International Journal of Food and Fermentation Technology
Citation: *Int. J. Food Ferment. Technol.*: **12**(01): 47-70, June 2022
DOI: 10.30954/2277-9396.01.2022.7

ASSOCIATION FOR AGRICULTURE ENVIRONMENT AND BIOTECHNOLOGY

Review paper

Millet: A Review of its Nutritional Content, Processing and Machineries

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Paper No.: 262 **Received:** 22-08-2022 **Revised:** 28-11-2022 **Accepted:** 08-12-2022

ABSTRACT

Millet is a staple food grain that has been consumed for thousands of years in various cultures. It is a good source of nutrients, including carbohydrates, protein, fiber, vitamins, and minerals. Millet is also characterized by its small size, round shape, and hard outer layer, which makes it an ideal grain for processing into various food products. It is processed into flour, grits, and other forms for preparation of porridge, bread, crackers and also can be used fermented foods such as beer and sourdough. It is also gaining popularity as a gluten-free alternative for people with celiac disease or gluten intolerance and suitable for people with digestive issues. Overall, millet is a nutritious and versatile grain with a long history of use in various food applications. Its growing popularity as a gluten-free alternative, combined with its health benefits and adaptability to a wide range of recipes, make it an attractive option for many consumers. Therefore, this review was written with an aim to succinctly provide an overview of the available literature take on the characterization, processing and applications of millet.

Keywords: Millet, Glycaemic index, dehulling, milling machineries

Cereal based products are the main source in the human diet. Generally, cereals belong to two main groups such as temperate cereals and tropical cereals namely wheat, barley, rye, and oats and rice, maize, sorghum, and millets respectively. Rice and wheat used in wide scale throughout world as a staple food. The total amount of cereal produced in 2019 is a record-high 2715 million tonnes (FAO, 2020). However, the many countries in world are currently dealing with a number of adverse concerns, including a growing population, climatic changes, rising food prices, a lack of water, environmental damage, and other socioeconomic effects. In the world, there are 815 million people who are suffering from hunger and malnutrition (Anonymous, 2020). Therefore, the millet crops which are climatic resilience than wheat and rice as well as it contributes to the nutritional and health security gaining importance day by day. It is one of the most significant drought-resistant crops and the sixth cereal crop produced globally. In addition, compared to other major cereals, millet

How to cite this article: Kalse, S.B., Swami, S.B. and Jain, S.K. (2022). Millet: A Review of its Nutritional Content, Processing and Machineries. *Int. J. Food Ferment. Technol.*, **12**(01): 47-70.

Source of Support: None; **Conflict of Interest:** None

has a shorter growing season, is resistant to pests and diseases, and is effective during droughts (Devi *et al.* 2014). From the aforementioned, it is clear that policymakers must concentrate on: (a) increasing food production to meet the constantly growing demand for food to feed the population, which is expected to reach 9 billion by 2050 in Asia and Africa (UN, 2015); (b) properly using land for crops in accordance with the patterns of food consumption; and (c) maintaining the sustainability of food with high nutritional value for all. The Indian Government take initiative and responded by doing the following: (a) designating 2018 as the National Year of Millets; (b) increasing the minimum support price of millets by 50% to encourage farmers to choose millets as their preferred crop; (c) securing the incorporation of millets in programmes like the adaptation of African agriculture and technologies for African Agriculture Transformation Programme so that farmers in Africa preferred growing millets; and (d) proposing to the FAO to designate 2023 as the International Year of Millets after approving this application the United Nations has designated year 2023 as "International Year of Millets". Millets consist of very high concentration of macro and micronutrients like protein, dietary fibre, vital fatty acids, minerals, and vitamins (N. Sharma *et al.* 2023).

One of the most common cereal grains consumed worldwide is millets, which are particularly popular in dry and semi-arid regions of Asia (China and India) and Africa. This might be due to effective photosynthetic system of millet, as their seeds only take 6–8 weeks to mature. These grains are widely available, extremely affordable, and sometimes referred to as "poor man's food," particularly for those who live in hot, arid climates (Amadoubr & Le, 2013). The high nutritional value and agro-industrial significance of these plants make them of significant interest (Saleh *et al.* 2013; Y. Zhu *et al.* 2018). Several plant-based diets have been advised by numerous international health organizations to enhance health and fight against different chronic diseases. However, paying special attention to the nutritional value and millet cultivation can offer a comprehensive answer to the current problems of hunger and malnutrition. Millet consumption can help to contribute to the objective of "United Nations" to eradicate malnutrition by 2030 (Hou *et al.* 2018; Praveen & Tandon, 2016).

Millets typically come in seven types with different colours, sizes, shapes and growing regions. These grains are small-seeded, round cereals which are members of the *Poaceae* family, considered as the earliest and most likely the first cereal grain that humans have ever used for domestic purposes. The millets generally are as pearl millet (*Pennisetum glaucum),* finger millet (*Eleusine coracana*), kodo millet (*Paspalum setaceum*), proso millet (*Penicum miliaceum*), foxtail millet (*Setaria italic*), little millet (*Panicum sumatrense*), barnyard millet (*Echinochloa utilis*). They are known as coarse cereals beside maize (*Zea mays*), sorghum (*Sorghum bicolor*), oats (*Avena sativa*), and barley (*Hordeum vulgare*) (Bouis, 2000). The typical characteristics of millet are shown in Table 1. The technology for quick breakfast cereal requires very little cooking to generate highly sophisticated ready-to-eat products that also reduced the amount of time required for in-home preparation. Children today suffer from a variety of illnesses caused by their environments and eating habits. While there are initiatives being undertaken on a global scale to achieve food self-sufficiency, protect the environment, and deal with health issues. Millet is becoming more and more recognised as an important crop to address the population expansion and the food crisis. Millet grains are perfect for vegetarians and vegan food because of their high protein content, which is primarily used in Asia-Pacific, America and Europe region.

As a result, demand of millet-based products is increasing in these regions. Millets are thought to have additional nutritional health benefits. These include an improvement in the health of the muscular system and digestive system, a decrease in cholesterol, the prevention of heart disease, protection from diabetes, and a reduction in the risk of cancer (Shobana *et al.* 2009).

Therefore, this review was written with an aim to effectively present an overview of the literature on the processing and uses of millet-based products. This knowledge would be crucial in identifying the research gap that prevents millet from being used to its full potential. Researchers and the food industry can use this information going forward to realize the extent of millet processing for the development of distinctive food products.

Production and Market Overview

The millet production in African region (48.5%) is highest followed by Asian countries (47.7%). The total millet production of the world in 2022 was estimated to be 30513 MT; however, India is the largest millet producer estimated to produce 205 lakh tonne millet in year 2022, followed by China and Niger countries accounting for more than 55.0% of the global production. Rajasthan (36%) is leading state

Table 1: Different characteristics of millet

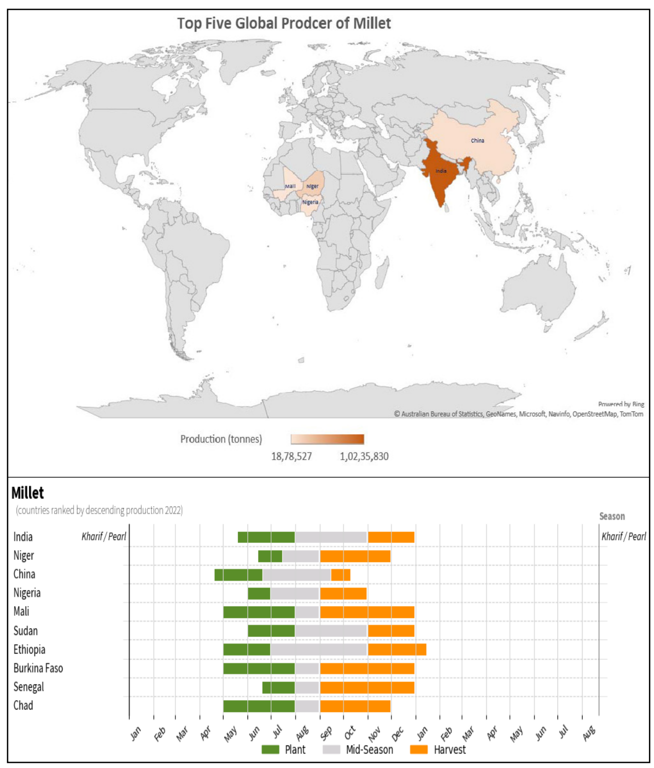
Millet	Scientific Name	Common Name	Physical Property	Origin	Picture
Foxtail millet	*Setaria italica*	Indian paspalum, Kangni, Water couch, Italian millet, Rala	Colour - Pale yellow to orange Shape - Ovoid Size - 2 mm length	China	
Finger millet	*Eleusine coracana*	Ragi, Wimbi, Mandua, Nachni, Kapai, Nagli, Marua	Colour - Light brown to dark brown. Shape – Spherical Size - 1–2 mm in dia.	East Central Africa (Uganda)	
Pearl millet	*Pennisetum glaucum*	Bajra, Cattail millet, Black millet, German millet	Colour-White, grey, pale yellow, brown, or purple. Shape - Ovoid Size 3–4 mm length	Tropical West Africa (Sahel)	
Proso millet	*Panicum miliaceum*	Cheena, Common millet, Broom millet, Vari	Colour - White cream, yellow, orange Shape - Spherical to oval Size - 3 mm long and 2 mm in dia	Central and eastern Asia	
Kodo millet	*Paspalum scrobiculatum*	Kodara, Ditch millet, Creeping paspalum	Colour- Blackish brown to dark brown Shape - Elliptical to oval Size - 1.2 to 9.5 µm long	India & West Africa	

