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Nutritional significance of finger millet and its potential for using in functional products

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Abstract:
Finger millet (*Eleusine coracana* L.), ragi or mandua, is one of essential minor millets extensively grown in the Indian and African subcontinents. It is a staple food in India, particularly for people belonging to low-socioeconomic groups. Finger millet is highly valued for its content of macro- and micronutrients. It is rich in carbohydrates, protein, and fat. Its micronutrients include calcium (0.38%), dietary fiber (18%), and phenolic compounds (0.3–3%), such as catechin, epicatechin, as well as ferulic, salicylic, protocatechuic, cinnamic, and hydroxybenzoic acids, etc. Finger millet is also recognized as a source of vital amino acids, including isoleucine, leucine, methionine, and phenylalanine, which are otherwise deficient in starchy meals. In addition, finger millet is well appreciated for its pharmacological properties such as anti-diabetic, anti-tumorigenic, anti-atherosclerogenic, antioxidant, and antimicrobial effects. To improve its nutritional and sensory properties, this grain can be processed by various traditional and advanced methods (soaking, malting, cooking, fermentation, popping, and radiation). These processing techniques equally assist in the reduction of anti-nutritional factors (tannins, phytic acid, oxalic acid, protein inhibitors, glucans) and their inhibitory effects. In this review, we highlighted the nutritional composition, health attributes, and uses of finger millet for the development of functional food products.
Researchers and producers can further explore the opportunities and scope for utilizing finger millet and develop more products in the same line to solve the current issues of food and nutrition security.

Keywords: Finger millet, cultivation, nutritional composition, health benefits, processing, fortification

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INTRODUCTION

Millet is a minor cereal belonging to the *Poaceae* grass family that is well known in India as ragi or mandua [1]. Cultivated in arid and sub-arid regions, it is considered a poor people's food [2, 3]. Since time immemorial, millets have been a well-known food for humans but in recent years they have been replaced by wheat and rice [4]. Globally, annual millet production amounts to 30.73 million tons, including 11.42 million tones (37% of the global yield) in India alone. India and Africa are the leading producers of finger millet, followed by Uganda, Nepal, and China [4]. India is one of the largest cultivators of millets, especially finger millet (*Eleusine coracana* L.), which accounts for about 85% of all minor millets [5]. Karnataka is the leading state that cultivates 58% of total finger millet production in India [6].

Finger millet is well recognized for its high nutritional profile, including protein (6–13%), calcium (0.34%), dietary fiber (18%), phenolic compounds (0.3–3%), and minerals (2.5–3.5%). In addition, it is a good source of a vitamin B complex (thiamine and riboflavin), as well as essential amino acids (methionine, isoleucine, leucine, phenylalanine, etc.) [1, 7–10]. Finger millet contains 30 times as much calcium as rice, namely 344 mg/100 g, which plays a positive role in bone development and maintenance, as well as in the functioning of nerves and muscles [4, 11, 12]. According to studies, finger millet possesses various medicinal and nutritional proties. It is well known for its biological properties (antitumorigenic, anti-atherosclerogenic, anti-diabetic, antioxidant, and antimicrobial) mainly due to polyphenols and dietary fiber [13, 14]. Also, finger millet prevents oxidation of low-density lipoproteins, hypertension, hypercholesterolemia, and diabetes mellitus, as well as improves gastrointestinal tract functioning and vascular fragility [8, 15]. Being an aboriginal crop, minor millet is utilized in formulations of geriatric and weaning foods, as well as health foods both in natural and malted forms [16]. Malted finger millet flour can be used to prepare bread, papad, chips, chapatti, bakery products, porridge, chakli, idli, biscuits, cookies, and beer, as well as gruel for new-born babies [17, 18]. Our review highlights various aspects of finger millet, including its nutritional composition, various effects of processing, as well as its utilization for the development of functional products.

STUDY OBJECTS AND METHODS

For this review, we searched for publications in Google Scholar, ResearchGate, ScienceDirect, and PubMed. Synonyms and alternative words were identified and used to obtain current literature in English. Our major search terms and key words were "millets", "millet phytochemicals", "major bioactive compounds in finger millets", "health benefits of millets bioactive compounds", "finger millet processing", and "finger millet products". Most of the research articles mentioned in the manuscript are recent and published between 2012–2019.

