**Little millets *(Panicum sumatrense)*:Nutritional, health benefits and processing**

Hradesh Rajput1\*, Sudhir Kumar1, Vishal Kumar2, Aman Rathaur3 and Kuldeep Kumar1

1Department of Food Technology, School of Advanced Agriculture Sciences & Technology, CSJM University, Kanpur, Uttar Pradesh

2Department of Dairy Science and Food Technology, Institute of Agriculture Sciences, Banaras Hindu University, Varanasi

3School of Advanced Agriculture Sciences & Technology, CSJM University, Kanpur, Uttar Pradesh

*\*Email-* [*hrdesh802@gmail.com*](mailto:hrdesh802@gmail.com)

# Abstract

Little millet (Panicum sumatrense), an ancient grain with high nutritional value that was domesticated in India, is a lesser-known minor millet predominantly cultivated in dry regions such as Karnataka and Tamil Nadu. Although it serves as a staple in arid and semi-arid areas and boasts superior nutritional benefits compared to major cereals, its consumption is largely confined to particular cultural events. This grain is rich in protein (7%), carbohydrates (~78%), fat (4.26%), essential minerals (notably iron: 9-12 mg/100g, phosphorus: 220 mg/100g, magnesium), and dietary fiber along with B-complex vitamins and powerful phytochemicals (including phenolics, flavonoids, and phytosterols), providing a substantial energy content of 370 Kcal/100g. The primary health advantages include enhanced cardiovascular health (due to magnesium), reduction in cholesterol levels (thanks to niacin), hypoglycemic effects (attributed to fiber), and antioxidant properties. Nevertheless, its use is limited by the labour-intensive processing required and the low bioavailability of nutrients caused by antinutritional components (such as phytates and tannins). This review delves into its nutritional profile, nutraceutical characteristics, health benefits, and investigates processing methods to create value-added products, emphasizing its potential as a functional food and a gluten-free option, especially for managing celiac disease.

**Key words:** little millet, nutritional quality, nutraceuticals, health benefits, processing

**INTRODUCTION**

Millets are part of a diverse category of small-seeded cereal grasses that belong to the Poaceae family, serve as essential staple crops in semi-arid and arid areas throughout Africa, Asia and certain regions of Europe. This term generally includes multiple genera such as Panicum, Setaria, Echinochloa, Pennisetum, Paspalum, and Eleusine. [1, 2]. Among these robust grains, which frequently flourish in conditions where other crops do not succeed, are the lesser-known "minor millets" like kodo, proso, barnyard, foxtail and little millet (Panicum sumatrense) [2].

Little millet, a historic crop that was first cultivated in India, is mainly classified into two varieties: the shorter nana (60-170 cm, with an inflorescence of 14-15 cm) and the taller robusta (120-190 cm, featuring a 20-45 cm inflorescence). This crop is primarily self-pollinating and is well-suited for growth at altitudes reaching up to 2100 m. It is primarily cultivated in the states of Karnataka and Tamil Nadu, with a maturation period ranging from 2.5 to 5 months [3]. Although it typically produces modest yields (<0.5 t/ha), its real worth is found in its remarkable resilience and enhanced nutritional characteristics when compared to numerous primary cereals [4].

Despite being nutritionally rich – containing significant protein, fat (4.7g/100g), dietary fiber (7.7g/100g), iron (9.3mg/100g), phosphorus (220mg/100g), and beneficial phytochemicals [4, 6] – little millet remains underutilized. Its high fiber content contributes to a low glycemic index and demonstrated hypoglycemic effects [5]. Nevertheless, the extensive adoption is primarily obstructed by the tedious nature of conventional processing techniques.

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**NUTRITIONAL COMPOSITION**

Little millets are abundant in essential nutrients such as proteins, carbohydrates, dietary fiber, vitamins and minerals. Although they contain carbohydrates in lesser amounts, their protein content is comparable to that of other cereals. Additionally, little millets possess a greater quantity of inorganic substances and exhibit a higher ash content.

**Carbohydrates**

The carbohydrates found in the milled grains of little millet consist of free sugars (2–3%), non-starchy polysaccharides (15–20%), and starch (60–75%). The main free sugars present are glucose, sucrose and fructose. Dietary fibers, which are composed of non-starchy polysaccharides, include cellulose, hemicellulose, and pectin-like substances. Oligosaccharides such as arabinose and stachyose, which may lead to flatulence, are absent. Only trace amounts of β-glucans and lignin-like substances are present. Of the total dietary fiber, 90% is insoluble fiber sourced from the aleurone layer and the cell wall components of the kernel. The starch consists of amylose and amylopectin in a ratio of 25:75, which is comparable to that found in other cereals. Millets are classified as high amylose grains, and certain waxy varieties are cultivated in China. The starch granules are densely packed within the cellular matrix, and a considerable portion of the endosperm exhibits a vitreous quality.[1]

**Proteins**

Little millets are recognized for their diverse protein fractions, which include albumins, globulins, cross-linked prolamins, and glutelins. They exhibit a higher concentration of prolamin and glutelin fractions, followed by albumin and globulin fractions. The true digestibility of millet proteins is reported to be between 95% and 99.3%.[8] The biological value and net protein utilization of little millet protein (BV = 58.8–65.6 and NPU = 55.7–62.9) exceed those of other millet varieties (BV = 48.4–56.5 and NPU = 46.3–54.5), while the digestible energy of little millet (95.6–96.1) surpasses that of pearl millet (85.3–89.9) [9].

