PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(4): 804–817
https://doi.org/10.14719/pst.4309

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REVIEW ARTICLE

Millets in Indian perspective: Importance, processing and value addition – A review

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OPEN ACCESS

ARTICLE HISTORY

Received: 11 July 2024
Accepted: 18 September 2024

Available online
Version 1.0 : 17 October 2024
Version 2.0 : 23 October 2024

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
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CITE THIS ARTICLE

Sindhu M, Geetha P, Sashidevi G, Thirupathi V, Karthikeyan S, Preetha P. Millets in Indian perspective: Importance, processing and value addition – A review. Plant Science Today. 2024; 11(4): 804–817. https://doi.org/10.14719/pst.4309

Abstract

Millet is a crop of ancient origins predominantly cultivated in Asian and African nations. This particular crop thrives in arid regions and requires minimal water resources. Notably, millet serves as a dietary staple in certain countries and offers economic opportunities for farmers, contributing to their livelihoods. Following the announcement of the official title of 2023 as the international year of millet, there has been an increased recognition and emphasis placed on millet. This comprehensive assessment aims to provide individuals with a clear understanding of millets by examining aspects such as recent production and consumption in the world, India, and Tamil Nadu, health benefits (cardiac health, gut health, weight management, gluten-free, sugar maintenance, antioxidants rich food), processing techniques (dehulling, milling, soaking, germination/malting, fermentation, flaking, popping, roasting, extrusion and microwave treatment) and the effects of processing on millets. Furthermore, it sheds light on initiatives and schemes from the Indian Government, in addition to the value addition of millets (weaning foods, baked foods, fermented foods, functional foods, beverages, and traditional foods), which can be beneficial for entrepreneurs and to improve a healthy lifestyle among the population. This review discussed the positive environmental effects of millet cultivation and value addition and the recent market of millet-based food products.

Keywords

Government initiatives; health benefits; millets; processing; production and consumption; value addition

Introduction

Millets, an integral facet of biodiversity, are essential to impoverished farmers' food security and agricultural systems in regions such as Sub-Saharan Africa (1). Millets are cultivated in over 130 nations today and are among the world's oldest foods. These served as an essential food for billions of Asian and African people. Belonging to the Poaceae family, millets were the first crops to be domesticated among the cereals. Different species of millets are namely, sorghum (*Sorghum bicolour)*, pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), proso millet (*Panicum miliaceum*), kodo millet (*Paspalum scrobiculatum*), foxtail millet (*Setaria italic*) and little millet (*Panicum sumatrense*), brown top millet (*Brachiaria ramose*), teff (*Eragrostis tef*) and fonio (*Digitaria exilis*). Millets are grown as a kharif crop in India since they require less water and agricultural input than other staple crops. Globally, 735 million people suffer from malnutrition, South Asia contributes 314 million, and Sub-Saharan Africa contributes 362 million (2). Millets are used to reduce malnutrition because of their health benefits and cost-effective nature. Here in this review, how to utilize the millet, the benefits of millet, and the available millet products in the market are discussed.

Production

Around 15 million tonnes of pearl millet, followed by 5 million tonnes of foxtail millet, 4 million tonnes of proso millet, and around 3 million tonnes of finger millet, are produced globally in 2021 (3). Malawi, Ethiopia, Zimbabwe, Sudan, Tanzania, Somalia, Kenya, Zambia, India, Uganda, Botswana, and other countries are the leading producers of millets. According to FAO Stat 2021 (4), the average global millet yield is 1229 kg/ha, but India produces 1239 kg/ha on average. Over 170 lakh tonnes of millet are produced in India; this accounts for 80 percent of Asia's Production and 20 percent of the world's Production (Ministry of Agricultural Welfare, 2022). Although more than 29 million hectares of land are used to grow pearl millet, the majority of the world's supply is produced in just two areas: Asia (11 million) and Africa (15 million).

India's millet production has declined over time due to several factors, including problems with supply and demand (5,6). Supply-led factors include marginalized cultivation, reduced profitability, competition from profitable substitutes, decreased quantity and quality of millets, and insufficient rewards for millet cultivation in Kharif, leading to poor grain quality. Demand-led factors are urbanization, growing per capita income, Government initiatives, low grain shelf life, inconvenient preparation methods, and inadequate social standing, which contribute to the rapid urbanization of towns and cities.

With the current production and consumption trends in India, there will be a deficit in the supply of sorghum and finger millet in the near future. This break can be bridged by civilizing productivity. Millet production occurs in fewer states with low productivity, so focusing on increasing production in these states can lead to a rapid rise in production. Millets are mainly cultivated as unsustainable rain-fed crops. Therefore, increasing the use and cultivation of high-yielding cultivars, providing irrigation at least at the crop's critical stage, and implementing good cropping techniques will boost output and productivity (5).

However, recognizing the millets, the Indian Government has implemented initiatives to boost millets production and consumption, including the declaration of the international year of millets-2023. Fig. 1 represents the average millet production in India (6). India's millet production and area of cultivation are presented in Table 1.

The production details in Tamil Nadu are given in Table 2. In Tamil Nadu, the Government makes two special zones, the south zone and the north zone, to support millet production. In North Zone 3, 20,217 hectares of area were covered, and the South Zone covered 1, 84,140 hectares (APEDA, GOI, 2023).

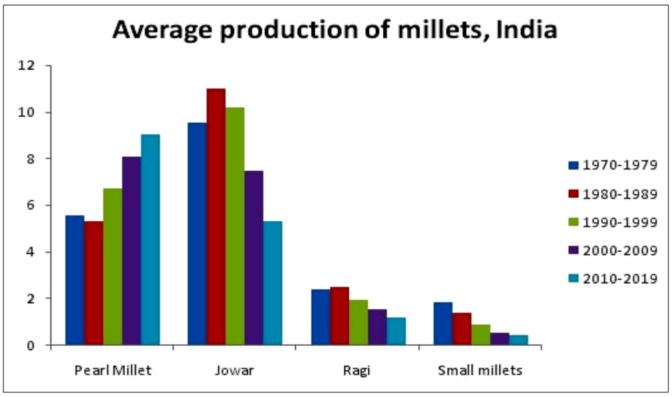

Fig. 1. Average millet production in India.

Table 1. Millet production in India (2023-2024) (Source: APEDA, GOI, 2024).