RESULTS AND DISCUSSION

Cultivation of finger millet. In Nepal and India, finger millet is grown on 274 350 hectares of land, yielding 305 588 million tons with an average productivity of 1115 kg/ha, as a kharif and rain-fed crop on marginal lands and in hilly regions. Finger millet is primarily farmed in Africa, widely in Uganda, Kenya, and Tanzania, as well as in Ethiopia, Eritrea, Mozambique, Rwanda, Malawi, Sudan, Namibia, Senegal, Niger, Nigeria, Madagascar, Zambia, Zimbabwe (to a minimal degree), and India [19]. India, as a leading producer, cultivates 1.98 million tons of finger millet on 1.19 million hectares of land, with a productivity of 1661 kg/ha [20].

In Asia, the major cultivators are India, Nepal, Malaysia, China, Japan, Iran, Afghanistan, and Sri Lanka [21, 22]. In the eastern, central, and western parts of India (Uttar Pradesh, Bihar, Tamil Nadu, Karnataka, and Andhra Pradesh), this crop is cycled along with maize in a mixed cropping system. In the mid and far western regions, however, it is monocultured [23].

Finger millet is highly tolerant to biotic and abiotic stimuli and is highly adaptable to the local climate. It can adapt to harsh weather conditions, requiring minimum inputs, and has higher nutritional characteristics when grown in desert environments [24, 25]. Scientific emphasis has been placed on the crop's capacity to grow in warm altitudes, on soils with minimal moisture and low fertility [26]. Finger millet is a short plant that needs a minimum day duration of around 12 h and flourishes at higher elevations, where other major grains fail to survive. It can grow between 500 and 2400 m above sea level. On average, it demands 500 mm of yearly rainfall, but it can also withstand 300–4000 mm of precipitation. The crop performs best in the tropical regions of India and Africa, where the average maximum temperature approaches 27°C and the average minimum temperature does not drop below 18°C. Dry weather encourages the harvest of healthy grains at maturity, whereas rainy weather causes grain blackening. Finger millet prefers climates where the average temperature ranges from 11 to 28°C, although it can also tolerate higher temperatures [20]. The crop is grown from sea level to higher elevations in the Himalayas, up to 2400 m above sea level [27].

Finger millet is a desirable crop in an intensive cropping system since it requires less time to grow and can be farmed in all seasons. The seeds have a long lifespan (more than five years) and are resistant to storage pests, which makes them an excellent reserve for food security crisis periods [28]. Finger millet grows well in a wide range of soils, including red lateritic soil, mixed grey soil, and unaltered soils with coarse parent materials. In the tropics, it is typically grown in reddish-brown lateritic soils which require proper drainage [29]. However, the crop is more prevalent in sandy loam textured soils where it receives evenly distributed rainfall.

Finger millet is a drought-resistant and weather-tolerable crop due to its efficient C4 photosynthetic pathway [28, 30, 31]. It is cultivated in abundance in the Koraput district of Odisha, accounting for 16% of the total gross cropped area and 28% of the total area under cereal crop cultivation. In Koraput, it thrives in temperatures ranging from 14 to 40°C, with an annual average rainfall of 1320–1520 mm. In this district, tribal groups mostly farm local finger millet land races, such as telugu mandia, dasara mandia, san mandia, and bada mandia by adopting traditional agronomic ways. Finger millet can also resist slight moisture stress, though too much dampness or stagnant water would limit its growth and yield potential. It also declines the growth of weeds and resists numerous diseases [32]. In addition, finger millet appears to be more capable of using rock phosphate than other grains [33].

Nutritional composition of finger millet. Finger millet is well known for its high contents of calcium, dietary fiber, and phenolic compounds [8]. It is also a good source of carbohydrates, proteins, vitamins, and iron [34]. Chandra *et al.* compared the nutritional composition of finger millet, wheat, maize, sorghum, and rice [1]. They found that finger millet was superior to the other cereals with respect to dietary fiber, calcium, and some micronutrients. The husk of finger millet is a rich source of phenolic compounds, minerals, and dietary fiber [35]. The nutritional profile of finger millet is presented in Table 1.

Carbohydrates. The total carbohydrate content of finger millet has been reported to be in the range of 72–79.5%, consisting of free sugars (1.04%), starch (65.5%), and non-starchy polysaccharides or dietary fiber (11.5%) [40]. The dietary fiber content is much higher in finger millet (11.5%) than in brown rice, polished rice, and all other millets, namely foxtail, little, kodo, and barnyard millet. The carbohydrate content of finger millet is comparable to that of wheat but lower than that of polished rice. However, the starch content of finger millet is lower in amylose (16%) than that of the other millets. Also, finger millet starch has the highest set back viscosity (560 BU) followed by cooling which further favors retrogradation [3].