Barnyard millet	*Echinochloa crusgalli*	Bhagar, Sawan, Jhingora, Kudraivali, Oodalu, Barti	Colour – White Shape – Tiny round Size – 2-3 mm long	Japan & India	
Little millet	*Panicum sumatrense*	Kutki, Samai, Samalu, Haliv	Colour - Grey to straw white Shape - Elliptical to Oval Size - 1.8 to 1.9 mm long	Southeast Asia	

followed by Uttar Pradesh (12%), Karnataka (11%), Gujarat (9%) and Haryana (8%) (Govt. of India, 2022). Fig. 1 shows Millet Production Seasons in different countries. The compound annual growth rate (CAGR) for the global millet market is anticipated to be 4.8% over the forecast period (2022-2027). In 2020, COVID-19 had a significant impact on the millet market. On the negative sides, the market saw a disruption in the supply chain, a labour shortage, the closure of small processing facilities, etc. as a result of the repeated enforcement of lockdowns. Despite all of these negative effects, retail sales significantly increased. People have switched from consuming junk food to nutrient-rich superfoods like millets and their derivatives in an effort to strengthen their immune systems. Throughout the projection period, millets are anticipated to see a growth in consumer demand (US Department of Agriculture, 2022).

Structure of millets

Sorghum and many millets have comparable anatomical and basic kernel structures. It is distinguish as pericarp (outer covering), endosperm (starchy section), and germ (embryo and scutellum or first reserve tissue) which are the three main anatomical components. The pericarp of foxtail, common, and finger millets like bag and is only loosely connected to the endosperm at one location. In these utricle-type kernels, the pericarp easily separates, exposing the inner endosperm beneath the seed coat or testa. The pericarp is firmly attached to the endosperm in the caryopsis-type kernels of sorghum and pearl millet, therefore it requires a little additional energy to break the pericarp. The sorghum kernel is regarded as a naked caryopsis, despite the fact that only a small number of African varieties retain their glumes after threshing. Generally, sorghum contains 84.2% endosperm, 9.4% germ, and 6.5% pericarp.



Source: *FAO 2020.*

Fig. 1: Top Millet Producing countries and its seasons

Nutritional composition of millets

Millets are richer in dietary fibre, abundant in minerals and nutraceuticals, and have more protein (9–14%) and carbohydrate (70–80%) than wheat. Millets are good sources of micronutrients and phytochemicals (Singh *et al.* 2012). The nutritional compositions of different types of millets are given in table 3. The table shows that highest protein among the millets is found in common millet followed by pearls millet and foxtail millet. Barnyard millet is a good source of iron (18.6mg/100g) followed by pearl millet and little millet. Finger millet is an amazing source of calcium having 350 mg/100 g. It is nutritionally rich than most of the cereals in respect of protein, vitamins, minerals and energy (Arora *et al.* 2003). Proso millet, foxtail millet, and barnyard millet are in order of having less free lipid and more protein than pearl millet. Many millet varieties, including finger millet, kodo millet, and little millet, are low in protein but high in dietary fibre and phenolic content. Kodo millet has a high lecithin content, is very simple to digest, and is highly good for boosting the nervous system. Niacin, B6, folic acid, and other B vitamins, as well as minerals including calcium, iron, potassium, magnesium, and zinc, are abundant in kodo millets. Barnyard millet is a natural gift from nature for today's sedentary human population because it has a low and slowly digesting carbohydrate content. Linoleic acid is the main fatty acid in barnyard millet, followed by palmitic and oleic acid. Additionally, it exhibits a strong retrogradation of amylase, which promotes the formation of more resistant starches. Therefore, it may be suggested to people who have diabetes mellitus and cardiovascular disease. Foxtail millet protein characterization showed that its protein concentrate is a potential functional food ingredient and the essential amino acid pattern suggests possible use as a supplementary protein source to most cereals because it is rich in lysine (Hithamani & Srinivasan, 2014; Pradeep & Sreerama, 2015; Serna-Saldivar & Espinosa-Ramírez, 2019; Sharma & Niranjan, 2018; Dayakar *et al.* 2017).

The concentration and activity of antioxidants can be altered by processing techniques such soaking, malting, decortications, and cooking. While finger millet has 12–16% protein and 2-5% lipids, sorghum and the majority of millets only have about 10% protein and 3.5% lipids. Sorghum and millets are

Table 2: Structural and Physical Properties of Millet

Parameter	Millet						
	Foxtail	**Little**	**Barnyard**	**Kodo**	**Proso**	**Pearl**	**Finger**
Seed Type	**Caryopsis**	**Caryopsis**	**Caryopsis**	**Caryopsis**	**Utricle**	**Caryopsis**	**Utricle**
L^*	75.47	69.66	70.65	64.96	75.51	72.71	71.09
a^*	4.10	2.95	3.09	2.33	2.29	0.08	3.53
b^*	19.14	12.33	13.11	12.12	14.24	9.11	5.84
a_w	0.429	0.486	0.522	0.634	0.757	0.673	0.704
1000 kernel weight (g)	—	—	3.3-5.0	—	5-7.1	2.5-14.7	2-2.5
Germ size (μm) (L × W)	270X980	—	—	—	1100X 977	1420X 620	980 X 270
Endosperm to germ ratio	—	—	—	—	12:1	2.5:1	11:1
Testa (layers)	Remnant	—	Present	Present	1	1	5
Aleurone (layers)	1	1	1	1	1	1	1
Starch form	**Polygonal, round**	—	**Hexagonal, round**	**Polygonal, round**	**Hexagonal, round**	**Polygonal, round**	**Polygonal, round**
Waxy	Yes	—	No	No	Yes	No	Yes
Gelatinization Temp (°C)	63.1				68.5	66.7	64.3.