**Lipids**

The fat is found both in the bran and in the endosperm. Typically, the fat contains over 60% unsaturated fatty acids, including linolenic acid.[1] Little millet has a lipid content ranging from 1.8% to 3.9%. The embryo accounts for approximately 24% of the total fat in the grain. The analysis of the fatty acid profile reveals that saturated fatty acids comprise 17.9% to 21.6%, while the content of unsaturated fatty acids is between 78% and 82%. When lipids extracted from millets are expressed as a percentage of the dry weight of the seeds, they amount to 7.2%. This lipid fraction consists of 85% neutral lipids, 12% phospholipids, and 3% glycolipids. Of the total neutral lipids, 85% were identified as triacylglycerols, with the remainder consisting of small amounts of mono- and diacylglycerols, free fatty acids, and sterols. Both campesterol and stigmasterol were observed to exist in equal proportions in their free and esterified states. Lysophosphatidylcholine (42%) was identified as the predominant phospholipid in millet seeds. Lesser quantities of lysophosphatidylethanolamine (21%), phosphatidylcholine (24%), as well as traces of phosphatidic acid, phosphatidylglycerol, phosphatidylinositol, and phosphatidylserine were also detected. The primary glycolipids identified were sterol glycoside, esterified sterol glycoside, cerebrosides (ceramide monohexosides), monogalactosyldiacylglycerol, and digalactosyldiacylglycerol [10].

**Vitamins**

Little millets are excellent sources of Vitamin E and B-complex vitamins, with the exception of Vitamin B12. The total amount of niacin present is 10.88 mg; however, only 13% of this niacin can be extracted using cold water. Mature millets exhibit relatively low concentrations of Vitamin C. The tocopherol levels in millets are lower compared to those in soybean and corn oil. In millet seeds, the α-tocopherol content is notably low, with tocopherols mainly comprising the γ-isomer. The vitamin activity of α-tocopherol is considerably higher than that of other tocopherols. The efficacy of γ-tocopherol in terms of Vitamin E is less than 10% when compared to α-tocopherol [11]. The crude oil obtained from the kernel of common millet has a Vitamin A equivalent of 8.3–10.5 mg and Vitamin E content of 87–96 mg per 100 g. However, during the refining process, it has been found that the activity of vitamin A diminishes, and there are significant decreases in Vitamin E levels as well. In the case of little millet, the overall niacin content is significantly greater than that found in other cereal grains.

**Minerals**

The mineral composition of little millets closely resembles that of other grains such as sorghum, yet they are particularly rich in calcium and manganese. Little millet is characterized by a notably high iron content, which ranges from 9% to 12%, and its total mineral or ash content surpasses that of many commonly consumed cereals, including sorghum. Little millets possess a highly fibrous hull, and it is customary to dehull them prior to consumption. Nevertheless, this dehulling process significantly diminishes the mineral content, with the degree of reduction varying according to the specific species of millet. Millets serve as an excellent source of phosphorus, which is essential for energy production. It plays a crucial role in ATP, the energy currency of cells, and also supports the nervous system and cell membranes. A well-prepared cup of little millet offers 26.4% of the daily magnesium requirement and 24% of the daily phosphorus need. The magnesium found in millets contributes to the relaxation of blood vessels and the regulation of blood pressure, enhances nutrient delivery by improving blood circulation, and thus further promotes cardiovascular health. Millet should be considered among heart-healthy options due to its substantial magnesium content. Magnesium enhances insulin sensitivity and lowers triglyceride levels, and it acts as a cofactor for over 300 enzymes.

**Bioavailability of Nutrients from Millets**

Despite the fact that little millets are rich in various beneficial nutrients, their availability is restricted by certain factors. The bioavailability of the nutrients present in little millets is diminished due to the existence of antinutritional elements. Among these are phytates and tannins. Furthermore, the high fiber content of millets also plays a role in their decreased bioavailability. Phytates and tannins adversely affect the absorption of minerals. Rao et al. (1983) conducted a study on iron absorption from millets in humans, comparing it to the absorption from rice and wheat.[12] They found that the iron absorption from millets was less than that from rice and wheat. The iron content can be enhanced as ionizable iron through techniques such as grain germination or by lowering tannins through solvent extraction. Consequently, the elevated levels of micronutrients in millet are counterbalanced by their restricted bioavailability. It is essential to investigate various cooking methods to evaluate the bioavailability of micronutrients, including minerals and B vitamins, through in vivo studies. Additionally, the effects of physiological conditions such as pregnancy, lactation, age, and nutritional status on bioavailability should be analyzed. Vitamins and minerals are absorbed based on the body's requirements.

**Fibre**

Muralikrishna et al. found that hemicelluloses A in little millets represent a non-cellulosic variant of beta-glucan, whereas hemicelluloses B are composed of hexose, pentose, and uronic acid.[13] The health benefits associated with dietary fiber include reduced levels of blood cholesterol and sugar, in addition to enhanced bowel movements. In addition to fiber, millets are rich in various health-promoting phytochemicals such as polyphenols, phytosterols, phytoestrogens, lignins, and phytocyanins. These substances provide protection against age-related degenerative diseases, including cardiovascular diseases (CVD), diabetes, and cancer, by functioning as antioxidants, detoxifying agents, and modulators of the immune system. [14]

**NUTRACEUTICALS**

The term nutraceuticals, similar to pharmaceuticals, refers to bioactive compounds derived from food sources that exhibit a protective effect against degenerative diseases when in their isolated form.

**Phenolic Compounds**

Phenolic compounds encompass a wide array of substances characterized by the presence of an aromatic ring that contains one or more hydroxyl groups, along with various substituents. The main categories of phenolic compounds are generally classified into phenolic acids, flavonoids, and lignans. These compounds are primarily found as glycosides linked to different sugar molecules or as other complexes associated with organic acids, amines, lipids, carbohydrates, and additional phenols. They are recognized as a significant source of antioxidants and play various roles in alleviating diseases associated with oxidative stress, including cancer and cardiovascular diseases, thus establishing their reputation as well-known antioxidant compounds. Research has shown that bound polyphenols (extractable with 1% HCl) are most prevalent in little millet, with a concentration of 9.64±0.28.[15] The phenolic content in rice samples was found to be lower than that in millet samples, indicating that millet serves as a superior source of nutraceutical compounds. Bound phenolic compounds demonstrate properties such as antioxidant activity, antiobesity effects, antidiabetic capabilities, antimutagenic and anticarcinogenic effects, as well as antimicrobial and antiviral characteristics, with the capacity to inhibit the growth of various organisms, including HIV and the influenza virus. Furthermore, these compounds assist in preventing DNA cleavage caused by lipid oxidation radicals (reference). If the study is exclusively focused on diseases, this assertion can be made. Consequently, it can be concluded that a 1% acidic-methanol extract derived from various millets represents a promising source of health-promoting polyphenols.