Protein. According to Ambre *et al.*, the protein content of finger millet depends on its varieties and ranges from 5 to 12% [16]. Swami *et al.* had malted finger millet for 8, 12, 16, 20, and 24 h and reported that longer germination times led to higher protein contents (14–17.5%) [41]. By induced hydrolytic activity, the germination of finger millet seeds increased the nutritional value [42]. Finger millet is a rich source of amino acids, including methionine (3.1 g), isoleucine (4.4 g), leucine (9.5 g), and phenylalanine (5.2 g) [43]. Of all amino acids present in finger millet, 44.7% are essential, such as methionine and tryptophan. Their content is higher than the required 33.9% of essential amino acids in the FAO's reference protein [16].

Table 1 Nutritional components of finger millet

Constituents	Amount	References
Moisture, g/100 g	7.15–13.1	[36]
Carbohydrate, g/100 g	72.6–83.3	[8, 36]
Protein, g/100 g	6.0–8.2	[24, 37]
Lipid, g/100 g	1.8–3.5	[36, 38]
Dietary fiber, g/100 g	15.0–22.0	[24, 36]
Minerals, mg/100 g:		
Calcium	220–398	[7, 24, 36, 39]
Phosphorous	130–250	
Sodium	49	
Potassium	430–490	
Magnesium	78–201	
Iron	3.30–14.89	
Manganese	17.61–48.43	
Zinc	2.3	
Vitamins, mg/100 g		
Retinol	6.0	[3, 24, 36]
Thiamine	0.20–0.48	
Riboflavin	0.12–0.19	
Niacin	1.00–1.30	
Ascorbic acid	1.0	
Amino acids, g/100 g:		
Isoleucine	4.4	[7, 24, 36, 37]
Leucine	6.6–9.5	
Methionine	2.5–3.1	
Phenylalanine	4.1–5.2	
Valine	4.9–6.6	
Threonine	3.4–4.2	
Lysine	2.2	
Tryptophan	1.1–1.5	
Fatty acids, %		
Oleic acid	49	[14]
Linoleic acid	25	
Palmitic acid	25	

Finger millet is mainly valued for its content of methionine, which is lacking in the diets of millions of poor people who mainly depend on starchy staples along with cassava, plantain, polished rice, or maize meals [44]. Finger millet's protein composition looks comparatively well-balanced because it has more lysine, threonine, and valine than other millet grains.

Minerals. Among all cereals and millets, finger millet comprises the highest calcium and potassium amounts of 344 and 408 mg, respectively [3]. Singh and Raghuvanshi reported a huge variation in the mineral content of finger millet, depending mainly on genetic factors and environmental conditions [45]. Yet, the importance of minerals in human nutrition cannot be overestimated [11].

Lipids. Kumar *et al.* reported that the lipid content in millets is comparable to that of wheat and rice (2.0 and 2.7%, respectively) and ranges from 1.43 to 6.0 g/100 g [38]. Finger millet lipids carry 70–72% of neutral lipids (primarily triglycerides and traces of sterols), 10–12% of glycolipids, 5–6% of phospholipids, 46–62% of oleic acid, 8–27% of linoleic acid, 20–35% of palmitic acid, and traces of linolenic acid. Finger millet has the lowest lipid content among all varieties. This could be one of the major factors contributing to its long-life properties, compared to other varieties [3].

Vitamins. Micronutrients present in finger millet, including vitamins, are required for the typical development and self-maintenance of human body. Vitamins are divided into two major groups, fat-soluble and water-soluble [13]. Most of the probiotic food consists of fatty acids, vitamins, and other vital nutrients that enhance the body's resistance against pathogenic microorganisms [2]. Thapliyal and Singh stated that the fermentation of finger millet enhances the concentration of vitamins, including riboflavin (0.60 mg/100 g), pantothenic acid (1.6 mg/100 g), and niacin (4.2 mg/100 g) [8].

Anti-nutrients. Being a good source of vital nutrients, finger millet also comprises several antinutritional factors that significantly affect its nutritional value. They lead to poor digestion of proteins and a low bioavailability of carbohydrates and minerals such as calcium, iron and, copper. Major antinutritional factors present in finger millet include tannins, polyphenols, flavonoids, HCN, phytates, oxalic acid, digestive enzyme inhibitors (amylase inhibitor function, trypsin inhibitory activity), and goitrogens [40, 46].