Sl. No.	Millets name	Production (Tonnes)	Area (Ha)
1.	Sorghum	40,34,000	36,47,000
2.	Pearl millet	95,31,000	70,08,000
3.	Finger millet	13,86,000	10,37,000
4.	Small millets	4,29,000	4,96,000

Table 2. Millet production in Tamil Nadu (Source: APEDA, GOI, 2023).

Sl. No.	Millets name	Production (Tonnes)	Area (Ha)
1.	Sorghum	5,19,821	4,50,000
2.	Pearl millet	1,85,083	67,492
3.	Finger millet	2,74,474	84,545
4.	Small millets	26,280	17,928

Consumption

Over 80 percent of the world's millet is consumed as food, the remaining portion going towards feed (7%) and other purposes (such as seed, beer, etc.) (APEDA2021). Africa consumes the most millet worldwide. It contributes to the global output at 55 percent, followed by Asia at 40 percent. African countries, mainly Niger, Mali, Nigeria, Burkina, and Sudan, hold more than 40 percent of the global millet consumption. In Africa, in May 2021, governments introduced policies to support the production and consumption of millet. Public and private investments are limited to millet seed development and Production (FAOSTAT).

The National Sample Survey Office (NSSO) revealed the data by examining the consumption pattern of minor millets. The rural areas of Assam (18.82kg/hsh/m) and Bihar (18.69kg/hsh/m) have the highest consumption of millet in India (7). The per capita consumption of sorghum (82.44%), pearl millet (64.86%), and finger millet (59.44%) was found to be lower in urban families. Compared to urban homes, the rate of decline was more significant among rural households. However, some current research recommends that the consumption of millet is rising because of these crops' dietary and health benefits, which is encouraging (6). Creating awareness about millet's nutritional and environmental benefits and developing products that suit consumer demands will foster consumption.

Nutrient composition

Millets have better nutrient composition compared with other staple foods in India. It contains more minerals than cereals and pulses. The glycemic index of the millet is low compared to rice and wheat flour. Millets are a great way to get essential nutrients like vitamins, minerals, and proteins (8). Especially millets are rich in antioxidants and phytochemicals. By incorporating millet into the diet, one can support general health and well-being and nutrient requirements (9). Millets grown in marginal regions exhibit a relatively rich composition of nutrients when compared to conventional cereal crops. The millets contain 320-370 kcal energy, 60.9-72.6 g carbohydrates, 6.2-12.5 g protein, 1.1-5.0 g fat and 1.2-9.8 g crude fiber, 1.5 to 1.7 g ash per 100 gram of millet (10). Millet starch content ranges from 60 to 75 percent, with amylopectin (16 to 28%) and amylose (72% to 84%) as well as nonstarchy polysaccharides (15–20%) and sugars (2–3%) (11). Kodo and little millets have any grain's highest dietary fiber content at 37–38 percent. Generally, millet acts as a detoxifying agent because of it's dietary fiber and ability to eliminate toxins. It increases the transit time of food in the gut, which reduces the risk of inflammatory bowel disease (12). Lipid composition varied from 1 to 5 percent, comprising neutral lipids (85%), phospholipids (12%), and glycolipids (3%), as reported by Himanshu et al. (11). It also has a larger percentage of polyunsaturated fatty acids (4.2%) than other cereals (13). According to Patil et al. (14), the crude protein content of millets ranges from 6 to 13 percent; mineral content ranges from 1.9 to 14 percent. The protein present in millet contains sulphur-containing amino acids such as methionine, cysteine, etc. Compared to other grains, millets have higher proportions of magnesium, manganese, and phosphorus. Nutrient composition in millets is given in Table 3. The amino acid profile of millets is presented in Table 4. Kumar et al. (15) mentioned that millets are rich source of many vital components *viz*., iron (2.2-17.7 mg/100 g), calcium (10-348 mg/100 g), phosphorus (200-339 mg/100 g), zinc (32.7-60.6 mg/100 g) and vitamins such as niacin (0.09-1.11 mg/100g), riboflavin (0.28-1.65 mg/100 g) and thiamine (0.15-0.60 mg/100 g) which render them a perfect energy food. Finger millet, sorghum, pearl millet, and foxtail millet are potential resources of antioxidant molecules that might scavenge free radicals. The total phenolics and tannin content of the pigmented type of finger millet have moderate reducing ability, and pearl millet serves as a source of antioxidants in our diets (16). The primary limitation in millet nutrition lies in its bioavailability, primarily for its presence of elevated levels of anti-nutritional factors, such as phytates and tannins. Such factors can be mitigated through various processing techniques (14).

Benefits of millets to health

Millets can be known as an ingredient for functional foods and nutraceuticals as they offer the right amount of dietary fiber, proteins, minerals, and vitamins. Millets can be taken by people suffering from obesity, celiac, and heart disease, which are gluten-free and have higher fiber than the other cereals. Millets are preferred for those who are allergic to gluten. Pearl millet, sorghum, and finger millet have hypocholesterolemic activity and reduce the risk of cardiovascular diseases by the bile acid and steroid binding action. Additionally, it can manage certain types of diabetes by retarding carbohydrate absorption and im-

Table 3. Nutrient composition in millets (g/100 g) (31, 42).

Minerals	Carbohydrates	Protein	Fat	Fiber	Minerals
Pearl millet	67.00	10.36	7.63	1.26	2.20
Finger millet	72.05	7.30	1.30	11.50	2.70
Foxtail millet	63.20	11.20	4.00	6.70	3.30
Proso millet	70.40	12.50	3.10	14.20	1.90
Kodo millet	66.60	9.80	3.60	5.20	3.30
Barnyard millet	68.80	10.50	3.60	12.6	2.00
Little millet	65.55	8.92	2.55	6.39	1.72

Table 4. Amino acid profile of millets (mg/100 g) (68, 100).

	Kodo millet	Little millet	Proso millet	Finger millet	Foxtail millet	Barrnyard millet	Pearl millet
Arginine	3.18	5.96	0.29	0.3	0.22	0.27	0.3
Tryptophan	1.32	1.35	0.05	0.1	0.06	0.05	0.11
Histidine	2.14	2.35	0.11	0.13	0.13	0.12	0.14
Phenylalanine	6.27	6.14	0.31	0.31	0.42	0.43	0.29
Lysine	1.42	2.42	0.19	0.22	0.14	0.15	0.19
Tyrosine	-	-	-	0.22	-	-	0.2
Cystine	1.92	1.85	-	0.14	0.1	0.11	0.11
Threonine	3.89	4.24	0.15	0.24	0.19	0.2	0.24
Valine	5.49	5.31	0.41	0.48	0.43	0.41	0.33
Leucine	11.96	8.08	0.76	0.69	1.04	0.65	0.75
Isoleucine	4.55	4.14	0.41	0.4	0.48	0.36	0.26
Methionine	2.69	2.21	0.16	0.21	0.18	0.18	0.15
Glutamic acid	18.25	20.22	-	-	-	-	-

paired glucose tolerance (17). A consistent kodo millet diet is favorable for women who are suffering from higher blood pressure and cholesterol signs of cardiovascular disease (9). The sodium levels were lower than potassium in all the sprouted millets studied, which can be consumed in large quantities and are beneficial to health.