The capacity of phenolic compounds to function as antioxidants is attributed to their ability to donate hydrogen atoms to electron-deficient free radicals through hydroxyl groups present on benzene rings. This process results in the creation of a resonance-stabilized phenoxyl radical, which exhibits reduced reactivity. Polyphenols have been shown to diminish the activity of digestive enzymes such as amylase, glucosidase, pepsin, trypsin, and lipases.[16] Pietta observed that polyphenolic compounds, which include flavonoids, phenolic acids, and proanthocyanidins, are esteemed for their radical-scavenging properties and are expected to play a crucial role in the prevention of various diseases and health issues.[17] The consumption of dietary phenolic compounds may provide health benefits associated with a lower risk of chronic diseases.[18] The interaction among phenolics may be important in modulating amylase inhibition, potentially aiding in the management of type 2 diabetes mellitus, which is characterized by high blood glucose levels.[19,20] As inhibitors of amylase and glucosidase (similar to acarbose, miglitol, and voglibose), polyphenols contribute to a reduction in post-prandial hyperglycemia.[21]

**Flavonoids**

Flavonoids are categorized as a type of secondary metabolites present in plants, characterized by a core structure comprising a 15-carbon skeleton. This skeleton includes two phenyl rings and one heterocyclic ring. Serving as pigments in plants, flavonoids are produced from phenylalanine.[22] The structure typically displays a fundamental C6-C3-C6 arrangement. These structures include a diverse range of polyphenolic compounds defined by a benzo-y-pyrone framework, such as anthocyanins, flavonols, flavanols, and isoflavones, which are abundant in fruits and vegetables. They are primarily found in glycoside form, with the exception of flavanols, which often polymerize into condensed tannins. Tannins can be classified into two types: condensed and hydrolyzable. Most condensed tannins are polymers derived from flavan-3-ols (catechins) or flavan-3, 4-diol (leucoanthocyanidins), whereas the majority of hydrolyzable tannins consist of glucose or polyhydric alcohols that are esterified with gallic acid (gallotanins) or hexahydrodiphenic acid (ellagitannins).

Flavonoids such as catechin, quercetin, anthocyanin, and tannin are advantageous for health. They significantly contribute to human health due to their pharmacological properties as free radical scavengers. [23] The antioxidant capacity of flavonoids is affected by the number and arrangement of hydroxyl groups in their structure, as well as by the presence of electron-donating and withdrawing groups. Research conducted by Miller et al. (2000) suggests that whole grains exhibit nearly equivalent antioxidant activity (AA) to that of fruits and vegetables when assessed on a per-serving basis.[24] Some studies emphasize the presence of flavones among the various types of flavonoids.

**Phytic Acid**

Phytic acid is scientifically known as myoinositol 1,2,3,4,5,6 hexakis-dihydrogen phosphate. The concentration of phytic acid in different foods can range from 0.1 to 6.0%.[25] It has been found to be present in the bran of cereal grains or within the cotyledon of oilseeds and legumes, situated inside the protein bodies.[25] Lorenz observed that the phytate concentrations in various little millet types range from 170 to 470 mg per 100 g of whole grain and also pointed out that dehulling leads to a decrease in phytate levels by 27–53%.[26] Dehulling causes a 12% reduction in phytic phosphorus levels in common millet, a 39% reduction in little millet, a 25% decrease in kodo millet, and a 23% decline in barnyard millet.

**Carotenoid and Tocopherols**

Food sources are rich in pigments, with carotenoids being a prominent example. More than 600 carotenoids have been identified. These compounds are well-known for their provitamin A characteristics. Furthermore, carotenoids are essential in disease prevention due to their antioxidant properties. From a structural perspective, carotenoids consist of isoprenoid units that form a long polyene chain containing between 3 to 15 conjugated double bonds. The positioning of these double bonds influences their absorption spectrum. Carotene is a cyclized derivative distinguished by cyclization at one or both ends, whereas xanthophylls are formed when oxygen is incorporated. Various modifications can occur through isomerization, chain elongation, or degradation. A recent investigation by Asharani et al. indicated that the total carotenoid content in little millet is 173 μg/100g. [27] The carotenoid concentrations observed in millets are comparable to those in wheat (150–200 μg/100 g) and sorghum (180–230 μg/100 g), but are significantly lower than those found in maize (1800–5500 μg/100 g) and its varieties (2400–3200 μg/100 g).

Vitamin E is a fat-soluble compound that is frequently found in nature, consisting of a group of eight unique molecules. Although these molecules differ in structure, they all contain a chromanol ring along with a 12-carbon aliphatic side chain. This side chain includes two methyl groups located in the middle and at the terminal end. The family comprises four saturated tocopherols and four tocotrienols, which have three double bonds. Both tocopherols and tocotrienols are categorized into four distinct variants: alpha, beta, gamma, and delta. These variations result from the differing quantities of methyl groups present in the side chain. An analysis of vitamin E conducted using HPLC indicated elevated concentrations of γ- and α-tocopherols, while tocotrienols were found in lower amounts in millets. The overall tocopherol content in various types of little millet is approximately 1.3 mg per 100 grams. Vitamin E performs several roles, including acting as an antioxidant, mitigating inflammation, decreasing superoxide production in mitochondria, and serving as an anti-atherosclerotic agent.

**HEALTH BENEFITS**

Research in epidemiology has shown that diets abundant in plant-based foods, particularly those incorporating whole grains, can provide protection against non-communicable diseases due to their high content of beneficial nutrients and phytochemicals. Little millets, known for their wealth of powerful health-boosting phytochemicals, are considered functional foods.