Source: *Annor et al. 2014.*

Table 3: Nutritional chart for millets

Parameter	Millets						
	Foxtail	**Little**	**Barnyard**	**Kodo**	**Proso**	**Pearl**	**Finger**
Principal nutrients (g/100 g)							
Protein	11.02	9.44	10.45	9.07	12.61	11.86	7.41
Fat	4.01	3.72	3.50	3.22	3.08	4.28	1.71
Carbohydrate	60.90	65.60	65.50	66.20	70.40	61.80	66.80
Total Mineral	3.38	4.77	4.23	3.16	2.85	2.25	2.70
Dietary fiber (g/100 g)							
SDF	5.87	5.65	4.15	3.85	2.05	1.91	1.94
IDF	11.06	8.57	10.19	13.13	9.48	9.85	9.15
TDF	16.93	14.21	14.34	16.98	11.53	11.76	11.09
Mineral elements (mg/100 g)							
Fe	2.64	1.43	5.07	1.17	0.92	6.85	4.82
Zn	2.43	3.61	2.13	1.62	1.38	2.82	2.45
Ca	34.19	17.17	22.31	14.58	13.41	24.93	350.33
Mn	0.44	0.32	1.10	0.47	1.25	1.60	3.86
Cu	0.20	0.38	0.34	0.27	0.47	0.54	0.69
P	310	220	280	320	150	350	258
Na	10	—	—	10	10	10	17
Lipid	46.8	49.7	47.7	26.5	37.1	56.7	9.3
Energy (Kcal)	351	329	300	1388	341	363	336
Antinutrients (mg/100 g)							
Phytic acid	973	633	676	1268	526	878	468
Total tannin	28.7	15.7	35.5	48.1	21.8	23.9	42.1
Oxalic acid	11.19	6.87	20.65	3.41	8.54	26.50	39.38
Vitamins (mg/100g)							
Thiamin	0.59	0.30	0.33	0.15	0.41	0.38	0.42
Riboflavin	0.11	0.09	0.10	0.28	0.20	0.21	0.19
Niacin	3.2	3.2	4.2	0.09	4.54	2.8	1.1
Vitamin E	3.1	—	—	—	—	1.9	2.2
Phenolic/Flavonoids compounds, μg/g							
Gallic acid	5-7	—	—	2.0	4-6	5-39	5-11
Syringic acid	17	—	—	141	6	6-7	10-25
Gentisic acid	17	—	—	4	8	n.d.	5
Vanillic acid	11-119	—	—	98	85-169	33	n.d.
Apigenin	102-160	—	—	2	2-16	4	n.d.
Myricetin	7	—	—	nd	7-16	10	11
Catechin	7	—	—	nd	nd	nd	1533

SDF-soluble dietary fiber, IDF-insoluble dietary fiber, TDF-total dietary fiber.

excellent suppliers of vitamins and minerals, as well as other micronutrients. Prolamin (also known as kaffirin), which makes up a large amount of sorghum protein, has the unusual property of to become less digestible when cooked, whereas millets have a better amino acid profile. Sorghum proteins are said to be much less digestible after heating than other cereal proteins, which may be advantageous for some dietary groups. On the other hand, millets have lower levels of cross-linked prolamins, which may be another factor boosting the millet proteins' level of digestibility (Dayakar *et al.* 2017).

Phytochemicals

Millets are a rich source of many phytochemicals, such as pinacosanols, phenolic acids, anthocyanins, phytosterols, and tannins. These phytochemicals are beneficial for human health. One of the most diverse groups of phytochemicals present in all plant tissues, phenolic compounds play a crucial role in the human diet. Cereal grains include a diverse range of free phenolic compounds, their glycosides, esters, and insoluble-bound counterparts that are linked to polysaccharides in the cell walls (Miller *et al.* 2000). Phenolic compounds are concentrated in the bran layers and are susceptible to losses during the separation of seedcoat during the milling process (Tian *et al.* 2004). Millets mostly include free and conjugated phenolic acids, which include hydroxybenzoic and hydroxycinnamic acid derivatives. Millets also contain a number of flavonoids, including anthocynidins, flavanols, flavones, flavanones, chalcones, and aminophenolic substances. The content and composition of phenolic acids and flavonoids vary depending on the type and variety of millet grain, which can be found in various sections of the grain. The phytochemicals found in various millet grains are becoming more important because of their benefits for health, particularly in the treatment of diabetes (Ren *et al.* 2016). The crucial role of the amylolytic enzymes α-glucosidase and α -amylase in carbohydrate metabolism has been found to be inhibited by some certain phenolic compounds (Ren *et al.* 2016; Zhu, 2015), however the interaction and participation of other important enzymes with phenolic compounds is unclear. The leptin receptor is a key enzyme involved in numerous physiological processes, including the regulation of obesity and hypoglycemia (Zhu, 2015).

It shows that millet has phenolic acid such as hydroxybenzoic acid (gentisic acid, vanillic acid, protocatechuic and syringic acid), hydroxycinnamic acid (p-coumaric acid, sinapic acid, ferulic acid, and cinnamic acid), and flavonoids (catechin, quercetin, apigenin, and taxifolin) (Akanbi *et al.* 2019). The millet kernel, which can be consumed, is a rich source of phytochemicals, including dietary fibre and polyphenols (0.2–0.3%). Phytates, polyphenols, and tannins present in millet play a significant role in ageing and metabolic disorders and contribute to antioxidant activity. Among the millet grains, finger millet has the highest calcium concentration (344 mg/100g) good source of phosphorous and iron; it is also abundant in phytates (0.48g/100g), polyphenols (0.61%), and tannins (0.61%) which can contribute to antioxidant activity and important factor for aging and metabolic diseases. Its protein is unique because of the sulphur rich amino acid contents. Similar to cereal proteins, the millet proteins are poor sources of lysine, but they complement well with lysine-rich vegetable (leguminous) and animal proteins.

Processing of Millet

Many processing technologies are used in the production of value added food products in relation to the enhancement of nutritional characteristics, sensory properties, and accessibility. The bioavailability of micronutrients in plant-based diets can also be improved by using a number of traditional and mechanical food processing techniques. These include germination/malting, soaking, fermentation, mechanical processing, and thermal processing. These methods seek to make micronutrients more physically accessible, reduce the amount of antinutrients such phytates, or raise the content of compounds that boost the bioavailability (Hotz & Gibson, 2007). The decortication process is not necessary for millet grains including finger millet, pearl millet, and sorghum since they lack a husk covering. For this kind of grain, cleaning and grading are crucial processes. They are then prepared for cooking by being ground up into either flour or grits. One of the reasons why these grains continue to be a staple in the diets of the indigenous populations is their simplicity of processing.

Mechanised Processing Technology

1. Decortication/Dehulling

The removal of the pericarp, hull, and outer coat of grain is known as decortication. The kernels of a number of millet grains are utricles type so it is necessity of removing the "hull" before the grain is subjected to further processing (N. Sharma & Niranjan, 2018). The decortication process is not necessary for millet grains including finger millet, pearl millet, and sorghum since they do not have husk cover. The process of cleaning and grading are crucial for this type of grain. They are then prepared for cooking by being ground up into either flour or grits. This simplicity of processing of this millet gains is one of the reasons that these grains regularly used to be a staple food in the diets of the many indigenous peoples. The small millets like Foxtail, Little, Kodo, Proso, Barnyard millet have a hard cellulosic husk layer that humans cannot digest so removal of this husk is primary task of processing of these millets.

The husk can be removed by using shear of impact force. Shear force is used in a manual or motorised stone grinding mill, whereas impact force is used in manual pounding or centrifugal hulling equipment. The de-hulling method and the type of machinery used affect the milling characteristics and nutrient retention in the de-hulled millets. In Large-scale processing of small millets about 12 to 30 percent of the husk removed during dehulling operation and also almost all bran layer removed which leads to decrease the nutritional value of the millet products. The phenolic content is higher in the husk and seed coat of grains as compared to whole and de-husked grains so that the further dehulling process results in the loss of dietary fibre, beneficial chemicals, and about 80% of phenolic content (Goudar & Sathisha, 2016). The stone dehullers and modern dehullers considerably reduced the protein, crude fibre, oil, and ash contents of pearl millet by 1.58, 1.61, 1.24, and 0.8%, respectively. These methods have also significantly reduced the amounts of calcium (129-115 mg/100 g), phytic acid (301.10-77.95 mg/100 g), iron (5.13-3.11 mg/100 g), and phosphorous (509-380 mg/100 g). The moisture content and nitrogen-free extract of the millet grains have not been impacted by dehulling process (Babiker *et al.* 2018). According to a study on manual and mechanical dehulling of pearl millet, 10% to 15% of the bran is removed after 6 minutes of decortication. In this process the iron's bioavailability increased from 2.33 mg to 25.14 mg/100 g, but zinc levels dose not changed. The iron-rich bran part of pearl millet can be added to speciality food using the right decortication techniques, addressing the global nutrient deficiency (Krishnan & Meera, 2021).