Phytates and tannins are two major anti-nutrients that reduce the bioavailability of vital nutrients, which can be eliminated by employing food processing methods such as fermentation and germination. Kumari *et al.* reported that non-processed brown finger millet had a higher radical quenching activity than the processed one and postulated that tannins and phytic acid were responsible for the activity [12, 47]. The seed coat of finger millet contains quite a few phytochemicals which might also have health benefits [3]. The brown variety of finger millet was found to exhibit the highest level of phenolic compounds, compared to other varieties [3].

Health benefits of finger millet. Finger millet is well known for its health-beneficial properties, such as hypoglycemic effects, as well as antioxidant and antimicrobial activities [48]. Kumari *et al.* reported that the non-processed brown finger millet had a higher radical quenching activity than the processed one due to tannins and phytic acid [12, 47]. Apart from that, finger millets exhibit several health-beneficial effects. In particular, they lower glucose and cholesterol levels and have neuro-protective, antioxidant, wound-healing, and anti-cataractogenesis properties [35]. Tatala *et al.* reported an improved status of hemoglobin in children who were given finger millet-based food [49]. As it is a gluten-free grain, it is highly beneficial for those who are suffering from celiac disease [43]. Lee *et al.* found that finger millet may prevent the risk of cardiovascular diseases by reducing the plasma triglycerides levels in hyperlipidemic rats [50].

Effects of processing on finger millet. Finger millet is pulverized in order to prepare food products, such as roti, kazhi, and kanji with health-promoting properties [3]. Table 2 illustrates the effects of different processing methods on the functional and nutritional qualities of finger millet. Figure 1 represents various processing methods for developing functional products from finger millets. A brief account of processing methods and quality characteristics is given below.

Soaking. Soaking is a process where finger millet grains are steeped in distilled water overnight at a room temperature of about 30–60°C, followed by the discarding of the water and cleaning of finger millet grains thoroughly by using clean water to remove unwanted particles. Afterwards, they are dried and then milled at 60°C for 90 min to reduce the moisture content [42, 59]. During the soaking, the water needs to be changed once or twice in order to prevent the excessive growth of microorganisms [51]. Rajasekhar *et al.* reported that after soaking, finger millet had an increase in true density, porosity, hardness and angle of repose, as well as a decrease in longitudinal and lateral diameter, sphericity, surface area, 1000 kernel weight, bulk density, color (L^*, a^*, b^*), and terminal velocity [60]. Ocheme and Chinma observed a slight increase in protein, ash, dry matter, water absorption capacity, hygroscopicity, and swelling ability of millet flour resulting from soaking and germination, as well as a decrease in fat, phytic acid, gelation capacity, and viscosity [61].

Milling or grinding. Generally, finger millet is pulverized to obtain flour for food products. Firstly, finger millet it cleaned to remove foreign particles, such as stalks, stones, chaffs, etc. Then, it is passed through abrasive or friction mills to remove the non-edible cellulose tissue. Sometimes, decortication or pearling are also used to dehusk the finger millet grain [14]. During the milling process, grains undergo different operations

Table 2 Effects of processing on finger millet

Processing	Effects	References
Soaking	Enhances the bioavailability of minerals, improves digestibility, nutritional value and sensory attributes	[51, 52]
Milling or grinding	Influences the yield by separating out glumes (non-edible cellulosic tissue) Leads to the loss of fiber and phytochemicals when grain is milled to obtain flour	[1] [46]
Popping or puffing	Improves the nutritional value by inactivating some of the anti-nutritional factors Enhances aroma (due to the Maillard reaction), color, taste, and appearance of processed raw materials	[13, 51]
Malting	Improves digestibility, lowers down anti-nutrients, and enhances nutritional value	[53]
Cooking	Enhances soluble phenolic acids and inactivates heat-labile anti-nutritional factors Makes food more palatable, safe, and suitable for consumption	[54, 55]
Fermentation	Reduces anti-nutritional factors, leads to biochemical changes, decreases pH, and increase total sugar Helps preserve food products	[2, 51]
Drying	Increases protein content, digestibility, bioavailable micronutrients, desired moisture content, and color retention	[18]
Roasting	Increases the bio-availability of minerals like calcium and iron Increases the shelf life of food	[8, 9]
Decortication/Dehulling	Reduces polyphenolic pigments and phytate content Decreases the total mineral content but increases the bio-accessibility of calcium, iron, and zinc	[17, 56]
Extrusion	Modifies texture and other physical properties, gelatinization of starch and denaturation of protein, starch fragmentation	[57]