**Cataractogenesis Inhibition**

Western countries are facing challenges associated with retinopathy and cataracts, which are among the leading causes of blindness worldwide. Diabetes is a significant risk factor for both conditions. In India, the prevalence of blindness is reported at 15 per 1000 individuals, with cataracts accounting for 80% of these instances. In cases of cataracts induced by diabetes, there is an accumulation of sorbitol. This accumulation is facilitated by the enzyme aldose reductase (AR). The attachment of glucose to protein molecules, leading to non-enzymatic glycation that occurs in diabetes, is regarded as a key contributor to the formation of sugar-induced cataracts mediated by aldose reductase. [28] evaluated FMP for its capacity to inhibit AR, underscoring its potential in both antidiabetic and antioxidant functions. The phenolic compounds present in FMP, such as gallic, protocatechuic, p-hydroxybenzoic, p-coumaric, vanillic, syringic, ferulic, trans-cinnamic acids, and quercetin, significantly impeded cataract development in the eye lens. [28] Investigations into the structure and function of phenolics revealed that the existence of a -hydroxyl group at the 4th position is essential for the inhibitory effects on aldose reductase. Furthermore, the presence of an O-methyl group next to the -OH group in phenolics diminished the activity of aldose reductase.

**Antioxidant Activity**

Due to their significant amounts of antioxidants, fiber, and complex carbohydrates, little millets provide protective benefits against cancer, heart disease, and aging. These health issues arise from the generation of harmful oxygen species such as free radicals and peroxides, which lead to cellular damage. Studies suggest that little millets assist in protecting us from oxidative stress. Research has been conducted on phenolic acids obtained from the milled parts of little millet to evaluate their antioxidant and antimicrobial properties.[29] The different milled parts (whole grain, flour, and seed coat) have demonstrated high concentrations of polyphenols in acidic methanol extracts. The main phenolic acids identified include daidzein, gallic, coumaric, syringic, and vanillic acids, with daidzein showing the highest concentration. The Carotene–Linoleic acid assay was conducted to assess the antioxidant activity (AA) of the seed coat extract and the whole flour extract, indicating that the seed coat has an AA of 86%, while the whole flour extract achieves only 27%. Asharani et al., 2010, noted that the edible flours of little millet have a total antioxidant capacity of 4.7 + 1.8 mM TE/g. Ferulic acid is thought to offer various health advantages, such as reducing total cholesterol levels, enhancing Vitamin E bioavailability, improving sperm vitality, and serving as a protective agent against skin damage caused by UV radiation. Ferulic acid has shown strong antioxidant, free radical scavenging, and anti-inflammatory properties,[30] and has yielded positive results against cancer and tumors.

Currently, over 50 phenolic compounds from different categories, including phenolic acids and their derivatives, dehydrodiferulates, dehydrotriferulates, flavan-3-ol monomers and dimers, flavonols, flavones, and flavanonols, have been positively or tentatively identified in four phenolic fractions of various whole millet grains (kodo, finger, foxtail, proso, little, and pearl millets) using HPLC and HPLC-tandem mass spectrometry. Consequently, according to available literature, little millet grains can serve as functional food components and natural antioxidant sources.

**Cardiovascular disease**

Obesity, tobacco use, poor nutrition, and lack of physical activity elevate the likelihood of heart attacks and strokes. Many countries around the world are experiencing an increase in the rates of cardiovascular diseases. Research has shown that rats consuming a diet rich in both native and processed starch from little millet exhibited the lowest levels of blood glucose, serum cholesterol, and triglycerides when compared to those fed rice and other minor millets. Furthermore, phenolic extracts derived from little millets were assessed for their ability to prevent lipid peroxidation in vitro, particularly in relation to copper-mediated oxidation of human LDL cholesterol, as well as in various food matrices including cooked comminuted pork, stripped corn oil, and a linoleic acid emulsion. At a final concentration of 0.05 mg/mL, the millet extracts were observed to reduce LDL cholesterol oxidation by 1% to 41%.

**Little millet against cancers and celiac disease**

Little millet grains are acknowledged in literature for their substantial levels of phenolic acids, tannins, and phytate, which are categorized as "antinutrients." Nevertheless, studies suggest that these antinutrients might lower the risk of colon and breast cancer in animal models. Additionally, it has been noted that populations that consume sorghum and millet exhibit lower rates of esophageal cancer compared to those whose diets are primarily based on wheat or maize.

The rising demand for innovative, flavorful, and "healthy" food options, coupled with an increasing number of individuals diagnosed with celiac disease, has led to the emergence of a new market for cereal products derived from grains other than wheat and rye. In this competitive landscape, little millet has carved out a notable niche. Celiac disease is an immune-mediated intestinal disorder triggered by the consumption of gluten in genetically predisposed individuals. It is among the most prevalent lifelong disorders globally. Historically, celiac disease was viewed as a rare condition, predominantly affecting children of European descent.

A gluten-free diet requires significant alterations in food choices within the grain category. Individuals adhering to this diet must replace foods made from wheat, barley, and rye with those derived from gluten-free grains. Given that little millet is gluten-free, it offers considerable potential for inclusion in food and beverage products tailored for individuals with celiac disease. Consequently, little millet grains and their derivatives may contribute to cancer prevention and the development of food products suitable for those affected by celiac disease.

**Millet and aging**

The interaction that occurs between the aldehyde group of reducing sugars and the amino group of proteins, known as nonenzymatic glycosylation, plays a crucial role in the complications associated with diabetes and the aging process. Little millet is abundant in antioxidants and phenolic compounds; however, research has indicated that phytates, phenols, and tannins can boost antioxidant activity, which is essential for health, aging, and metabolic syndrome. Furthermore, studies have revealed that methanolic extracts from little millet can inhibit glycation and cross-linking of collagen. Consequently, little millet may provide potential benefits in protecting against the effects of aging.