Millets extract from the seed coat was reported to have higher antibacterial and antifungal activity than whole flour extract due to the high polyphenol content in the seed coat (18). Different millets' free radical quenching potential revealed that they have significant antioxidant activity, which was analyzed by 1, 1, Diphenyl -2- picrylhydrazyl (DPPH) (19). Fig. 2 depicts the benefits of millets to health.

Fig. 2. Benefits of millets to health.

Heart health

Cardiovascular diseases are the leading cause of death globally, as per WHO. Millets consist of higher sterols and pinacosanols, which prevent cholesterol synthesis. In the case of cardiovascular health, fiber helps lower cholesterol levels by binding to cholesterol in the digestive system and preventing its absorption into the bloodstream. Phytochemicals present in plants have various health benefits. Some phytochemicals in millets, such as phenolic acids and flavonoids, improve heart health (20). Millet consumption improves lipid profiles, including reduced LDL (low density lipoprotein) cholesterol levels. Incorporating millet into the diet can improve lipid profiles and reduce cardiovascular disease risk. Anitha et al. (21) meta analyzed the 19 studies related to cardiovascular disease with millet intake and revealed that millet consumption improved blood lipid profile, reduced blood pressure, and an overall reduction in associated risk of CVD (Cardio Vascular Disease). A study conducted by Hou et al. (22) found that a foxtail millet diet significantly reduced systolic and diastolic blood pressure in mild hypertensive patients. Yin et al. (23) reported the positive effect of millet bran oil and refined millet bran oil consumption on lipid metabolism in obese mice. It reduces lipid accumulation in the liver, brown and white fat hypertrophy, and dyslipidemia. Foxtail millet protein increased the plasma high-density lipoprotein cholesterol level, whereas it decreased the plasma total cholesterol (TC), triglyceride (TG), and low-density lipoprotein-cholesterol (24). Similarly, proso millet protein (lysine and threonine) reduced the TC, TG, and LDL cholesterol (25).

Diabetes control

Diabetes is a long-term metabolic disease identified by hyperglycemia (high blood sugar level) related to the conversion of protein, lipid, and carbohydrate metabolism. It is referred to as one of the most common endocrine gland disorders caused by insufficiency of insulin hormone production. Glycemic index (GI) is found as the carbohydrate-containing food raises blood sugar levels. Foods with a high GI are quickly digested and absorbed, causing a sudden increase in blood sugar levels (26). On the other hand, foods with a low GI are digested and absorbed more slowly, resulting in a slower and more gradual increase in blood sugar. Millets have low GI compared to other grains, which means they cause a slower and gradual increase in blood sugar. This is beneficial for managing blood sugar levels, especially for individuals with diabetes or those at risk of developing Type II diabetes (27). Gowda et al. (28) observed that the little millet intake prevented spikes in blood glucose levels and helped to control diabetes. Ren et al. (29) studied the effects of whole foxtail millet on type II diabetes through an *in vivo* study and concluded that consuming whole foxtail millet might benefit diabetes people. Millets help to prevent type II Diabetes due to their significant levels of magnesium. Magnesium is an essential mineral that helps to increase the efficiency of Insulin and glucose receptors by producing many carbohydrate-digesting enzymes, which manage insulin action (30).

Digestive health

Millets contain dietary fiber, which is vital in supporting healthy digestion. Dietary fiber helps to prevent constipation by adding bulk to the stool and promoting regular bowel movements. Saleh et al. (31) found that the dietary fiber in millets positively affects digestion and prevents constipation. The prebiotic effects of millets support beneficial gut bacteria growth (9), which helps in improving digestion and overall gut health. As per Wong et al. (32), the resistant starch or high protein diet provides an energy source for gut microbiota, which has been proposed as a potential pro-drug for treating inflammatory bowel disease (IBD) and decreasing DNA damage. According to Radhajeyalakshmi et al. (33), seed protein extracts from minor millets prevent *Rhizoctonia solani*, *Macrophomina phaseolina*, and *Fusarium oxysporum* growth. The minor millets have good prebiotic activity to promote gut health and digestion. By supporting favourable gut bacterial growth, millets promote a healthy gut microbiome, which is necessary for proper digestion and nutrient absorption (34). The millet bran fraction has a significant amount of dietary fiber that is not easily digestible. Insoluble fibers remove toxins from the digestive system and improve the faecal volume and intestinal transit by enhancing water-holding capacity (35). Animal studies in acutely malnourished pigs showed that millet-based supplements restored the gut microbial diversity and harmful bacteria decreased (36). Foxtail millet protein reduced gastric ulcers in mouse models by down-regulation of inflammatory cytokine expression in gastric tissue and improved oxidative status (37).

Weight management

The feeling of fullness provided by millet can help reduce overall calorie intake, which is beneficial for weight management. Millets are considered a favourable weight-loss diet due to their nutrient density and lower caloric content. Nutrient density refers to the amount of nutrients per calorie in a food. Millets are rich in essential nutrients like proteins, dietary fibres, vitamins, and minerals while relatively low in calories. This means that consuming millet keeps their calorie intake in check, is essential for weight management and contributes to their nutritional needs. Including millet in a balanced diet provides a satisfying and nutritious option (38). Geetha et al. (39) prepared a high-fibre mix using little and finger millet with legumes and leafy vegetables. Results revealed that high fiber mix had a significant effect on weight management. Similarly, Asritha (40) expressed that replacing refined wheat flour with millet helped reduce weight.