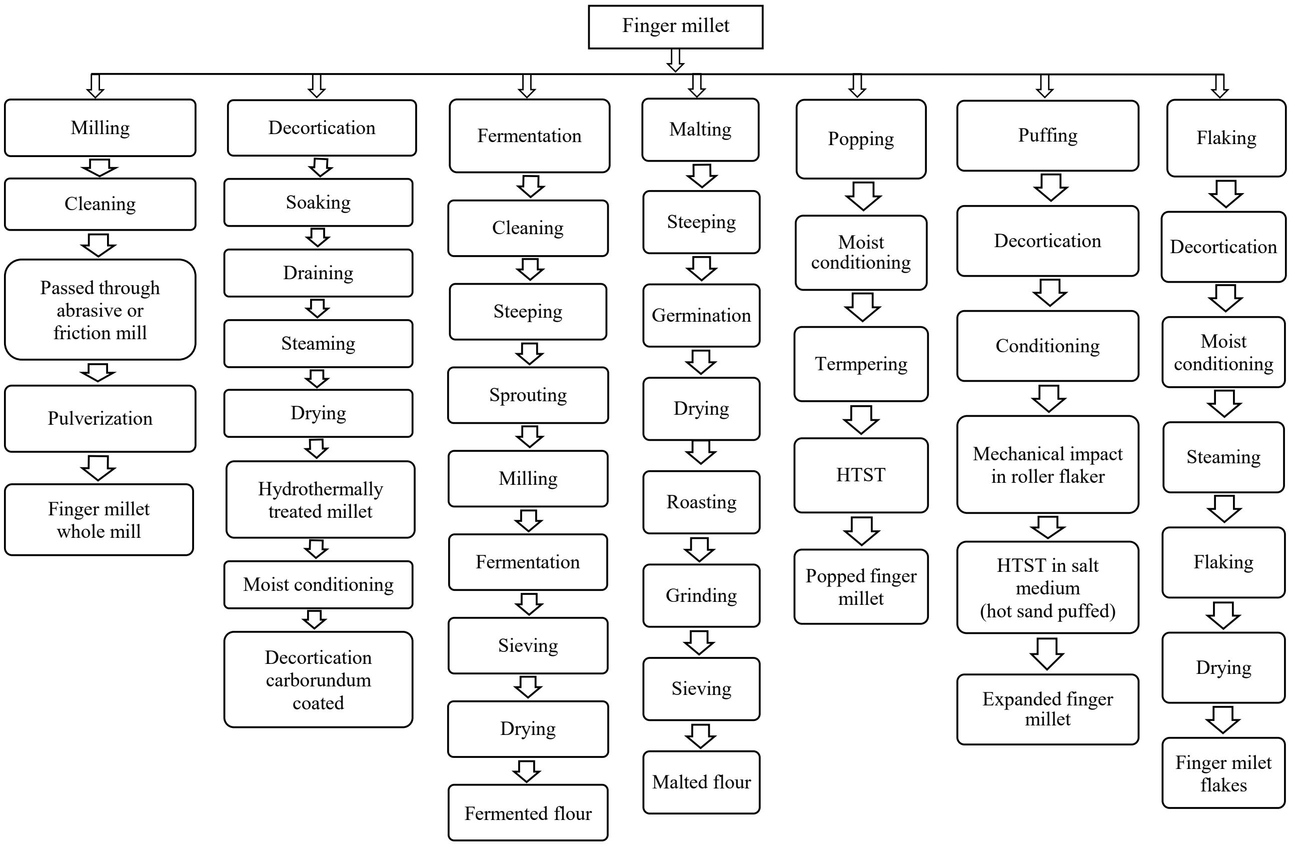

Figure 1 Processing techniques for finger millet products [3, 14, 58]

such as cleaning, sorting, hulling, branning, and kilning [62]. About 10% of water is added to help the removal of fibrous husk. Generally, milling is used to remove the fibrous bran or the seed coat of millet grains. During this process, some phytochemicals like tannins and phytates become lower, enhancing the bioavailability of iron [45]. Finger millet is usually milled by roller or hammer mills, while a centrifugal sheller can also be used to dehull/decorticate small millets. There is no uniformity in the size of particles when milling in a hammer mill, so it is not suitable for the preparation of stiff and thin porridge with rough texture. However, it can be used to prepare baked or smooth-textured foods [63].