**Antimicrobial activity**

Little millet fractions and extracts demonstrated antimicrobial properties. In a particular study, the seed protein extracts of little millet were assessed for their capacity to inhibit the growth of Rhizoctonia solani, Macrophomina phaseolina, and Fusarium oxysporum. The findings revealed that the 23-kDa thaumatin-like proteins (TLPs) were primarily expressed in the seeds and inflorescence of little millet. The extract obtained from the seed coat exhibited superior antimicrobial activity against Bacillus cereus and Aspergillus flavus in comparison to the whole flour extract. Consequently, the results suggest that the little millet seed coat has the potential to serve as a natural alternative for antioxidants and food preservation. Furthermore, a novel antifungal peptide with significant efficacy was isolated from little millet seeds. Therefore, phenolic acid extracts and other bioactive compounds may function as natural alternatives for food preservation and therapeutic applications. Nevertheless, additional research is required to confirm their potential antimicrobial effects.

**Challenges and Future Perspectives**

The reviewed literature suggests that the nutritional advantages and possible health impacts of little millet grains are comparable to those of major cereals like wheat, rice, and maize. Nevertheless, their use as food is predominantly restricted to rural households. This restriction is mainly attributed to the absence of advanced processing technologies for millet, which would enable the production of convenient, ready-to-cook or ready-to-eat, and safe commercial food products suitable for larger urban populations. However, as the population continues to expand, resulting in increased demands for food, feed, and fuel, it is crucial for society to enhance agricultural productivity—either by boosting yields on existing farmland or by utilizing previously uncultivated areas—or by altering current consumption patterns. Furthermore, it is essential to promote the diversification of food production at both national and household levels in conjunction with yield improvements. Providing healthier and traditional whole-grain and multigrain alternatives to refined carbohydrates can significantly contribute to dietary changes aimed at increasing the intake of minor-grain foods.[31]

Gluten protein is widely recognized for its significance in the production of manageable and high-quality baked goods, as well as other grain products that require dough with elastic and extensible characteristics. Nevertheless, considering that little millet is gluten-free and based on specific laboratory findings, it appears unsuitable for the creation of pure-millet baked goods and other easily manageable solid food items. Consequently, incorporating millet grains into wheat composite flours, complementary foods, and food blends seems to be the most effective approach for developing nutritional, "healthy," safe, high-quality, and shelf-stable food products at both household and commercial levels to enhance the utilization of little millet grains. Moreover, to produce high-quality products on a commercial scale for urban consumers, innovative processing techniques for decortication, milling, and other preparation methods of millet grain foods are crucial. Therefore, a reliable supply of high-quality millet grains for industrial purposes and the development of millet varieties with increased essential amino acid content are essential. Future research should investigate the nutritional benefits and potential health advantages of millet grains and their fractions in both animal and human models to support efforts aimed at promoting their use as food.

**Little Millet in probiotic and prebiotics foods**

Probiotics assist in preserving the natural flora or aid in the restoration of the colon when bacterial levels are diminished due to antibiotics, chemotherapy, or illness. The FAO/WHO defines probiotics as "live microorganisms that, when ingested in sufficient quantities, provide a health benefit to the host," but it is also essential to include information regarding the genus, species, and strain level, along with a safety evaluation. Many probiotic foods produce fatty acids, vitamins, and other essential nutrients that enhance the body's defenses against harmful microorganisms.[1]. Fermented foods are significant in the diets of individuals worldwide, with an estimated 20 to 40% of the food supply comprising these products.

A prominent intervention study carried out in Northern Ghana employs a naturally fermented little millet product as a probiotic solution for diarrhea in young children. Prebiotics are dietary elements that the host is unable to digest, providing advantages by specifically promoting the growth or activity of certain bacteria in the colon. Substances identified as prebiotics should remain undigested in the upper gastrointestinal tract, serve as selective nutrients for specific groups of colonic bacteria, alter the microbiota in the colon for a healthier equilibrium, and yield beneficial effects either in the gut or systemically for the host's health. Fermented foods and beverages made from little millet, a type of cereal, have been extensively studied and are an essential component of the diet in numerous African countries.

**PROCESSING OF LITTLE MILLETS**

**Food Manufacturing and Formulation Technologies**

**Conversion into pure-millet food products**

The use and processing of little millet in traditional recipes is a common practice in numerous developing nations across Africa and Asia. In various African countries, little millet frequently serves as a fundamental component in many dishes, typically prepared as steam-cooked meals (often referred to as "couscous"), thick porridge, or thin porridge, which can provide supplementary nutrition for infants and young children; it is also utilized in the production of beer. In Nigeria, kunu is a highly nutritious drink that can meet most of the body's dietary needs. Moreover, the analysis revealed that kunu made from little millet possesses the highest nutritional value; it boasts an excellent nutrient profile and serves as a good energy source due to its elevated protein content, suitable total solids, and balanced pH and acidity. Little millet is rich in calcium, which is vital for maintaining strong bones and healthy teeth.

To explore the possibility of producing lajia noodles from little millet, experiments were conducted on noodle manufacturing using various flours and analyses of starch grains. The results showed that it was impractical to stretch pure millet dough into noodle form. Research has been undertaken on the conversion of little millet grains into fura, a traditional millet dish in West Africa and a significant source of nutrients in the region, concentrating on its nutrient profile, flavanol contents, and storage characteristics. The results indicated that the flavanol levels in the grain decreased by approximately 46.3% during the transformation into fura. Additionally, the vitamin B2 content reduced by 31.4%, 34.3%, and 45.7% during the processing of the grain into meal, flour, and fura, respectively.

**Blending in composite flours and food products**

To enhance the nutritional quality of food and diets, as well as to address malnutrition and specific health issues, it is crucial to adopt various strategies that provide affordable and locally sourced food options for both adults and children. Research has shown that porridge made from extruded millet and press-dried cowpea possesses excellent nutritional quality and is suitable as a weaning food, offering an intermediate thickness, smooth consistency, and appealing color and flavor. In a specific study, biscuits were created using mixtures of millet flour and pigeon pea flour in the ratios of millet to pea at 100:0, 75:25, 65:35, and 50:50. It was determined that all these biscuits were rich in protein and digestible carbohydrates. Moreover, sensory evaluations indicated that all biscuits received favorable feedback, with the 65% millet and 35% pea combination achieving the highest ratings for taste, texture, and overall preference.