It is also reported that reduction in protein, fat, insoluble dietary fiber, ash, lysine, tryptophan, and other amino acid content after decortication process (Rani *et al.* 2018). In vitro protein digestibility was increased by up to 0.5% during the dehulling process by removing polyphenols and anti-nutrients such phytic acid from the outer layers of millet, which reduce protein digestibility by precipitating proteins ((Urooj, 2017). Additionally, a various studies found that decorticating certain millets boosted their estimated glycemic index and protein digestibility. Kodo millet significantly increased by 42%, while the estimated glycemic index of other millet increased by less than 6%. The fact that decorticated millet has a higher glycemic index than raw millet may be due to decreased quantities of insoluble dietary fibre, phenolic compounds, and lipids in the millet's outer layer (Annor *et al.* 2017). Proso millet possessed phytate contents that ranged from 170 to 470 mg/100 g whole grain, while dehulling caused phytate contents to reduce by 27 to 53%. De-hulling reduced the phytin phosphorus content of proso millet by 12%, small millet by 39%, kodo millet by 25%, and barnyard millet by 23%. De-hulling sorghum can reduce its total phosphorus and phytate content by 40 to 50 percent. It was discovered that the small millet grains, when steeped for 4 hours and subsequently dried in hot air at 45°C, showed the maximum milling and dehulling efficiency of 70.21% and 96.72%, respectively (Sahoo *et al.* 2020).

However, millet grains are typically decorticated before consumption to enhance their nutritional and sensory properties as well as to improve the appearance of their food items. Decortication of millet grains was found to decrease various nutrient levels, such as fibre and minerals and also some antinutrients. Therefore, the decortication technology must be used immediately to produce edible food products of millet on a large scale. Instead of using traditional decortication methods, advance methods will save time, money, and labour.

2. Milling/Grinding and Sieving

Grinding or milling of grains is often done to separate the endosperm, bran, and germ as much as possible, reduce particle size, and make it easier to produce refined flour. Particularly in rural areas and for domestic usage, millet grains are often ground using a non-motorized grain mill that is operated by hand or another non-electric technique. However, it is also possible to use a manual grain mill that has been connected to a gas or electric engine by a pulley system. Millet's chemical composition can be substantially changed during milling process. Additionally, the removal of the bran, which has a higher concentration of phytic acid and polyphenols than the whole millet grains, during the milling process lowers the level of these substances improved the protein digestibility and starch digestibility to a significant extent in the final processed products like chapati (bread) (Rathore, 2016). According to a study, milling finger millet reduced the amount of iron, zinc, and calcium while milling pearl millet grain significantly reduced the amount of vitamin B and E (Kruger *et al.* 2014; Taylor & Kruger, 2019). The milling yield increased when the millet being steamed at high pressure and temperature; however, steaming above the threshold level had a negative impact on the yield of head grains (Dharmaraj *et al.* 2013). In a study, the protein, fat, soluble dietary fibre, and insoluble dietary fibre content of milled finger millet was significantly reduced by simple sieving, decreasing from 7.15 to 6.33 g, 1.78 to 1.29 g, 1.55 to 1.79 g, and 20.23 to 12.15 g, respectively. Additionally, some minerals like calcium, iron, and zinc have decreased from 404.3 to 294.8 mg, 2.50 to 1.98 mg, and 6.52 to 3.29 mg, respectively. Thiamine and riboflavin levels per 100 g of flour decreased simultaneously from 0.552 to 0.342 mg and 0.243 to 0.196 mg, respectively. The bran separation that occurred when millet was sieved caused the loss of all nutrients (Oghbaei & Prakash, 2016).

The nutritional value of millet can be impacted by the milling process, with whole millet retaining more nutrients and fiber than milled millet flour. To maximize the nutritional value of millet, it is recommended to use whole millet or minimally processed millet flour. Millets are less convenient for creating flour-based food products, which could have a variety of nutritional benefits, due to a lack of milling technologies. In other words, attention must be paid to the use of advanced milling technology for millet grains on an industrial scale if there is to be a reliable supply of a sizable volume of millet flour that is very nutritious.

3. Fermentation

Fermentation is a process that involves the conversion of sugars into alcohol or organic acids by yeast or bacteria. It is one of the oldest and most affordable methods of food preservation (Fujimoto *et al.* 2019). Fermentation of millet can improve its nutritional value and safety, as well as enhance its flavor and texture. Some common fermented millet products include millet beer, sourdough bread, and fermented porridge. Fermentation can increase the bioavailability of nutrients, such as vitamins and minerals, as well as break down antinutrients, such as phytic acid, that can inhibit the absorption of certain minerals. Additionally, fermentation can improve the shelf life of millet products, as the process creates an acidic environment that inhibits the growth of harmful microorganisms. This can also enhance the safety of millet for human consumption, reducing the risk of foodborne illnesses.

Industrial fermentation of millet grain involves the large-scale production of fermented millet products, such as millet beer, sourdough bread, and fermented porridge. This process is typically carried out in a controlled environment using specialized equipment and microorganisms, such as yeast or lactic acid bacteria. Industrial fermentation allows for the production of large quantities of fermented millet products in a shorter period of time compared to traditional, small-scale methods. The controlled environment of industrial fermentation ensures consistent quality control, with the ability to standardize the product for commercial use. Fermentation can increase the bioavailability of nutrients in millet, such as vitamins and minerals, and reduce the levels of antinutrients, such as phytic acid. The acidic environment created during fermentation can inhibit the growth of harmful microorganisms, making the product safer for human consumption. Large-scale production through industrial fermentation makes fermented millet products more readily available to a wider market. Additionally, following fermentation, the protein and crude fat contents of pearl millet grains increased from 10.99 to 13.65% and 1.83 to 3.71%, respectively. This increase in protein content could be attributed to protein synthesis during fermentation. But due to the leaching of soluble inorganic salts, enzymatic destruction of fibre during fermentation, and metabolic activity of microbes on sugars, the amounts of ash (4.37-3.45%), crude fibre (1.20-0.54%), and carbohydrates (75.75-73.76%) decreased, respectively (Akinola *et al.* 2017). Another study found that after 16 hours of fermentation, pearl millet grains had a considerable rise in protein content of 15.32%. The solubilization of insoluble proteins during fermentation is most

Table 3: Fermentation effect on the nutritional profile of millets

Millet	Conditions	Results	References
Pearl millet flour	Native microflora; Temp- 27°C; Time- 72 h	• Protein content increased (117.96%); Tannin reduced (31.53%) and also Phytate reduced (48.78%).	Ojokoh and Bello (2014)
Finger millet grains	*Lactobacillus salivarius subsp. Salivarius* (LMG 9477T) at 30 °C for 48 h	• Tryptophan increased (17.8%), lysine increased (7.1%), and phenylalanine decreased (3.3%).	Mbithi-wikya *et al.* (2000)
Pearl millet flour	Native microflora at 30 °C for 24 h	• Reduction in phytic acid (51.9%).	Osman (2011)
Pearl millet flour	Native microflora at 37 °C for 12 or 24 h	• Improved protein digestibility (93.6%).	Hassan *et al.* (2006)
Little millet	Probiotic yeast *(S. boulardii)* for 5 days	• Protein and phosphorus increases. • Fat and total carbohydrates content decreased. • Decreased in phytic acid (from 188.95 to 167.56 mg/100 g).	Pampangouda *et al.* (2015)
Fermented broom corn millet sour porridge	*S. cerevisiae versus L. brevis and Acetobacter aceti* for 24 h at 30 °C	• *S. cerevisiae* showed the minimum titratable acidity and sensory scores compared with *L. brevis* and *A. aceti*. • Mixed-strains fermentation (1:1:1, v/v/v) was found to be the best combination of strains starter	Wang *et al.* (2019)
Pearl Millet	40°C, pH 5 and time duration of 8 hours.	• Increase in total reducing sugar, iron content, antioxidant activity and decrease in tannin content	(Srivastava *et al.* 2020)
Pearl Millet	2% baker's yeast at 30°C for 18h.	• Improved the phytochemical constituents	(Kumari *et al.* 2022)

likely what caused the protein content to increase (Mohammed *et al.* 2018). After fermentation, finger millet's total phenolic components were generally reduced by up to 41%, according to a study. This may be related to the reorganisation of some phenolic structures following self-polymerization as a result of the acidic fermentation conditions (Gabaza *et al.* 2016). The effect of fermentation on the nutritional profile of millets is shown in Table 3.

However, industrial fermentation of millet grain also has its limitations, including the high cost of equipment and infrastructure, as well as the need for specialized knowledge and expertise in the field. Additionally, the competition from other grains, such as wheat and maize, can also impact the market demand for fermented millet products. the equipment used for the fermentation of millet can include vessels for holding the mixture, stirrers for mixing and aerating, temperature control systems, pH control systems, sterilization equipment, filtration systems, and packaging equipment.