Gluten-free substitute

Millets are gluten-free and do not contain proteins called gliadin and glutenin, which bind together to form gluten. An autoimmune disorder called celiac disease is where gluten consumption triggers an immune response that affects the small intestine. Non-celiac gluten sensitivity is an individual's symptom similar to celiac disease but does not have the same immune response or intestinal damage. The gluten-free nature of millets makes them a suitable alternative for celiac disease or gluten sensitivity, as they can be included in their diets without causing any adverse effects. This is important because gluten-free diets can sometimes lack certain nutrients, such as fibre, iron, and B vitamins in grains containing gluten (41).

Antioxidant

Antioxidants assist in shielding the body from free radical-induced oxidative stress. The free radicals induce cell damage and lead to cancer and other degenerative diseases. Millets contain antioxidants, precisely phenolic compounds and flavonoids (14). Antioxidants contribute to overall health and reduce cardiovascular disorders, diabetes and cancer. Flavonoids and phenolic compounds act as anti-inflammatory and anti-cancer agents. They reduce inflammation in the body and hinder the development of cancer cells. Antioxidants support the immune system and protect against age-related diseases. They can strengthen the immune response and lower age-related macular degeneration and cognitive decline (42). Bhuvaneshwari et al. (16) found that finger millet, sorghum, pearl millet, and foxtail millet were potential resources of antioxidant molecules that might scavenge free radicals. The total phenolics and tannin content of pigmented type of finger millet have moderate free radical scavenging ability. The phytochemicals in kodo millet are essential as an antioxidant, anti-inflammatory, antimicrobial, immune boosting, preventing DNA damage, and reducing or inhibiting cancer cell growth (43).

Processing and its effects on millets

The grain quality of millet is good enough for processing. It contains 75 percent of endosperm, 17 percent of germ, and 7 percent of bran (pericarp and aleurone). Fig. 3 illustrates the structure of millets. The different types of processing are given in Fig. 4. Primary processing, such as (i) wetting, (ii) de hulling and (iii) milling, and secondary processing, such as (i) fermentation, (ii) malting, (iii) extrusion, (iv) flaking, (v) popping, and (vi) roasting processes are involved in processing grain for a variety of end uses. Processing is done at small, medium, and commercial scale entrepreneurs (44). Various processing methods can affect the physical and chemical composition of millet. So,

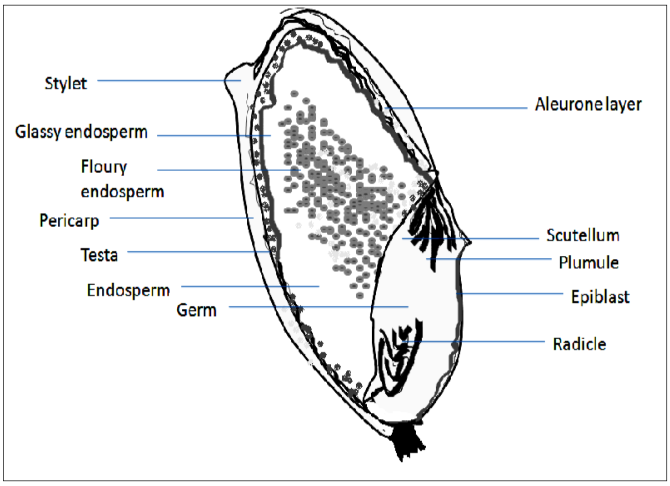

Fig. 3. Structure of millets.

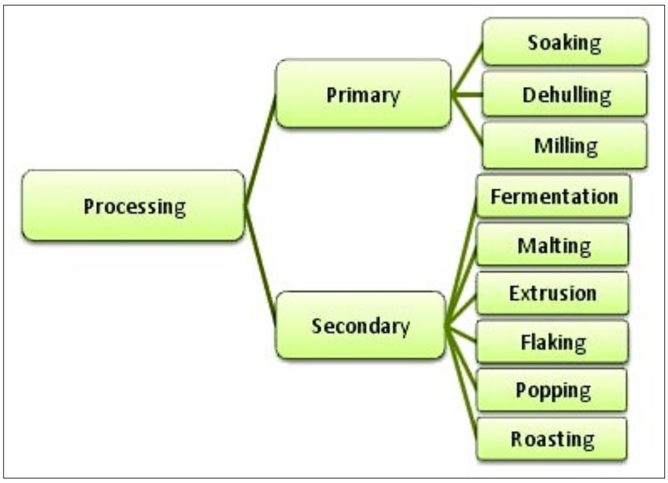

Fig. 4. Types of processing.

we must know the suitable processing methods to reduce the nutritional losses (45).

Primary processing

De hulling

De hulling is not easy for millets compared to other cereals due to their small grain sizes. Traditional methods of dehulling have no significant difference in their grain composition**.** Mechanical processing technologies (e.g., dehulling) enhance the taste and texture of millets and coarse grains. Hydrothermal treatment allows millets to be dehulled, cooking as discrete grains like rice (46). The fact that some nutrients (minerals, fibres, and antioxidants) as well as anti-nutrients such as phytates and tannin are concentrated in the outer layers (pericarp and aleurone layers) of the grains and decreased when the pericarp is taken out during dehulling (47). Dehulled millets may have a suitable digestion property because of reduced insoluble dietary fibre and phenol and lipid contents in the outer part of the grains (48). The protein content of millets is not affected by dehulling. De hulling significantly reduces anti-nutrient levels and improves mineral bioavailability. However, the millet's mineral, nutritional, total phenol, and antioxidant levels were reduced considerably (49). A study by Shobana et al. (50) showed that dehulled finger millet upma had low fiber content. The processing effects of de hulling large quantities of grains at commercial scale require innovative technology.

Milling

All millets can be hand-milled (household-level) or machine-milled (cottage-scale, small to medium-scale, and large-scale industrial). Millets are usually milled using non-motorized grain milling but can be attached to a mill for milling. During bread making, milling and heat treatment improves protein and starch digestion and reduces polyphenols, phytic acid, etc. Semi-refined flour obtained by separating the bran fraction has lower anti-nutrients and greater mineral bioaccessibility than whole flour. Steaming millet at high pressure and temperature improves milling yield. Excessive steaming reduces grain yield. Milling technology is required for large-scale millet flour production (31). Optimization of milling conditions for high-quality, high-nutrient flour is needed. By milling, protein digestibility is increased by 80 percent and starch digestibility is improved by 50 percent because of removing anti-nutrients such as phytic acids and tannins by bran separation. These anti-nutrients interfere with digestive enzymes and reduce digestibility. Another reason is the reduced particle size of the starch, which is more sensitive to digestive enzymes for hydrolysis (51). Particle size reduction is another factor, as it causes damage to the granules of the starch and increases their susceptibility to hydrolysis by digestive enzymes (52). However, millet is less practical for producing flour-based products since it contains numerous nutritional benefits. It is imperative to prioritize the implementation of enhanced milling technology for millet grains on an industrial scale to guarantee a steady supply of a substantial quantity of highly nutritious millet flour.