**Fortification and supplementation**

The fortification of grain-based foods has been acknowledged as an effective approach to combat nutrient deficiencies. Micronutrient deficiencies, particularly of vitamin A, iron, iodine, and zinc, are widespread in numerous developing countries as well as in some developed nations. Among these deficiencies, iron deficiency poses a significant public health issue in less-developed regions, impacting nearly 50% of infants, children, and women of reproductive age in lower-income areas of Africa, Asia, and Latin America. Research suggests that fortified pearl millet flour is a viable option for increasing zinc levels, thereby aiding in the battle against zinc deficiency. Furthermore, the heat treatment of fortified millet flour enhances the absorption of iron from both fortified and unfortified flour. Additionally, the inclusion of iron fortification does not impede the bioavailability of naturally occurring zinc within the flour. Moreover, the dual fortification of millet flour with ferrous fumarate, zinc stearate, and EDTA did not adversely affect the sensory attributes of the final products. The fortified flours exhibited an acceptable shelf life of up to 60 days, as demonstrated by the moisture content and free fatty acid levels. Consequently, the incorporation of fortifications into millet flours can augment their micronutrient content, including vital minerals and vitamins, thereby enhancing their nutritional profile, although the cost-effectiveness of this approach should be evaluated. The in vitro protein digestibility (IVPD) and amino acid composition of pearl millet blended with soybean protein (ranging from 5% to 15%) were examined. An increase in soybean content within the mixture consistently resulted in a reduction of the IVPD of millet flour. Additionally, the integration of soybean protein into millet flour significantly elevated lysine levels by 1.5 to 2.4 times. The concentrations of essential amino acids were also found to be greater in the cooked composite flours compared to those of the cooked native millet flour. It was also observed that enriching pearl millet with whey. It was observed that the enhancement of pearl millet with whey protein led to a notable rise in protein levels when compared to the control group. Sensory assessments indicated that the formulations enhanced with whey protein were preferred over the control variant. Consequently, it can be inferred that augmenting the nutritional quality of millet grains by incorporating natural food components is advantageous and may also be more cost-effective than depending on synthetic chemical fortification.

**Preservation Treatments**

Generally, mature dry cereal grains can be stored for extended periods under normal conditions. Conversely, their milled derivatives such as flour and final food products require specific treatments or optimal conditions to improve their shelf life due to the impacts of moisture and enzymes. Thermal processing is widely recognized as a method of food preservation that eliminates microorganisms, thus prolonging shelf life. However, while thermal processing typically enhances food digestibility, it may also result in a reduction of certain heat-sensitive nutrients, which diminishes overall nutritional quality. Research shows that blanching in hot water at 98°C for 10 minutes or dry-heating grains at 100°C for 120 minutes effectively reduces adverse changes in the lipids of pearl millet meal during storage. Additionally, hydrothermal treatment of pearl millet grains has been identified as an effective technique to deactivate lipase and prolong the shelf life of the resulting flour. Flour derived from hydrothermally processed grains demonstrated satisfactory physical, functional, and pasting properties, significantly improving storage stability (P < 0.05) for up to 50 days at ambient temperatures (15 to 35°C), compared to only 10 days for control flour. Nonetheless, hydrothermal processing did not change the total nutrient composition of finger millet but did affect its nutrient profile. The impact of refrigeration on the overall protein and amino acid composition of raw and processed flour from two pearl millet cultivars was investigated. It was noted that the impact of refrigeration, in conjunction with the duration of storage, cooking, or dehulling, differed among amino acid profiles and cultivars. Regardless of the method of processing or the length of storage, the levels of amino acids remained consistent after refrigeration for both cultivars. Furthermore, it has been documented that thermal treatments can be employed to enhance the shelf life of whole pearl millet flour, with methods such as toasting, boiling, or a combination of both resulting in flour that cooks more rapidly. The influence of irradiation on the overall protein and amino acid profiles in both raw and processed flour of two pearl millet cultivars was also investigated. Storing irradiated whole and dehulled flour for a period of 60 days resulted in a minor decrease in protein content, even post-cooking. The effect of irradiation, when paired with the treatments applied to the grains and/or flour, on amino acid levels varied among the cultivars. Most amino acids remained stable throughout all treatments, with the exception of leucine, glutamic acid, and phenylalanine. As a result, it can be inferred that refrigeration, irradiation, and hydrothermal treatment, or combinations of various methods, may extend the shelf life of millet grains, their milled fractions, and associated food products.

This extension is attributed to the inactivation of internal enzymes and microorganisms due to these treatments. However, the application of these methods must be fine-tuned to prevent undesirable changes in the quality characteristics of millet grains and their food products.

**Other Processing Technologies**

The application of high hydrostatic pressure (HHP) in food processing has expanded within the food industry as an alternative to thermal processing, aimed at preserving the sensory and nutritional attributes of food products. Investigations have examined the impact of HHP treatment on the viscoelastic reinforcement of wheat cereal matrices with significant replacement levels. It was concluded that HHP is an effective technique for modifying the gelatinization and gelling characteristics of hydrated flours sourced from oats, millet, sorghum, and wheat. High-intensity HHP treatments exceeding 350 MPa do not necessarily improve the starch gelatinization in batters. By selecting an appropriate dough yield (DY=200) and pressure levels (350 MPa), HHP treatment can enhance the viscoelastic properties of composite wheat dough matrices with up to 60% replacement. Furthermore, it was suggested that additional research is required to gain a deeper understanding of the qualitative and quantitative effects of pressure-treated oat, millet, and sorghum flours on the techno-functional and nutritional characteristics of composite wheat breads. The effect of depigmentation on the sensory qualities and nutritional features of pearl millet pasta was also investigated. Pearl millet grains were subjected to depigmentation by soaking in 0.2 N hydrochloric acid for 18 hours, followed by washing, blanching (at 98°C for 30 seconds), and sun-drying. The findings indicated that depigmentation is an effective processing technique for producing acceptable pearl millet products with enhanced in vitro protein and starch digestibility.