4. Puffing

It is a typical processing method used to prepare extended ready-to-eat snacks and other items from any type of grain. The millets were presoaked at the required moisture level for popping/expansion, and then exposed to hot sand in a ratio of 1:6 at high temperature (230-250 °C) and less time (20–30 s). When raw millet grains were heated at a high temperature for a short period of time to achieve the desired expanded form, popping of the decorticated finger millet was quite common. Prior to exposure to a heating environment, raw grains must be flattened into the desired shape and kept at the desired moisture level in order to achieve the highest expansion ratio (Saleh *et al.* 2013). Grain popping enhances both the physical form of the grain's expansion properties as well as the grain's functional qualities. Additionally, the millet grains' abundance of certain antinutritive components is significantly reduced. After puffing, the endosperm in millet grains contributes to the kernel's starch content and increases its carbohydrate content, whereas an increase in protein was caused by an increase in the hydrolysis of protein into low molecular weight protein. In contrast, after puffing, crude fibre and fat levels decreased by 1.71 and 0.06%, respectively, in another study. Although the calcium amount dropped from 27 to 18 mg/100 gm (Patel *et al.* 2018). The millet grains' starch hydrolysis rate increased during in vitro digestion during the puffing process. It might be caused by the tannins being eliminated during puffing since they might prevent the in-vitro digestion of starch. In contrast, in another study, popping of the finger millet boosted its protein digestibility (R. Huang *et al.* 2018).

Puffing is one of the HTST (high-temperature, short-time) processing methods used to make expanded cereals for snacks, breakfast, and ready-to-eat products. It is the Popping or puffing gives it the desired flavour and aroma to the food product (Kapoor, 2013). Puffing has a considerable impact on the nutrient profile of grains. In one study, different kodo millet cultivars were tested to determine their nutritional profile and puffing stability. It has been discovered that puffing millet at 230°C for 3 minutes while stirring continuously until the sound of puffing stops significantly increased the amount of protein and carbohydrates in the grain from 7.92 to 8.12% and 68.35 to 74.38%, respectively. After puffing, the endosperm in millet grains contributes starch to the kernel, increasing the amount of carbohydrates, while the rise in protein was caused by an increase in the hydrolysis of protein into low molecular weight protein. In contrast, after puffing, crude fibre and fat levels decreased by 1.71 and 0.06%, respectively and the calcium content dropped from 27 to 18 mg/100 gm (Patel *et al.* 2018). It was found that the protein, carbohydrate, and iron contents of puffed finger millet increased from 6.3 to 7.1 g/100 g, 71.9 to 75.73 g/100 g, and 3.7 to 5.1 mg/100 g, respectively, while the calcium, crude fibre, moisture, and fat contents decreased from 342 to 338 mg/10 g, 18.9 to 15.8 g/100 g, 13.1 to 12.2 g/100 g, and 1.3–0.63 g/100 g respectively. The denatured lipolytic produced by thermal processing may be the source of the reduced fat content (Singh Chauhan & Sarita, 2018). Additionally, popping has decreased the antinutrient content, lowering levels of tannins and phytic acid from 870.8 to 610.2 mg/100 g and 851.4 to 333.1 mg/100 g, respectively, and trypsin inhibitor activity from 4188 to 3090 U/g (Shigihalli *et al.* 2018). Another study also noted a 54.78% decrease in phytic acid in the puffed pearl millet grains. The formation of insoluble complexes between phytate and other components, such as phytate protein and phytate-protein-mineral complexes, may contribute to the apparent decrease in phytate content during thermal processing (Kumari *et al.* 2018).

5. Malting

Malting is the controlled germination of grains in a moist environment. Amylases, proteases, and other enzymes are mobilised during the process, changing the grain's structure and composition (Awolu, 2017). Malting boosts the amino acids, total sugars, and B-complex vitamins while lowering the starch and dry matter levels and increasing the activity of hydrolytic enzymes. Additionally, it increases the availability of bioactive chemicals and the bio-accessibility of minerals in millets. More importantly, malting can assist increase the in vitro protein and starch digestibility of millets and effectively reduce their antinutrient effects (Abioye *et al.* 2018; Krishnan *et al.* 2012; S. Sharma *et al.* 2016). Malting can significantly increase the in vitro protein and starch digestibility of millets and effectively reduce their antinutrient effects (Ali *et al.* 2003). Higher amylase activity, lesser pasting viscosity, and greater water and oil absorption capabilities are all characteristics of pearl millet and finger millet malt. The protein and crude fibre contents of pearl millet were raised during malting by steeping at 25 °C for 24 hours, germination at varied intervals, and hot air treatment at 55 °C for 18 hours (Adebiyi *et al.* 2016; Obadina *et al.* 2017). On the other hand, it was noted that after malting, the concentrations of fat, carbohydrate, and amino acids significantly decreased. The protocatechuic acid concentration of malted finger millet has significantly decreased. Malted millet flour has been shown to improve the nutrient and sensory quality profiles of a variety of traditional and conventional foods, including ogi, cake, bread, and extruded products (Anuradha *et al.* 2010; Bhol & John, 2014; Obatolu, 2002). The germination of finger millet increases from 8 to 24 h and the protein content of millet malt increases from 14% to 17.5% (Swami *et al.* 2013).

Conventional Processing Technologies

1. Soaking

Soaking of grains is a popular household food processing technique. The cooking of millet is much improved by soaking it in cold or hot water overnight. Soaking millet before cooking can have a positive effect on its nutritional value. Soaking can increase the absorption of nutrients, such as vitamins and minerals, as well as reduce cooking time. Additionally, soaking millet can also break down antinutrients, such as phytic acid, that can inhibit the absorption of certain minerals in the gut. Soaking millet for a period of 6-8 hours or overnight can help improve its nutritional value, making it easier to digest and increasing its overall nutrient content. However, it is important to note that soaking can also lead to the loss of some vitamins, such as vitamin B and C, so it is recommended to balance soaking time with the preservation of these nutrients. Additionally, soaking makes it possible to add whole millet to breads, which would not be possible without properly cooking the grain. It has been demonstrated that soaking increases the bioavailability of minerals by lowering anti-nutrients. The amount of phytic acid in finger millet was greatly reduced by soaking it in distilled water for a mean of 250 mg for 12 hours, 241 mg for 24 hours, and 221 mg/100 g for 48 hours, respectively. The direct hydrolysis of phytic acid by phytase in seeds or the water after leaching into the soaking media was thought to be the cause of the decrease in phytic acid. It is also found that during soaking process the iron and zinc contents of millet reduced due to the leaching of minerals in soaking water (Bindra & Manju, 2019) .

2. Cooking

Cooking can be thought of as a household method for creating simple traditional staple foods. It is a simple approach of processing related to millet's change in nutrients (Patel & Thorat, 2019). The nutritional value of millet can be affected by cooking, as some vitamins and minerals may be lost in the process. The extent of nutrient loss depends on various factors such as cooking time, temperature, and the method of cooking. Boiling millet in water, for example, may cause some of the B-vitamins and minerals to leach into the cooking water, reducing the overall nutritional value of the grain. To minimize nutrient loss, it is best to cook millet using methods that retain as much of the nutrients as possible, such as steaming or pressure cooking. Cooking can cause a decrease in the levels of some vitamins, such as vitamin B and C, as well as minerals like calcium, iron and zinc. However, cooking can also make certain nutrients more digestible and bioavailable, such as starch and protein. To preserve the maximum nutritional value of millet, it is recommended to use minimal water during cooking and to not overcook it. Additionally, using a pressure cooker can help reduce the loss of nutrients during cooking.

Total phenolic content has been used to study how cooking affects the antioxidant activity of pearl millet. The breakdown of cellular components during thermal treatment led to the release of additional bound phenolics, increasing the phenolic content of pearl millet grains from 2394 to 3137 g GAE/g. This large increase in phenolic content was the outcome of the boiling process (Siroha & Sandhu, 2017). It was observed that cooking proso millet greatly reduced its protein digestibility by aggregating the protein through hydrophobic interactions, possibly with the help of tryptophan residues that were exposed on the surface (Gulati *et al.* 2017). Spherical protein bodies (1–2.5 mm) cooked at high temperatures have microstructural changes that may be linked to the reduction in digestibility. The raw protein bodies contained significant cavities, but the cooked protein bodies only had tiny holes. However, there was no substantial difference in the protein bodies' size or shape. But a microscope test made clear that pepsin was unable to digest the cooked protein bodies (Gulati *et al.* 2018).

