability to withstand climate challenges reduces the need for chemical fertilizers[75], promoting sustainable agriculture without harming the environment. Millet cultivation and consumption can contribute to achieving 'Climate Action' (SDG 13). Millets help in two ways: by enhancing food production resilience to climate change and by reducing reliance on synthetic fertilizers and pesticides, thereby mitigating environmental impacts[14].

In conclusion, this review offers insights on the effect of both fermentation and germination on the nutritional profile of barnyard and kodo millet. By examining changes in proteins, carbohydrates, alpha-amylase inhibitory activity, and various anti-nutrients, the research demonstrates that these processes can significantly improve the nutritional profile of millets, making them more beneficial for diverse consumer needs. The findings highlight that utilizing various processing techniques can enhance the functional properties of millets, thereby supporting their potential application in developing protein powders and other food products aimed at promoting health and nutrition.

Future Perspectives

Millets are considered to be the 'food of the future' due to their rich nutritional profile, including proteins, fibers, vitamins, and minerals, which can help minimize nutritional deficiencies, especially in developing nations. As resilient crops that require less water, millets act as a sustainable substitute for cereals, which are resource-intensive grains, making them a suitable option amidst the rising concerns over climate change. Their low glycemic index and high fiber content, aligns with the increased health and wellness trend, especially among those seeking gluten-free options, which serves to further drive demand. Furthermore, millets enhance food security by offering reliable nutrition in difficult agricultural environments and by being incorporated into a variety of culinary creations, such as beverages and snacks.

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