**Value Added Products of Millets**

**Conventional food products**

**Roti (unleavened pan cake):** Roti, which is a flatbread made without yeast, Mudde, a type of dumpling, and porridge are the main food items derived from millets.[9] The protein in millet lacks gluten, rendering it unsuitable as the sole ingredient for baking. To prepare roti, millet flour is mixed with hot water to partially gelatinize the starch. This method ensures the necessary adhesion of particles, enabling the dough to be shaped into thin pieces. The flattened dough is then cooked on a hot surface. Roti is akin to wheat chapati or maize tortillas. Mudde is produced by steaming millet flour dough and shaping it into balls. It bears resemblance to the ‘TO’ found in Africa. Millet flour combined with cold water and a small amount of buttermilk is allowed to ferment slightly overnight. The next morning, this mixture is cooked to produce porridge.

**Multi-grain flour:** Multigrain flour, commonly known as composite flour, is produced from a mixture of various flours sourced from millets and pulses. This flour type is rich in vital nutrients such as protein, vitamins, minerals, and dietary fiber, addressing the changing dietary needs of those who favor contemporary and health-conscious eating practices for large-scale use and community initiatives. The inclusion of sorghum-rich multigrain flour offers a remarkable chance to improve both the taste and nutritional benefits of sorghum roti.[32] Multigrain flour, formulated by combining wheat and finger millet in a 7:3 ratio (wheat to finger millet), serves as a simple semi-finished product suitable for making chapatti. In this combination, while the gluten content is considerably reduced, the method of flattening the chapatti is not compromised. However, the chapatti may exhibit a slightly darker hue. Adding finger millet to chapattis not only boosts the flavor but also significantly aids in managing glucose levels for those with diabetes.[33] The elevated fiber content in multigrain flour is advantageous for individuals suffering from constipation.[34]

**Fermented foods:** Fermented foods such as dosa and idli are widely enjoyed in various regions of India, often consumed during breakfast or as part of evening meals, especially in the southern areas. The fermentation process reduces antinutrients while enhancing flavor, and it also boosts the nutritional content by increasing levels of protein, calcium, and fiber.[19]. Millets can serve as a complete substitute for rice in the preparation of idli and dosa, both of which are steamed and cooked dishes. A mixture of millets and blackgram in a 3:1 ratio is ground with water, and this blend is allowed to ferment overnight. The resulting fermented batter is then steamed to create idli or cooked on a hot skillet to make dosa or wet pancakes.

Enjera, a well-known dish that originates from Ethiopia,[20] is made by wet grinding teff, allowing the batter to ferment, and then cooking it on a hot surface similar to dosa. In comparison to dosa, enjera is less nutritionally rich as it consists solely of teff.

**Parboiling of millets:** The method of parboiling rice is widely recognized as a traditional approach to its preparation. It has been noted that steaming finger millet improves the endosperm, facilitates the formation of grits, and decreases the stickiness of mudde. [21] Additionally, it has been noted that parboiling kodo millet enhances its milling properties. It is well-known that parboiling brown rice boosts milling quality and minimizes thiamine loss during the milling process. Parboiled rice is also utilized to produce expanded rice, a convenient, ready-to-eat item. This may similarly apply to millets.

**Papad:** Papad is a traditional delicacy originating from South India. The recipe includes finger millet flour, which constitutes 15-20% of the ingredients, combined with other essential components such as black gram, rice, and various spices. In Karnataka, it is common for the amount of finger millet flour to increase to as much as 60%. The process of making papad begins with cooking the finger millet flour in water until it becomes gelatinized. The dough is then rolled out and cut into thin sheets of the desired shapes and sizes, followed by drying these papad pieces until they achieve a moisture content of 7%. The pericarp of the finger millet grain remains intact with the starch, giving the papad a slightly dark color, which lightens after frying.[28]

**Non-conventional food products**

A multitude of research studies focused on millet processing have yielded encouraging findings concerning their successful use in a range of traditional and convenient health foods. As a result, numerous researchers have sought to create processed products such as popped, flaked, puffed, extruded, and roller-dried items; fermented, malted, and blended flours; as well as weaning foods, among others. For instance, initial studies on the popping and milling of millets have demonstrated positive results.[4].

**Millet flakes:** Debranned small millets soften in boiling water within a mere 5-10 minutes. This beneficial trait of millets can be utilized to produce quick-cooking cereals. Pearled grains are soaked in water, steamed, or cooked under pressure to fully gelatinize the starch, then dried to about 18 percent moisture before being pressed to the desired thickness between heavy-duty rollers, and subsequently dried further to create flakes.[32] When mixed with warm water or milk, these flakes easily absorb moisture and can be used to prepare both sweet and savory dishes. When deep-fried, the flakes expand and transform into crispy snacks. The smaller size and quick absorption properties of millets render them perfect for making flakes.

**Popping/puffing:** Popping or puffing is a straightforward processing method for cereals that yields products that are ready for consumption. Popped grains possess a crunchy and airy texture, having been pre-cooked. This popping technique frequently enhances both flavor and aroma. Among the various cereals, finger millet provides a particularly delightful taste when popped. The volume of popped finger millet varies from 8 to 10 ml for each gram. Popped grains are typically utilized as snacks. Traditionally, popped finger millet flour is enjoyed when mixed with jaggery (brown sugar) and milk, a dish known as hurihittu. At present, popped finger millet flour is produced and sold at the cottage industry level in certain areas. Additionally, popped millets serve as ingredients in brewing. Malleshi and Desikachar (1981). [33] It has been observed that for millets to fully expand, the moisture content of the grain should be approximately 19 percent, with a popping temperature close to 250°C. Moreover, they investigated the differences in popping characteristics among various varieties.[34]. Decorticated finger millet underwent a brief high-temperature process to convert it into expanded millet, a new ready-to-eat product. It was noted that the appropriate grain shape and moisture level were crucial for achieving millet with the highest expansion ratio. The ideal parameters for producing a product with the maximum expansion ratio were found to be around 40% moisture content before flattening, a shape factor ranging from 0.52 to 0.58, and drying times of 136 to 150 minutes.