Secondary processing

Malting

Soaking, germination, and drying are the three primary steps in traditional malting methods in many countries. It's common to use the terms "malting," "sprouting" and "germination" interchangeably (53). Each operation's length and circumstances vary greatly, which affects the quality of the malt and subsequent products. Soaking (6 hours overnight) is a preprocessing technique that can result in various functional and nutritional modifications. Grain soaking is a common home food preparation method. Reducing anti-nutrients through soaking has been shown to improve mineral bioavailability. However, the leaching of anti-nutrients that inhibit amylase enzymes, which are crucial to the starch digestion process, may cause enhanced starch digestibility in soaking (54). While soaking pearl millet grains reduces their iron content by 25 %, it also helps break down endogenous phytates, mainly when milling and heating are carried out simultaneously (55). As the length of the soaking time increased in an acid medium (HCL), there was a reduction in the number of minerals such as phosphorus, calcium, and iron (56). Similar soaking methods are followed at the household level for preparing infant foods (31).

During germination (24 to 48 hours), vital kernels activate and synthesize endogenous enzymes after water absorption and a requisite respiration period. The kernel composition changes because the macronutrients (proteins, lipids, and carbohydrates) break down, and micronutrients (vitamins and minerals) are released during germination due to the endogenous enzymes. Fermentation and germination reduce anti-nutrients in millet and improve certain amino acids and vitamins bioavailability (57). Sharma et al. (58) reported that germination significantly increased the bioaccessibility of minerals and the *in vitro* digestibility of proteins (14% to 26%) and starches (86% to 112%). The germination impacts on starch digestion reduced the resistant starch. Sharma et al. (58) revealed that the tannin and phytate content in the kodo millet decreased after 13 hours of germination to 0.234 mg/100 g and 0.997 mol/kg, respectively. The decrease was because of the phytase activity during germination. Panda et al. (60) compared the compositions and physico-functional properties of raw and sprouted millet flours. Sprouting increases the nutrients and vitamins, except the protein and crude fiber, in all the studied millets. It also increased the physical-functional properties of millet flour, such as water absorption capacity, paste clarity, water solubility index, and foam capacity. According to Kumar et al. (61), an increase in germination time increases sugars and crude fibre, while starch, protein, fat, and mineral content decreases. Vitamin C and calcium were increased, but other minerals decreased. Germination for 48 hours increases the total phenols and tannin contents and reduces the malting loss. These studies showed that millet flour has potential for the food industry after sprouting. Xiang et al. (62) observed the phenolic compounds, feruloylquinic acid and *N, N′-bis-(p*-coumaroyl)-putrescine biosynthesized during germination of proso millets. Other phenolics, including *trans*- and *cis*-ferulic, *trans-p*-coumaric, vanillic acid, and ferulic acid dimers (DFAs) increased significantly.

Fermentation

Traditional methods involve millets to produce malt, which can be used to formulate infant food and alcoholic and lactic acid-fermented beverages. Despite having limitless potential, the weaning food industry has not advanced quickly because of the installed capacity for industrial malting. Industries face numerous issues that degrade product quality and impact overall usage. The storage quality of the grain, nutritional losses following processing, high cost of imported equipment, and cultivar variation are the issues working against improved millet utilization in developing nations (63).

Fermentation is used to improve the nutritional properties of raw materials and preserve the food. Different methods are used to ferment millet: natural fermentation, water-based, flour-based, and dried millet-based fermentation. Newlove et al. (64) fermented the millet using the following method: the millet was soaked for 72 hours to ferment, it was strained, and the flour was mixed with water to form the dough. That dough was left for 2-4 days for fermentation and then prepared into porridge. The dominant microorganisms responsible for the fermentation of millets are *Leuconostoc mesenteroides*, *Lactobacillus fermentum,* and *Staphylococcus faecalis*. Fermentation in pearl millet reduces mineral content but enhances crude protein and flavonoids. Natural fermentation reduces phytic acid content and polyphenols in pearl millet. Fermentation in finger millet had an effect on mineral extractability. Kumari et al. (65) revealed that in pearl millet, the carbohydrates and certain amino acids were reduced after 16 hours of fermentation, but the tannin content increased at the same time. According to Adebiyi et al. (66), nutrients like fat, carbohydrates, and fiber were reduced, and protein ash content increased after fermentation of millets. Additionally, fermentation improves the gut microbiota by balancing the good and bad microbes, and as mentioned in the gut health topic, millets act as a prebiotic source for the good microbes. Combination of *Lactobacilli* and Yeast is more effective in increasing starch and protein digestibility. Commercial cultures are used in fermented beverages using finger millet and skim milk is produced. Enzymatic hydrolysis modifies the millets protein functional properties. Industrial application of fermentation and enzymatic hydrolysis is needed for the production of high-quality and safe millet food products (31). The fermentation process decreases the leucine-to-lysine ratio and increases the thiamine, riboflavin, and tryptophan and bioavailability of minerals (67).

Extrusion

Extrusion is a modern technique used in food processing to prepare ready-to-cook (RTC) foods, snacks, speciality items, and supplementary foods. It is a thermo-mechanical refinement process in which the millets to be extruded are pressed through a previously defined opening using pressure and temperature (68). It is commonly used to make breakfast cereals, snacks, pasta, pet foods, and other products. The extrusion leads to gelatinized starch, denatures protein, inactivates anti-nutritional factors, and improves digestibility. Following their degradation, the profile of carotenoids is exposed during extrusion cooking due to higher shear forces and thermal stresses. The degree to which the starch and feed moisture are mechanically blended promotes the diffusion of oxygen, which increases the pressure inside the barrel due to systemic warming. Previous research on extrusion cooking has demonstrated that it facilitates the dissolution of xanthophyll present at the zein protein nucleus, facilitating the further extractability of the zein-carotenoid complex. The colour change was observed in the extrudates because of the depolymerization of proteins, specifically the breakdown of free amino acids into smaller molecules. This process is accompanied by the formation of disulphide bonds (69). The extruded products prepared with a 50:50 ratio of composite maida (control) and millet powder were acceptable in colour, texture, cooking quality, sensory characteristics, and nutrient content. The results suggest that the cereal production process can be followed so that the millet can produce RTC products, increasing their availability and consumption (70). Chavez et al. (71) prepared an extruded product with sorghum and coffee powder to improve the antioxidant capacity and results were positive. Lakkoju (72) conducted research on extruded products and stated that a 50:10:10:30 ratio of sorghum, finger millet, barnyard millet, and chickpea flours blended gave the best results in the physical and sensory properties.