3. Roasting

Roasting of millet is the process of heating the grain in a dry pan until it turns a golden-brown color and releases a nutty aroma. This process enhances the flavor and aroma of the grain and can be used to make it easier to digest. Roasting also helps to extend the shelf life of millet by removing moisture and inactivating any potential contaminants. The temperature and length of roasting will depend on the desired outcome and can vary based on personal preference. Additionally, roasting can increase the range of aroma components and give millets a distinct aroma. According to a study, roasted pearl millet grains were tested at 120°C, 140°C for 5, 10, and 15 minutes, and 160°C, 180°C for 3, 5, and 10 minutes, to evaluate their nutritional content. The iron content has significantly increased by 274%, according to the results. When samples are roasted at a high temperature, leached iron from the roasting iron pan may migrate into the samples, increasing the iron content. However, it decreased the content of crude fibre, moisture, protein, and fat by 1.04, 0.71, 2.02, and 0.56%, respectively. The elimination of certain amino acids was the cause of the decline in protein content (Bi *et al.* 2019, 2020). Many antioxidants included in millet can lower the amount of free radicals brought on by oxidative stress and prevent cancer. These beneficial chemicals may be adversely impacted by millets being roasted. The total phenolic content of proso millet increased significantly from 295 to 670 mg/100 g after roasting it for 10 minutes at 110 °C (ferulic acid equivalent). It was noted that roasting might encourage the hydrolysis of C-glycosylflavones and result in the release of phenolic chemicals eventually (Azad *et al.* 2019). Different traditional processing techniques used for millet processing is shown in Fig. 4.

Advanced Processing Technology

1. Microwave technology

Electromagnetic radiation at a frequency between 300 MHz and 300 GHz is known as microwave energy. Moisture levels drop quickly as a result of

Table 4: Traditional processing techniques used for millet processing

Sl. No.	Unit operation	Objective	Technique used	Limitations
1	Threshing	Separation of grains, husks, and panicle	Beating method	High labor and time, lower output efficiency
2	Winnowing	Separation of foreign materials like chaff, straw, husk, etc., from desired fraction	Manual air blowing and winnowing	Low output capacity, weather dependent
3	Dehulling	Aleuron layer separation as hull from kernel	Wooden pounding	Required huge labor and higher time
4	Soaking	Maintain the desired softness by addition of moisture	Water pounding	Weather-dependent, risk of unwanted contamination, lower output capacity
5	Germination	Alteration of physiological form of grains to achieve nutritional change in grain	Using moist cloth	Lower output capacity and efficiency
6	Blanching	Inactivation of undesirable enzymatic activities	Hot water or steam exposure	Difficult to achieve accurate temperature time combination, batch process
7	Roasting	Flavor and taste improvement	Open type of roasting pan or *Kadhai*	No control on burning of grains
8	Popping	Flavor and taste improvement with defines texture	Popping pans/ *kadhai*	Difficult to maintain accurate process conditions, risk of unwanted contamination, lower output

the microwave energy, and the nutritional profile is decreased (Ekezie *et al.* 2017; Gavahian *et al.* 2019). The small millet treated in microwave had remarkable concentrations of proteins (4.48-10.32/100 g), carbs (78.37-81.69/100 g), oil absorption capacity (OAC) (0.90 g/g), and water absorption capacity (3.23 g/g). As a result, small millet treated with a microwave demonstrated notable nutritional benefits, and the similar trend was found in foxtail millet flours (Dayakar Rao *et al.* 2016; Kumar, Kaur, *et al.* 2020; Kumar, Sadiq, *et al.* 2020; Rao *et al.* 2021). The structure of the starch granules is reduced after microwave processing of proso millet starch. Microwaves also caused the stromal wall to thin, the network model to appear as fine strands, and it became more uniform (Zheng *et al.* 2020). Sorghum's fungal activity was decreased by 33.4% and 26.2%, respectively, under microwave heating at 500 and 350 W. The phenolic content and antioxidant potential also significantly increased by 47.1–50.8 mg of GAE/g and 40.9%–59.1%, respectively. Therefore, microwave treatment millet has the advantages of being a quick, dependable, effective, safe, and environmentally friendly method of food processing (Almaiman *et al.* 2021).

2. Infrared Technology

IR is one of the nonthermal preservation techniques that has had a substantial impact in reducing grain spoilage. This is effective in preventing germination and extending shelf of millet grain. In the technology the grains typically undergo IR treatment in a bulk or packed system under carefully monitored dosage settings. The phenolic content of pearl millet, proso millet, and finger millet showed outstanding nutritional profiles in the 2.5 kGy doses, and the concentration of 2,2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH) was increased from 42.77%-72.65%. As a result, IR dosages have a good impact on millets' antioxidant properties and shelf life (Wani *et al.* 2021). The finger millet treated with 10 kGy of IR dose it shows a trend towards decreasing antinutrients, bulk density, and swelling index, but it increases the nutrient contents, colour, water absorption and oil absorption capacity in the millet slurry (Gowthamraj *et al.* 2021). Recently, a storage research utilised IR methods to monitor the stability of three dehulled and whole millets (foxtail millet, sorghum, and pearl millet) over 90 days. At 0.50 kGy, the fungal count was not effectively reduced, and at 0.75 kGy or higher, γ-irradiation doses inhibit the proliferation of fungal microorganisms. The study shows that IR is a secure postharvesting treatment for whole and dehulled millet (H. Huang *et al.* 2021).

3. Cold extrusion

Cold extrusion is the method of heating food with a single screw below 100°C. The raw material is heated to a consistent temperature while being hydrated, mixed, and shaped (Shelar & Gaikwad, 2019). The popular cold extruded products are pasta, vermicelli, noodles, flakes, and extruded rice etc. The amylose content of the proso millet pasta is almost 20%, which may be advantageous for the production of gluten-free pasta due to its ability to gel and its high cold paste consistency. Also, when compared to market samples, the proso millet pasta exhibits significant development of carotenoids, slow digestion of starch, and low total soluble solids loss (Cordelino *et al.* 2019). The vermicelli prepared from barnyard shows fair amount of beta carotene (1039 µg/100g) and iron (3.81 mg/100g) (Goel *et al.* 2021). The pasta prepared from 10% and 15% fermented little millet was more acceptable then market secure good sensory score (Khwairakpam *et al.* 2020). Kodo millet pasta had iron, zinc, and calcium levels of 1.55, 2.35, and 28.65 mg/100, respectively, and had a 4.5-month shelf life. Compared to conventional cold extruded products, millet-based cold extruded products have a better nutritional profile (Sarojani *et al.* 2021).

Millet-Based Food Products

1. Flour/Composite Flour

One of the most common traditional forms of millet for human consumption is as flour. It can be taken as millet flour alone or combined with other common types of flour in the right proportions. To achieve the appropriate physicochemical, nutritional, and functional characteristics in the flour, different flours are blended specifically. In light of this, substituting wheat flour with other grains such as finger millet, proso millet, or barnyard millet with respective percentages of 20%, 10%, and 15% proved possible. The amount of millet flour added to the mixture increases the ash content while decreasing the protein, gluten value, volume of the dough loaf, and damaged starch percentage (Kaur & Singh, 2005).

The incorporation of millet flour blend was also found to improve the quality of composite flour containing kodo and barnyard millet flour, whole wheat flour and defatted soy flour in terms of increasing nutrient density, thinner gruel by lowered viscosity, and an increase in the level of syneresis that may improve the resistant starch content on storage (Vijayakumar & Beryl, 2009). The effect of replacement of wheat flour with 0%, 20%, 40%, 60%, 80%, and 100% finger millet flour, 60% finger millet flour, emulsifiers and hydrocolloids on the batter microscopy, rheology, and quality characteristics of muffins were also studied. Use of a combination of additives in muffins with 60% finger millet flour significantly improved the volume and quality characteristics of muffins (Rajiv *et al.* 2011). The chapatti prepared from pearl millet flour (40%) and pregelatinized starch (2%) decreased water absorption, and dough development time from 56 % to 50 % and 2.7 min. to 1.5 min respectively showed excellent textural hardness and sensory characteristics (Nasir *et al.* 2021). The composite flour including 85% pearl millet flour as well as kidney bean and tigernut flours could be a feasible substitute for 100% wheat flour in the production of bread (Awolu, 2017).