Popping or puffing. Popping is a process where starch is gelatinized and expanded. For this, finger millet grains are kept at high temperature for a short time, which results in vapor production and expansion of endosperm [64]. This technique can also reduce antinutritional factors in finger millet. In addition, it is less expensive and easy to use [40]. Both popping and puffing are the oldest traditional methods of cooking grains. The popping of finger millet grains inactivates some antinutrients and enhances protein and carbohydrate digestibility (Table 2). Popped millets also have improved color, taste, appearance, and aroma. For puffing, extra water is added during the conditioning process to increase moisture up to the limit of 18–20%, which is then kept for 4–6 h under normal temperature. After conditioning, the puffing process is carried out by agitation on a hot sand layer at about 230–250°C for a short time. A highly desired aroma develops in the millet due to the sugar present in the aleurone layer from the reaction with amino acids that causes the Maillard reaction. Modern air puffing machines can be the best solution for sand particles sticking to the product [51].

There are various types of popping and puffing methods, including sand and salt treatment, hot air popping, gun puffing, popping in hot oil, conventional method, and microwave heating [64]. A decrease in the calcium content and an increase in the iron content have been observed during the popping of finger millet, whereas the amount of anti-nutritional factors, such as trypsin inhibitor and oxalic acid, decreased gradually. Thus, popping of finger millet results in lowered anti-nutritional factors and increased nutritional content [65].

Malting. Shahidi and Chandrasekara reported changes in the composition of free and bound polyphenol contents in the malted finger millet [43]. Malting can gradually help lower anti-nutritional factors, as well as enhance the nutrient content [38, 53]. Sprouting of finger millets at 30°C for 48 h improves protein digestibility and reduces oxalate, phytic acid, and tannin contents by 45, 46, and 29%, respectively. Germination is a traditional process in which dehusked grains are steeped in distilled water for 2–24 h and then incubated at 30°C for 48 h [59].

In a study by Hithamani and Srinivasan, finger millet grains were soaked overnight in distilled water [66]. On the following day, the grains were removed from water and kept under normal temperature for 48 h, with water sprayed over them perodically. The germination process is stopped by drying the germinated grain in a hot-air oven. The drying time and temperature play an important role because they not only affect enzymatic activity but also help in developing the color and flavor of compounds [67]. Kumar *et al.* reported that malting enhanced the bio accessibility of iron and manganese in millet by 300 and 17%, respectively [38]. Malting increases the nutrient content by inducing hydrolytic activity. Banusha and Vasantharuba reported that malting gradually increased the reducing sugar and free amino acid contents [42].

Germination of finger millets, which has been used for hundreds of years, helps soften the kernel structure and enhance nutrient contents. It also increases the contents of vitamins, minerals, essential amino acids, and carbohydrates, thus enhancing the useful optical properties of the grains [68]. Malting of finger millet increases the vitamin C content, phosphorus availability, as well as synthesizes lysine and tryptophan [69].

Cooking. Cooking is a processing method which involves boiling of finger millet grains in water until their structure becomes soft. It is the most commonly used traditional method of food processing which aids in reducing anti-nutritional factors (e.g., tannin content by 30%) and also makes the food palatable [54]. Also, cooking decreases the microbial load and thus enhances the sensory properties of cooked grains [34]. Porridge can be prepared by mixing boiled water with flour [18]. Cooking was found to increase the resistant starch content in finger millet, as compared to other processes [3].

Fermentation. As reported by Ilango and Antony, the fermentation of finger millet led to the breakdown of long-chain fatty acids and starch molecules [70]. The pH value dropped by 2.1 units and the contents of lactic and acetic acids rapidly increased by 6.5 and 3.7%, respectively. Also, the total fat content reduced by 42.9%, which helped lower the phytic acid content by 72 and 54% in 96 and 72 h, respectively. Finger millet is a rich source of calcium as it is, but its contents of iron, manganese, and calcium can be further increased by fermentation [71].

Fermentation is more effective than malting in reducing phytic acid since it enhances the chemical and physiological accessibility of micronutrients in the body and reduces anti-nutritional factors such as phytates and tannins. The nutritional value of millet grains becomes higher due to an increase in the bioavailability of nutrients [71]. Fermentation is widely employed all over the world, as it significantly increases the shelf life of food products. Fermented products have more intense sensory characteristics such as aroma, taste, and flavor [63]. It is the most effective and oldest method to increase the shelf life of products, i.e., food preservation [54].

Drying. In a study by Emmambux and Taylor, germinated finger millet was dried at temperature ranging between 40 and 70°C by a fluidized bed dryer [18]. This process increased the protein content, digestibility, and bioavailability of micronutrients. The flour made from dried sprouted finger millet can be utilized to prepare papad, noodles, bread, and several other Indian dishes, such as idli, chakli, and porridge. A decrease in the lightness of finger millet seeds was observed [15]. Finger millet can be dried by bed dryers, drum dryers, and in the sun. In sun drying, which is a traditional method, grains are generally spread and kept under sunlight for a specific period of time. After drying, the grains can be stored in bags for 5–10 years. These grains are highly effective in preventing disease, but they are very small and not easy to handle, which is a major obstacle [52, 72].