Popping, puffing and flaking

To create ready-to-eat food from millet grains at the commercial scale, the popping technique, a revolutionary technology that optimizes puffing conditions, can be employed alone or in conjunction with other pretreatments to use the millet grains. Jaybhyae et al. (73) made a ready to eat (RTE) snack food from barnyard millet. Bhargavi et al. (74) prepared popped snacks from pearl, finger, and little millet. The research studies proved that the foxtail millet could be successfully processed using both traditional (popping and flaking) and modern (roller-drying and extrusion-cooking) methods. The expanded product was made by treating dehulled finger millet briefly at a high temperature. The best parameters for producing a product with the most significant expansion ratio were 40 percent moisture content before flattening and a drying duration varying from 136 to 150 minutes (75). Popping ratio and volume are influenced by bulk density, porosity, kernel size, moisture content, and sugar or salt. Popped millet have higher calorie and carbohydrate values, but significantly lower fiber and fat . This is mostly because of the grains outer coats, which contain higher levels of fat and fiber, are more susceptible to processing than the inner layer's nutrients (76). The pasteurization process of High-Temp-erature Short Time (HTST) generates grains or flakes enlarged by taking the thermo-physical features of starch. Anti-nutrients like tannins and phytates decreased with increased the minerals bioavailability.

Popped or puffed grains are dried to shallow moisture content (3–5%) by preserving the product. Air puffing devices produces popped or puffed millets in large quantities. Modern consumers could profit from manufacturing very palatable and nutrient-dense RTC millet flakes with the use of rolling technology. RTC flakes had higher total dietary fiber (TDF) levels than the natural grain. When subjected to steam gelatinization under pressure, the soluble dietary fiber increased due to the solubilization and depolymerization of non-starch polysaccharides. Total dietary fiber may be increased due to the emergence of enzyme-resistant macromolecules made up of lipid, protein, starch and non-starch polysaccharides. As per Patil et al. (14) the total dietary fiber increased due to the formation of resistant starch.

Microwave treatment

The range of microwaves frequencies are 300MHz to 300GHz. The molecular interaction with an electromagnetic and electric field directly provides microwave energy to the product. Sharanagat et al. (77) treated the kodo millet flour under the microwave, 720W for 270 sec to increase the colour value of the flour (Redness - 2.47 to 5.84; Yellowness - 15.89 to 20.66). This could be caused by the heating induced oxidation of polyphenols always known as the maillard reaction or caramelization process. Gopal and Bhuvana (78) concluded that the microwave heat treatment affected the kodo millet flour's peak viscosity, oil absorption capacity, pasting temperature, water absorption capacity, breakdown viscosity, holding viscosity, and final viscosity. Water absorption capacity is higher due to formation of porous structure and damage of the grain starch but oil absorption capacity is reduced in microwave -treated kodo flour due to the reduction in a polar amino acid, dissociation of protein. Microwave (900W for the 90s) treated millets showed reduced lipase activity and increased free fatty acids (79). Kumar et al. (80) noted the reduction in fat content of microwave-treated proso millet (3.24 to 3.05%) and little millet (1.91 to 1.79%). Singh et al. (81) studied the anti-nutrient content of millets those treated with microwave and showed that tannin content was 45.53, 45.18 and 77.54 percent reduced in finger millet, pearl millet, and sorghum, respectively.

Value addition

A very small portion of value-added millets are produced in India. India has begun conducting more research to increase the shelf life of millet goods and develop more effective processing equipment. Millets are frequently processed into flour and flour based products. Roti, a food staple crafted from pearl millet, has long been a fundamental dietary item among farmers in Gujarat, India. It is also subjected to partial boiling and subsequently consumed as porridge in combination with milk. On occasion, millets are transformed into beverages. Drinks derived from millet or cereals exclusively contain naturally occurring sugar and serve as exceptional sources of antioxidants, vitamins, and other substances that promote good health. The manufacture of beverages, weaning food, beer, biscuits, and confections uses millets to produce functional foods (82). Grits, flour and meals are made from cereals like sorghum, millet and corn. Sorghum, wheat composites, and maize are used for making soft biscuits and cookies; non-wheat breads and cakes are the focus of growing scientific and technological investigation, with promising results (48, 82).

Weaning foods

Soft, easily digested foods must always be added to the infant's early feeding regimen. In India, millet porridge is commonly used as a weaning food. In a clinical experiment, weaning food blends made of fermented pearl millet/roasted cowpea in 60:40 and 70:30 ratios were reported to have lower levels of phytic acid and higher in vitro protein digestibility (82). Popped and flaked millet flours are used in the weaning mix (67). Asma et al. (83) prepared weaning blends using a twin roller drum dryer, which contains 20 percent legumes, 10 percent oilseeds, 42 per cent sorghum, and 28 percent additives like skim milk powder, oil, sugar, and vanillin as per FAO/WHO/UNU recommendations. The blends contain a good ratio of protein (16.6% to 19.3%), fiber (0.9% to 1.3%), energy (405.8 to 413.2 kcal/100g), iron (5.3 to 9.1mg/100g), calcium (150 to 220 mg/100g) and a considerable amount of lysine. Arokiamary et al. (84) prepared pear millet based supplementary food and observed the improvement in biochemical and cognitive development of the 5-6 years old children.