2. Bakery Products

The majority of products that are baked are made with grain flours and other ingredients. Different kinds of millets were used to prepare well-known bakery products like biscuits, cakes, and cookies. It consist of low gluten content and high dietary fibre, these millet-based baking and confectionery food products are becoming more and more well-known every day. Due to the low gluten content in most millets, it must be added in various amounts, ranging from 10% to 50%, to standardise products like bread (20%), cake (30%), cookies (50%), soup sticks (20%), and khari (40%), which are all made with refined wheat flour. Furthermore, addition of millets in baked products made them more superior in nutritional value, fiber content, and various micronutrients (Patel, 2013).

3. Extruded Products

It is a high-temperature, short cooking method in which flour of grains are put into an extruder, a device used for extrusion. The equipment is kept at the proper setting for feed rate, temperature, residence time, and pressure. With variable flour compositions, feed rates, cooking temperatures, cooking pressures, and residence times throughout the cooking process, a variety of different varieties and different attributes of millet-based extruded products can be prepared.

Table 5: The Traditional and innovations food products of millets and their pysicochemical characteristics

Sl. No.	Millet	Product Name	Result	Reference
1	Proso millet	Gluten-free cup cake	• The incorporation of 75% of proso millet to development of the cake • improvements in volume, color, taste, and texture	(Fathi *et al.* 2016)
2	Foxtail millet	Foxtail millet gels	• The addition of $FeSO_4$ and $CaCl_2$ boosted the formation of foxtail millet gel, and a slight change due to NaCl was found. • The acceptability of foxtail millet gels can be improved by combining 11% foxtail millet flour, 0.2% $FeSO_4$, or 0.5% $CaCl_2$ to produce good gels	(Nagaprabha & Bhattacharya, 2016)
3	Foxtail millet	Instant upma mix	• The combination of 5% soy grits, 20% wheat semolina, and 75% foxtail millet • The sample contains 11.20%–12.90% protein, 6.38%–8.14% fat, 1.15%–7.47% fiber, 59.87%–70.16% carbohydrates, and 245.62–256.90 Kcal/100 g energy value.	(Dhumketi *et al.* 2017)
4	Kodo millet and little millet	Cookies	• Both grains were pre-processed using soaking (18 h), fermentation (30 h), and malting • cookies developed by combination of 35:35 (KM:LM) • Kept the cookies stable for 60 days	(Himabindu, 2017)
5	Little millet	Extruded product	• Prepared from little millet; rice; and maize in the ratios of 10:45:45. • It has protein levels (3.25%–4.38%), fiber values (1.05%–2.88%), fat content (0.82%– 0.17%), hardness (0.11–0.24 N), ash content (0.75%– 1.45%), moisture content (4.45%–5.70%) and reduced the calorific value (378.98%–365.73%), and expansion ratio (4.01–2.63)	(Saini & Yadav, 2018)
6	Foxtail millet	Millet Milk	• millet milk extraction was found after 18 h of millet germination and 8 h of soaking.	(Sheela *et al.* 2018)
7	Foxtail millet	Dosa mix	• 12 h of fermentation was ideal for making foxtail millet dosa	(Harichandana *et al.* 2021)

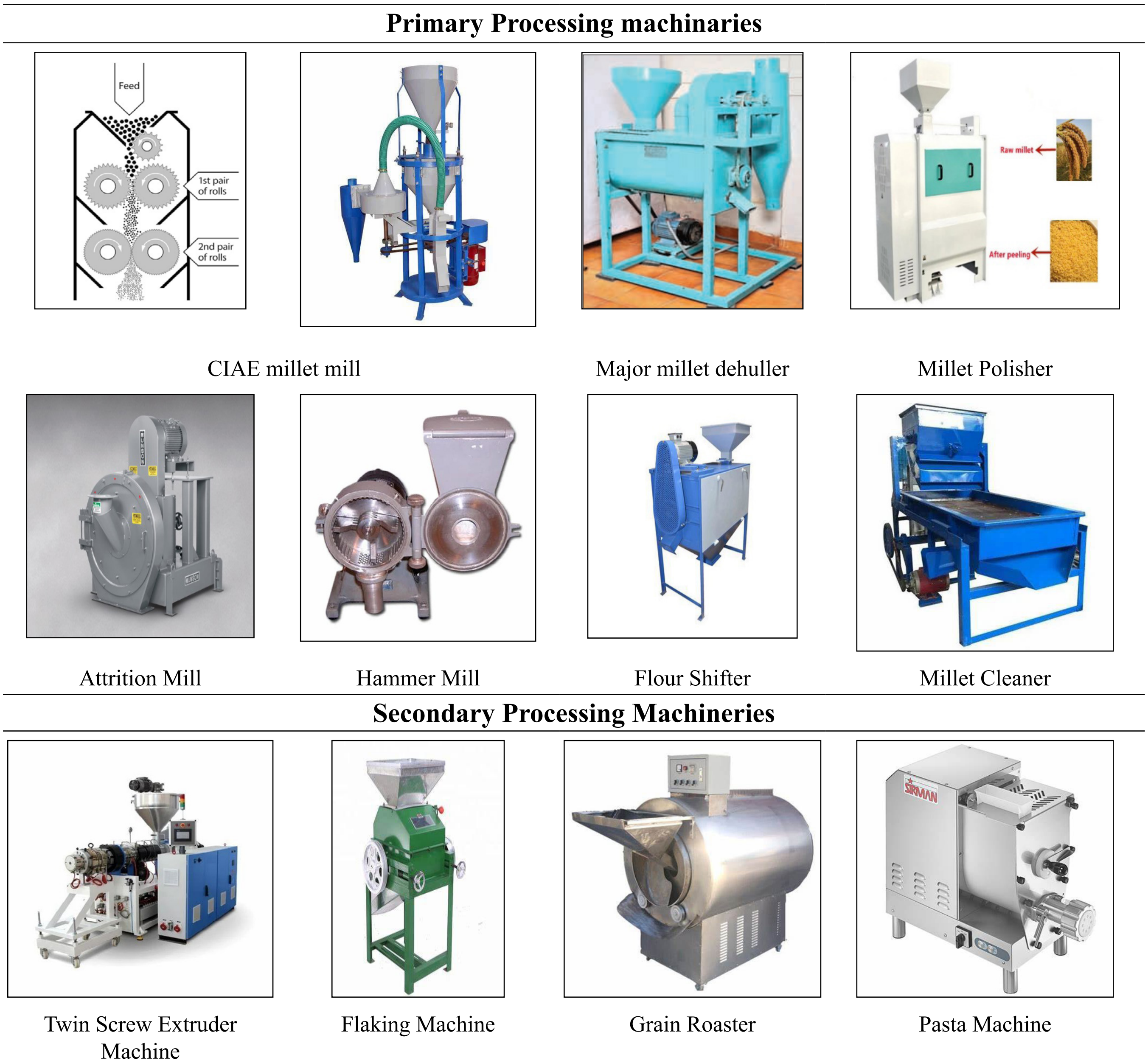


Fig. 2: Primary and secondary processing machineries for millet

Machineries used for Millet Processing

Millets are a low-value, small-seeded crop so that many times improperly cleaned, graded, and dried before being sold, resulting in low prices in market and also difficult to store at safe level. The main obstacles to the broad consumption of these crops and the acceptance of their food products are the presence of hard pericarp, dark colour, some anti-nutrients, and a lack of availability of secondary processing equipment's. The availability of rice, wheat, or sorghum, the use of these millets in household consumption has been discouraged by the laborious post-harvest activities as well as changes in lifestyle in rural regions. Therefore, by developing simple to use primary millet processing technology, drudgery in millet processing might be minimised. Dehulling, destoning, cleaning, grading, milling, and sifting are the unit activities used in millets' primary processing. The different machineries used for primary and secondary millet processing are shown in Fig. 2.

1. Destoner for millet: This device removes stones and other contaminants from millet grains. The machine consists of a 450 × 800 mm perforated dimple sheet deck of sieve for fluidization and effective separation, an aspirator with centrifugal blower for removing light weight impurities, and an oscillating sieve box made of wood, 700 × 1000 mm in size to hold two sieves with sieve changing provisions.