**Weaning food:** Barley malting is mainly performed on an industrial scale in temperate regions, whereas sorghum malting is prevalent in African nations for brewing. In certain areas of India, the malting of finger millet has been a traditional practice. Research indicates that finger millet exhibits greater amylase activity than both sorghum and other varieties of millet. Malleshi and Desikachar (1986) found that malted finger millet has a pleasant flavor and contains sufficient starch-hydrolyzing enzymes. The peak amylase activity occurs after 4 to 5 days of germination. It is abundant in calcium and sulfur-containing amino acids, making it an excellent foundation for weaning food mixtures. Typically, millet malt is used to prepare infant food and beverages, often combined with warm milk or water and sweetened, a custom that has persisted for centuries. The malting process enhances the digestibility, sensory attributes, and nutritional advantages of finger millet while significantly reducing antinutritional factors. The resulting food is nutritionally comparable to commercial weaning products and is easily accepted and tolerated by young children. The application of malted finger millet for the production of malt extract and syrup for brewing has also been documented. Although malts from other small millet varieties are acceptable, they produce fewer amylases than finger millet. A mixture of refined finger millet malt flour with milk powder, sugar, and a flavoring agent serves as a thickener for milk-based beverages. Additionally, combining malt flour with hydrolyzed barley malt to create dextrin, along with flavoring it with cocoa and vacuum self-drying, yields a light product suitable for milk beverage mixes.

**Noodles-vermicelli:** Extrusion technology is an innovative method for converting raw materials into value-added products. A prominent illustration of this is Kurkure, which enjoys significant popularity among children. Evolving lifestyles are resulting in substantial shifts in dietary patterns, and due to the convenience of extruded foods as ready-to-eat (RTE) options, they have become a desirable choice for snacking.[28] The changing dietary preferences of children and adolescents have created a robust market for noodles, both in India and globally. The growing acceptance of millet noodles, especially those made from finger millet, can be attributed to increased awareness of their health benefits. Noodles are categorized as convenience foods produced through a cold extrusion process, resulting in a firm and brittle texture after drying. Noodles made from a blend of millet and legume flours offer a nutritionally balanced alternative, making them suitable as supplementary or weaning foods. The ratio of finger millet to wheat flour is kept at 1:1, while the mixture of finger millet with wheat and soy flour is designed in a 5:4:1 ratio.[28]. The grains are soaked in water for 1 to 2 days, then ground while still moist, cooked into a mash, extruded, and dried, resulting in a flavorful, crispy product once deep-fried. The quality of these products is comparable to those made from rice. These items can be manufactured economically as a small-scale industry since the necessary equipment is relatively simple, and the initial investment is minimal.

**Bakery products:** Millet flour is commonly utilized in the preparation of various baked goods, such as biscuits, nankhatai, muffins, and bread. Despite the absence of gluten in millet grains, which is essential for creating elastic and stretchable dough, this characteristic renders them less suitable for producing solid food items like baked goods or noodles made solely from millet. The incorporation of millets into baked products not only enhances their fiber and micronutrient content but also presents significant opportunities for millets to enter the bakery market with a range of value-added products. Recent research has focused on improving the nutritional profile of cakes by increasing their mineral content and integrating malted finger millet flour. Recently, finger millet has attracted attention, and initiatives are being undertaken to present it to consumers in more accessible forms. For bread production, optimized composite flours that incorporate millet have been developed. A blend of barnyard millet and wheat flour has been formulated and assessed. Sensory analysis results indicated that the bread produced from composite flours was nearly as acceptable as traditional wheat bread. Furthermore, the potential for utilizing oat, millet, and sorghum in bread-making was investigated, with wheat flour being substituted in proportions ranging from 0% to 60%. The findings suggested that oat, millet, and sorghum could serve as effective alternatives. Biscuits were prepared using various ratios of millet flour and pigeon pea flour, with differing proportions of millet to pea flour. Sensory evaluations demonstrated that all biscuits received positive ratings, with the combination of 65% millet and 35% pea flour achieving the highest scores for flavor, texture, and overall preference. The production of biscuits using flour composites in ratios of 60:40 and 70:30 (w/w) of finger millet to wheat flour was assessed concerning dough characteristics and biscuit quality. It was concluded that the optimal blend for biscuit quality was the 60:40 mixture of finger millet and wheat flour.

Furthermore, the seed coat of finger millet is a consumable component rich in dietary fiber, minerals, and phytochemicals. The Seed Coat Matter (SCM), generated during the processes of millet milling, malting, and decortication, can be employed as a composite flour for biscuit production. Millets have the potential to replace as much as 20 percent of wheat in bakery flour recipes. Incorporating larger quantities of millet flours may influence the texture of the products, yet it does not compromise their nutritional benefits.

**Conclusion**

This article discusses recent research focused on improving the processing and nutritional qualities of millet grains and their food products. The findings indicate that millet grains are rich in various health-promoting nutrients, such as dietary fiber, minerals, vitamins, and phytochemicals like phenolic compounds, positioning them on par with more commonly consumed grains and highlighting their potential health benefits. Nevertheless, innovative processing and preparation techniques are crucial for enhancing the bioavailability of micronutrients and improving the overall quality of millet-based diets. Further studies are required to assess the bioavailability, metabolism, and health impacts of millet grains and their constituents in humans. Additionally, it is essential to create millet-based food products that offer convenience, flavor, texture, color, and extended shelf life at prices that are affordable for low-income communities. Furthermore, promoting the integration of millet grains into urban markets can generate economic opportunities for farmers, necessitating the development of significantly enhanced millet products.

In summary, the low gluten content present in millet grains, which is critical for producing dough with elastic and stretchy characteristics, renders them less suitable for creating entirely millet solid food products, especially in baking or noodle manufacturing. However, they can be transformed into liquid or semi-liquid food forms, such as beverages and porridge, as well as various traditional home recipes. As a result, there is a pressing need for innovative processing methods to convert millet grains into liquid food alternatives that preserve high nutritional quality and safety, ensuring their availability to large populations in both rural and urban settings.

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