Baked foods

The cakes made from finger millet gel cake, carrot cake, chocolate cupcake, masala cake, rusk, muffins, and soup sticks have good looks, textures, and flavors overall. There have been attempts to enhance the nutrition by adding malted finger millet flour, namely in terms of its fiber and mineral content. It is possible to replace 40 percent of the wheat flour in baked goods like cakes and cookies with finger millet flour. The properties of bread prepared from a combination of foxtail millet and wheat flour were investigated by Passi et al. (85), and the bread with 30 percent foxtail millet flour incorporated was found to be the most acceptable. Sarabhai et al. (86) used enzymes such as glucose oxidase, xylanase, and protease to prepare gluten free foxtail millet bread. The findings revealed that adding protease enzyme at 0.1 g/100 g improved textural and sensory characteristics. Anu et al. (87) prepared salty and sweet biscuits from refined wheat flour, pearl millet and green gram in ratio of 30:60:10 and 50:40:10. It is more nutritious than those prepared from refined wheat flour alone. Krishnan et al. (88) attempted to investigate the possibility of using finger millet Seed Coat Matter (SCM) in the production of biscuits and compared with control. They found that the native and parboiled millet SCM 10 per cent and malted millet SCM 20 per cent added flours were good based on the sensory evaluation results. Hussain et al. (89) formulated cookies incorporating varying proportions of millet flours (0%, 25%, 50%, 75%, and 100%). The sensory evaluation results revealed that cookies containing over 50 percent millet flour were less preferred by the sensory panellists. However, the antioxidant capacity was notably higher in millet cookies compared to the control cookies.

Fermented foods

Lactic Acid Bacteria (LAB) are the most accepted and safe probiotic microorganism for functional food use. Sudha et al., (90) studied under-exploited millets to produce a fermented millet-based milk beverage. Sheela et al., (91) developed and evaluated the curd, which was made from fermented millet milk using five millets (little millet, foxtail millet, proso millet, barnyard millet, and kodo millet) respectively. Results of this study show that the nutritive substances can be increased by germination and fermentation, and overall acceptability of this product is also high.

As per the recent trend, millets have been fortified in the traditional staple fermented foods like *idli, dosa, dhokla, khaman, uthapam, paddu*. Sorghum dumplings or *Joladha Kadubu* is popular in the Banahatti region of Bagalkot district, North Karnataka. *Mudde* or *hittu* is prepared from finger millet a round-shaped boiled one prepared in Andhra Pradesh and Karnataka. It is known by different names like *kali* or *sangati* (Tamil Nadu), *dhindo* (Nepal and Bhutan), *baadi* (Uttarakhand) and *baari* (Himachal pradesh).

Functional foods

Nutraceuticals, like pharmaceuticals, are bioactive substances that have a preventive impact against degenerative diseases. Examples of these molecules include minerals, essential fatty acids and vitamins. Based on epidemiological research, those who follow a millet-based diet see a reduction in the danger of degenerative illnesses such as hypertension, diabetes, heart disease etc. Millets potential as functional foods has drawn attention because of their health-promoting phytonutrients. They digest easily because they do not generate acids or allergies (31). Flavonoids such as 4 Di-OMe luteolin, acacetin, 4-OMe tricin and tricin have the chemo-preventive efficacy of pearl millet. The pearl millet have an inverse relationship with heart attack and coronary heart disease mortality, much like the decreased incidence of diabetes observed in millet-consuming populations (31). The milk powder from millet was prepared by soaking and extracting milk using finger and pearl millet, followed by dehydration and milling (67).

Beverages

Beverages are drinks consumed for their thirst-quenching properties or for their stimulating effect. Generally, beverages are prepared from fruits and cereal grains. Millet-derived beverages encompassing both alcoholic and non-alcoholic varieties such as *malwa, Bantu, pombe,* and *opaque* or *kaffir* beer. *Mbege ale*, a beer crafted from a blend of millet, sorghum and banana, has undergone industrialization, packaging and commercialization under the name chibuku shake. In the under developed countries, the markets for the beer brands use millet to produce low-cost barley. African beers traditionally prepared from sorghum and millets, such as *pito* and *burukutu,* which have less carbonation (82). Kodo millet-based beverages has health benefits that are consumed by celiac and diabetic patients as they do not contain gluten and has low-GI. Sharma and Sharma (92) prepared and studied the probiotic enriched nutritional malt beverage from kodo millet, resulted high acceptability and high nutrient content. The fermented alcoholic beverage in the Eastern Himalayan districts of Sikkim and the Darjeeling hills of India is called "kodo ko jaanr," and it's made from dried finger millet. Another fermented finger millet beverage that is well-liked in India's Ladakh area is chhang. Malini et al. (93) prepared the pineapple core powder added finger millet beverage using *Lactocaseibacillus rhamnosus* (LGG) and optimized the formulation with 14:5:2:2 white finger millet, sugar, pineapple core powder, and LGG inoculums, respectively. In Tamil Nadu, ethnic communities drink *koozh*, rice, and milled flour-based fermented drinks (19). Porridge made from millet is a common dish not only in India but also popular in other countries.

Traditional foods

People who live in the foothills of the Himalayas utilize millet for its rich, whole grain bread and chapatti, as well as for its cereal and soups. The flat, thin roti cakes that form the basis of meals are commonly made in Maharashtra using millet flour. To prepare *rotis, idli, dosa, chakli*, *pakora, adai, athirasam, sweet halwa, vadai,* and *kolukattai*, 50–75 percent of a finger or barnyard millet flour is generally used. Other millet-based traditional foods in India's millet-growing states include foxtail millet based *burfi, huggi, kabab or sampali,* and tiny millet-based, *paddu, porridge, samai dosa* and *paysam* (5). *Baati* is the unleavened bread prepared using wheat flour with millet in Madhya Pradesh, Rajasthan, and Gujarat. *Chakli* is a crunchy spiral-shaped snack in maharashtra; different names like Chakri in Gujarat, murukku in tamil nadu, chakralu in Andhra pradesh call it. *Hurihittu* is the flour prepared from popped millets used as a weaning food. Ambali is the traditional fermented semi-liquid product of South Indian states. *Enduri pitha*, an Odisha dish, is a flavored cake prepared from a fermented batter of rice and black gram; for nutritional improvement, millet would be added (67).

It is one way to achieve nutrient fortification or enrichment, deactivation of certain allergens and anti-nutritional substances, has the potential to enhance the nutrients found in millets' bioavailability and prolong the product's shelf life. Processing and value addition help in attaining food safety and security, recovering losses for producers, and provide a variety of products to consumers. Personalized nutrition and health are enhanced by this value addition, which allows us to customize foods to meet our needs and take greater control of our own health, increase profitability, and raise the number of job opportunities.