2. Millet mill: The mill is a device used to remove the outer husk from little millets. A single phase electric motor could power it. Dehusking is done with the help of two abrasive rollers which are adjustable. The unhusked millets are fed through a hopper which fall between abrasive plates due to centrifugal force. Then, through a bottom outlet, the dehulled grains are collected. A cyclone separator is used to gather the dust and husk particles. The CIAE, Bhopal developed an eco friendly millet mill called "CIAE, Millet Mill" which is having pneumatic suction system. Due to that the husk is separated from the dehulled mass while during dehulling process of millets. This unit is having primary shaft speed of 960 rpm (for dehulling) and a blower shaft speed of 1920 rpm, it is a power-operated (1 HP, single phase) motor (for pneumatic suction). It can process all minor millets at a rate of 100 kg/h at 10-12% mc (wb). The machine dimensions are 860 mm × 842 mm × 1460 mm and the average co-efficient of dehulling for all millet are between 70 and 85%. This machine can able to handle all types of minor millets irrespective of their sizes and shapes. However, the effectiveness of this machine is dependent on the uniformity, size and moisture content of the millet grains (Balasubramanian *et al.* 2020).

Technically, there are three types of decortication techniques that can be employed to minor millets.

1. *Abrasive decorticators:* The fibrous pericarp is abraded away by abrasive decorticators. Abrasive decortication would be an effective method of removing the pericarp if all components of the grains could be removed at the same rate. Even when a grain is only gently abraded, however, different portions of the grain wear away at varying rates, and some endosperm is lost (especially from broken grains).
2. *Rubbing method:* In this method, the grain mass is rotated within a cylindrical chamber to accomplish decortication. When the grain is correctly tempered, the movement of one seed against another rubs off the pericarp. However, when the grain is very dry, the mill's interior parts are severely abraded. The endosperm particles are ground in a specialised mill after the hulls and endosperm pieces are separated in a cyclone.
3. *Metal friction machines:* Attrition mills are employed in these metal-friction devices. Particles often become smaller by attrition when their corners or surface irregularities are knocked off. These type of machinaries used very limited extend at commercial level (Chandi & Annor, 2016).

3. Grain polisher: The millets are dehusked and polished using a cone polisher, a centrifugal rice sheller, and a rice polisher. Barnyard millet can be polished in rice polisher. The best degree of polishing can be achieved at 10% (db) moisture content for 3 min of milling period. The protein, fat, ash, and fibre concentrations decrease in accordance with the rise in moisture and milling time during polishing (Lohani *et al.* 2012).

Grinder/Pulveriser

Hammer mills, burr mills, and plate or disc mills are the mills used to grind small millets. The minor millets do not undergo wet milling. Semiwet or dry milling processes are used for the majority of minor millet processing. The simplest and least expensive mills used to reduce the decorticated grains' particle size are hammer mills. Depending on the volume of

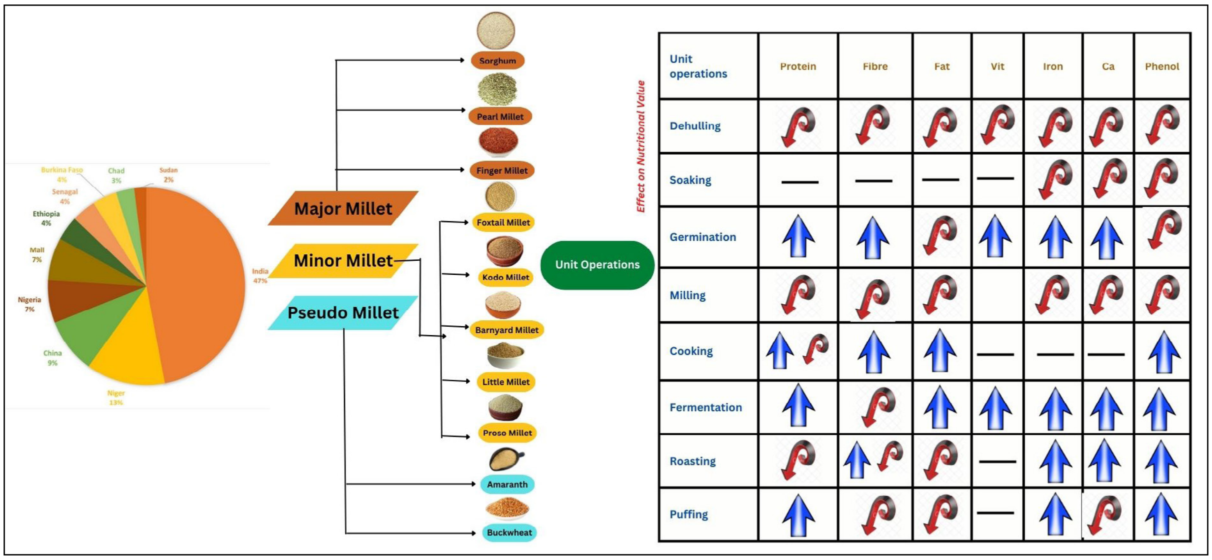


Fig. 3: Graphical Representation of Millet Processing

processes, these mills come in a variety of sizes. They are made up of rotors with hammers mounted on them that spin quickly inside of casings. A screen that controls the flour's particle size is placed above the outlet. Caking of the flour and a decrease in process throughput are caused by overheating and moisture develop during the hammer milling process. Millets are rarely milled by using roller which is suitable for wheat milling. The distribution of particle size of flour and the presence of damaged starch in cereals determine the functional quality of flours. Unfortunately, little research has been done to assess how different milling techniques have affected the functional property of millet flours. Also, there seems to be a distinction between the flour made using a traditional wooden pestle and mortar and that made using mechanical means. The traditional one appears to have superior nutritional characteristics.

The largest issue to developing a dehulling and milling equipment are that can produce flour of a standard quality. It is critical to recognise that some effort has been put forth in this direction. The continued demand for millet-based products and the continuous supply of products with properly harvested and well-stored millet grains are both essential to the industry's expansion.

5. Flour sifter: The grounded flour is sieved or sifted into two grades using flour sifter. It has stainless steel mesh with a 40 micron mesh size (ISS 40, ISS 70, and ISS 100), as well as provisions for easy removal and fastening of sieves and covers to prevent spiling of feed and product. The outlet for the fine and course materials provided at the proper height.

Challenges of millet processing

Millet processing can have several limitations. The equipment required for millet processing can be expensive, making it difficult for small-scale farmers or processors to access. Millet processing often requires specialized infrastructure and facilities, which are not widely available in some regions, particularly in rural areas. The supply chain for millet can be limited, with a lack of available storage and transportation facilities, making it challenging to distribute millet products. Maintaining consistent quality control can be a challenge in millet processing, as it is susceptible to insect infestation, moisture damage, and fungal contamination. Fig.3 represents the graphical representation of Millet processing.

Despite its potential health benefits, millet still faces limited market demand, especially compared to more widely consumed grains like wheat, rice, and maize. Millet processing can also face competition from subsidized grains like wheat and maize, making it difficult to compete in terms of price and market share. The technology used in millet processing may be outdated or not well-suited to the needs of the industry, making it difficult to produce high-quality products in large quantities. Process flows and processing equipment for small scales have been developed. But there are major intrinsic differences in the properties of the harvested grains. When the little millets are combined for processing, this issue gets worse. In that regard, small-scale processing has a slight improvement. However, a major obstacle to producing millet of high quality, i.e., clean little millet rices with little bran loss, is the lack of experienced workers who are knowledgeable about the grains and skilled in operating the necessary equipment. When the seed coat is partially or completely peeled off, the millet kernels' endosperm crumbles to fine grits, consisting primarily of a floury component. Due of these textural peculiarities, attempts to decorticate the millet using conventional methods for milling cereals, such as abrasion or friction mills, or by using alternative dehulling techniques, have not been successful to yet. As a result, wholemeal is utilised to produce processed products and millet is always ground into flour. Therefore, the limitations include a lack of knowledge and familiarity, difficulties in preparation of processed products, the sensory characteristics of millets, their high cost, a negative reputation among consumers, and a prolonged gestational cycle (Shah *et al.* 2023).

CONCLUSION

Millets are an important group of cereals with significant nutritional value. They have a rich composition of essential micronutrients and dietary fibers. Processing of millets affects their nutritional quality to a certain extent, but it also improves their functional properties, making them suitable for various food applications. It is important to implement appropriate processing techniques that can retain their nutrient content and enhance their functional properties. The consumption of millets can contribute to a balanced diet and help in addressing the global problem of malnutrition. Hence, promoting millet consumption and improving processing technologies can play a crucial role in improving the overall health and nutrition of the population.

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