Roasting. Roasting of finger millet grains enhances the contents of carbohydrates and ash, increases the bio-availability of minerals (calcium and iron), and reduces moisture, fat, protein, phenols, and antioxidant activity [9]. Roopa and Premavalli reported an increase in resistant starch, which reduced in all the other processing methods [73]. Chandrasekara *et al.* revealed a decrease in the free radical quenching activity during the roasting process [74]. In another study, roasting caused higher total phenolics, protein, and amylose contents, as well as a lower moisture content [75]. The food products from roasted finger millet grains contained the highest amount of resistant starch (3.1%), compared to other products [3]. In India, sand roasting is quite a popular method, which is mainly performed by street vendors to prepare various types of food products [76].

Decortication or dehulling. Before consumption, finger millet grains undergo dehulling and debranning processes which remove large portions of husk and bran [36]. Centrifugal shellers can be used to dehull or decorticate small millets [63].

Extrusion. Extrusion involves the development of a food material using high pressure and mechanical shear [77]. A study by Kumar *et al.* reported a reduction in phytates and tannins during the extrusion cooking or HTST, as well as an increase in the bioavailability of minerals [38]. Another study revealed that the extruded products had high cold paste viscosity, but their cooked paste viscosity was significantly lower [78]. The extruded products exhibited a greater digestibility of protein, but there was no difference in the in-vitro carbohydrate digestibility [77].

Utilization of finger millet in functional products. Finger millet can be used in a variety of ways and it can be a great substitute for other starchy grains such as rice. Nowadays, finger millet is being popularized in India for its functional characteristics [79].

Bakery products. *Cookies.* Abioye *et al.* prepared cookies using blends of wheat flour, germinated finger millet, and African yam bean [80]. The cookies were rich in nutrients and functional characteristics of the flour, but low in anti-nutritional factors. In another study, multigrain cookies were formulated with finger millet and sorghum in various proportions. The cookies containing 60% of fructo-oligosaccharides, 20% of finger millet, and 30% of sorghum showed good acceptability [81]. Sharma *et al.* evaluated the nutritional and sensory characteristics of finger millet-based cookies [82]. The samples with 30 and 50% of finger millet showed good acceptability and had a higher content of fiber and minerals, such as calcium, phosphorus, copper, and zinc. In another study, cookies were prepared from malted finger millet and wheat flour mixture (4:1) where jaggery melted in milk was introduced [83]. The cookies were baked at 170°C for 15 min.

Muffins. Two samples of muffins were prepared from: 1) plain finger millet (60%) and wheat flour (40%) and 2) malted finger millet (20%) and wheat flour (80%). The sensory acceptance of the former sample was 8.4 and the overall acceptability of the latter was 8.5. The shelf life of the muffins was estimated as 3 days at ambient temperature and 6 days at refrigerated temperature. The sensory properties of finger millet degraded during the storage period. Those muffins which were stored in aluminum foil at refrigerated temperature showed good quality, as compared to those stored in polypropylene bags at ambient temperature [84]. Muffins are very popular snacks mostly consumed by children. Finger millet flour can easily replace wheat flour, without any loss in taste or other characteristics. Furthermore, the addition of finger millet flour enhances the nutritional content of muffins [84]. Thus, the utilization of finger millets in bakery products is a healthy choice [51].

Bread. Bread is a very good source of nutrients that has a positive impact on human health. Its nutrient content can be enhanced by incorporating cereal grain flour [85]. Millet has been called a "nutri-cereal" for its nutrient content. Generally, wheat flour is used in breadmaking but finger millet could substitute for wheat flour because of its composition. Kaur *et al.* reported that the bread prepared from a blend of finger millet and wheat flour showed similar sensory scores [86]. Another study evaluated the sensory and textural properties of bread samples from composite flour [87]. Malted finger millet and red kidney bean were used to substitute 20 and 100 g of wheat flour, respectively. The results confirmed that the bread sample with malted finger millet had a better sensory score and textural attributes than the one with red kidney bean. However, the latter showed a better mineral and nutrient content than the former. Finger millet bread or hot porridge is commonly eaten with banana juice or sugar in the eastern and northern parts of Uganda [79].