Commercial marketing of value-added products

Canada, Russia, Ukraine, and the US export high-value items while importing millet. APEDA also reported that India has 40 percent of the global millet market; the country only exported 1 percent of its crop in 2021–2022, bringing in 417.82 crores (as opposed to 388.375 crores in 2020–21). APEDA claims that India only exports millets. India is the fifth largest exporter of millet among the world's millet exporters, contributing 20 percent. India is exporting around 30 countries, including the United Arab Emirates, Saudi Arabia, USA, Japan, and Nepal. Twenty-one states contribute to export millets, including Rajasthan, Maharastra, Gujarat, Tamil Nadu, Kerala, and Jharkhand. From 2021 to 2022, 1,59,3332 metric tonnes were exported. It aims to export goods valued at 650 crore by 2025. Agriculture and Processed products Export Development Authority (APEDA) has planned 16 programs for the promotion of millets and millet products in countries such as UAE, Indonesia, the United States, Japan, the United Kingdom, Germany, South Africa, Australia, Saudi Arabia, etc. to increase the millet exports of the country. Thus, the rising demand for millets in the global market and increased domestic Production in India are anticipated to drive the market in the coming years ("Millet Market Size - Industry Report on Share, Growth Trends and Forecasts Analysis (2024-2029)") (https://www.marketdataforecast.com).

APEDA will target various hypermarkets and retail chains in order to promote processed and value-added millets globally. According to the APEDA Chairman, the top 50 nations, importers, exporters, and supply sources connecting production bases have all been recognized. Indian government announcement states that between 2021 and 2026, the global millet business is projected to expand at a compound annual growth rate (CAGR) of 4.5 percent. Since the Government has decided to support millets and consumers are growing more aware of them, businesses are starting to warm up to the idea of doing so. Huge companies like Nestle, ITC, Britannia, HUL, Tata Consumer, Bira 91, and Slurrp Farm are announcing grand ambitions to expand their millet portfolios or introduce packaged goods, brews, and restaurant menus based on millet. Eatrite products of puffs from sorghum, foxtail, pearl millet, and extruded flakes, snacks, instant mixes, and sorghum muesli, millet vermicelli, pasta, and millet bakery products like cookies, bun, bread, cake, and pizza bases are going to be commercialized, and these products are under research in IIMR. It already commercialized value-added products from sorghum, such as rawa, kichadi rawa, idli rawa, flakes, vermicelli, pasta, and biscuits (94).

Government initiatives and programs

The importance of the crop is understood and introduced in meeting people's nutritional requirements of. The Government has initiated two programs to promote areas under millet (95).

National food security mission

The National Food Security Mission (NFSM) is implementing area coverage for coarse cereals in 28 states, including the northeastern and hill states. Districts with yields below the state average are given priority. According to NFSM data, coarse cereals are utilized in 265 districts across 28 states. Maize, pearl millet, finger millet, sorghum, barley, and minor millets (Kodo, barnyard, foxtail, proso, and little millet are included in NFSM coarse cereals. The National Food Security Mission (NFMS) introduced NFSM-Nutri Cereals in 212 districts across 14 states to increase millet consumption. Currently, 500 start-ups are active in India, and the Indian Institute of Millets Research has helped to develop 250 start-ups under the Rashtriya Krishi Vikas Yojana – Raftar program (7).

Initiative for nutrition security through intensive millets promotion

The Government budgeted Rs. 300 crores for 2011–12 under the Rashtriya Krishi Vikas Yojana to promote the millet as a nutrient-dense grain. A program called the Scheme on Initiative for Nutrition Security through Intensive Millets Promotion (INSIMP) was developed to put the remark into action. The program aims to raise the nation's millet output by showcasing enhanced post-harvest technologies and production methods in a coordinated way that produces discernible outcomes. In addition to raising millet yield, the scheme is anticipated to increase consumer demand for food products based on millet through processing and value-adding technologies (7).

Millets have emerged as key contributors to the sustainable development goals of the United Nations. Millets contribute to achieving Zero Hunger (SDG 2), Good Health and Well-being (SDG 3), Clean Water and Sanitation (SDG 6), Sustainable Cities and Communities (SDG 11), Climate Action (SDG 13), Biodiversity Conservation (SDG 15) and necessitates Partnerships for the goals (SDG 17) (96).

Effects of environment due to production

Grains called millets are very nutrient-dense. Humans, Birds, and other animals find them appealing because of their rich, nutritious content. Since these grains and birds have co-evolved, birds' beaks are equipped to hull them, whereas cattle and other ruminant animals have digestive systems that can break down the tough cellulose fibers in grains' husks. Additionally, millet has been crucial in enhancing the fertility and texture of soils, which has increased productivity and, consequently, farmer returns (97). Millets can withstand several dry weeks after the root system is formed. The plants come alive as it starts to rain, and when the season ends, they produce something. Millets are, therefore, reasonably good at aggregating nutrients, and if we are mindful of closing the nutrient loop locally, soil health can be significantly improved. Therefore, millet is a sustainable, cheap, ecologically friendly, and nutritious food source **(**The millet foundation-online portal).

Millets also use nutrients more effectively than other cereals. They can transform atmospheric nitrogen into nitrogen that plants can use to thrive. As a result, less pollution is emitted into the environment, and less fertilizer is needed to produce millet. Millets' deep root systems and brief development cycles make them an additional tool in the fight against soil erosion and enable them to take up more water and nutrients from the soil, reducing the irrigation need and contributing to fertility and soil texture. Additionally, millet as C_4 crops may lower greenhouse gas output compared with other cereals, which means they can absorb more carbon from the atmosphere. This increases the amount of carbon stored in the soil and reduces the quantity of carbon dioxide released into the environment (98, 99).

Conclusion

Based on the literature basis, we can see that millet grains are similar to major grains, which have more nutritional health benefits and contain health-promoting elements, including phenolic compounds, vitamins, minerals, and dietary fiber. The processing and its effects on the millet showed that the germination and fermentation improve the grain quality based on nutrients and anti-nutrient elimination. Popped millet especially increases dietary fibers. Some processing techniques like dehulling and milling reduced the nutritional value of millets due to the loss of the outer layer. Hence millet food products are affordable for the underprivileged and offer taste, texture, color, taste, and shelf life. Based on this, the Indian Government utilized the millet for food security missions. This will enhance the farmer's livelihood, also fetch more income from the export of value-added products from millet, and reduce malnutrition among people. Through these characteristics, millets contribute a major part to the sustainable development goals.

Acknowledgements

We acknowledge to Tamil Nadu Agricultural University for encouraging writing review articles.

Authors' contributions

PG prepared a layout and corrected the manuscript. MS collected articles and wrote the manuscript. GS corrected the manuscript. VT corrected the manuscript. SK corrected the manuscript. PP helped in writing article. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

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