Cake. In the bakery industry, cake is one of the most popular products among consumers. Malted finger millet and wheat flour were used in different ratios to formulate a cake [69]. The samples fortified with malted ragi flour were richer in minerals (calcium, iron, phosphorus) and crude fiber than the control sample. The sensory score was found to be the same at a ratio of 50:50. The cake with 70% of malted finger millet showed the highest mineral and fiber content, but had lower sensory characteristics due to the loss of sponginess and increased intensity of brown color. In another study, finger millet (nagli rava) was mixed together with butter milk to prepare batter. Subsequently, jaggery syrup, white butter, and baker's yeast were added, while the flavor was enhanced with cardamom. Fermentation was achieved after 1 hour and the cake was baked at 180°C for 20 min [83].

Biscuits. Biscuits were prepared from two compositions of finger millet and wheat flour, 60:40 and 70:30 w/w. The quality of dough and biscuits was evaluated and their hardness was measured by the textural profile analysis. According to the results, the samples with the 60:40 ratio of finger millet and wheat flour were harder than those with the 70:30 ratio, because wheat flour makes the dough more adhesive. Another study reported the advantages of the 60:40 ratio of finger millet and wheat flour [88]. During milling, malting, and decortication of finger millet grain, the outer layer of a seed coat forms a by-product. Krishnan *et al.* reported that the seed coat matter contained 9.5–12% of protein, 2.6–3.7% of fat, 40–48% of dietary fiber, 3–5% of polyphenols, and 700–860 mg/100 g of calcium [89]. Seed coat matter can be used in flour blends to prepare biscuits. According to the sensory evaluation, 20% of malted millet, hydrothermally processed millet, and 10% of seed coat matter could be used in composite biscuit flour.

Alcoholic beverages. *Beer.* Beer is known as doro, hwahwa, mhamba, or utshwala in various regions of Zimbabwe. Opaque beer is a popular alcoholic beverage in the southern part of Africa [90]. Millet beer ranges in alcohol content and taste between ethnic groups. For traditional brewing processes, mostly Bulrush (Pennisetum typhoideum) and finger millet malts are preferred [91]. Opaque beer is generally produced from millet with a high level of tannins. Malted finger millet and barley flour are blended together in various proportions (100:0, 50:50, and 0:100) for beer brewing. Gull *et al.* reported that the optimal conditions for beer production were a 68:32 ratio of finger millet and barley, a kilning temperature of 50°C, and a slurry ratio of 1:7 [14]. There are various cultivars of finger millet such as brown, light brown, and white [12, 36, 63]. In South Africa, mainly brown cultivar is used for brewing of traditional opaque beer [52].

Extruded products. *Noodles.* Blends of finger millet flour (30–50%) and refined wheat flour were used to develop noodles for diabetic patients. The sensory analysis showed that noodles prepared with 30% of finger millet flour had better acceptance than the other samples [92]. Two ratios of finger millet flour and rice flour (50:50 and 100:0) were used to prepare noodles. Water was added to increase moisture up to 35% and to cause pellets to form. Pellets were steamed to make sheets and form noodles by extrusion. Afterwards, the noodles were sterilized at 100°C and dried. The samples with both ratios of finger millet and rice flours showed good acceptance, but the sample with 100% of finger millet flour had better acceptability in color than the one with 50% of finger millet flour. Noodles can be packed in PET/LDPE bags for more than 1.5 years without any deterioration [93].

Fermented products. *Dosa.* Dosa is an Indian breakfast food. Sinthiya prepared dosa from finger millet flour and horse gram [94]. It was inexpensive and had a high protein content. Fermentation was carried out for 24 h in different proportions. The results showed a decrease in pH by 2.4 in 16 h. Fermented dosa showed higher sensory acceptance. Also, the study showed that dosa might help in overcoming malnutrition. In another study, finger millet, rice, and urad dal flours (2:2:1) were mixed with jaggery syrup and dry yeast to make batter which was fermented for 10 h with the adding of salt [83].

Koozh. Koozh is a popular fermented beverage. Generally, it is produced in rural India by traditional methods. Rich in nutrients, it also carries some health-promoting properties. Koozh is considered a unique fermented food because it undergoes fermentation twice, before and after cooking. Also, it takes two days to process [70]. Koozh is generally prepared from finger millet and it is well known for its flavor and nutritious value. In south India, it is consumed every day for breakfast [95].

Weaning food. The sprouting of finger millet is an important process in the preparation of infant food. Hejazi and Orsat stated that sprouted finger millet and amaranth grains enhanced the availability and digestibility of protein, which is an essential nutrient for infants' growth [53]. Nowadays, micronutrient deficiency is a global issue. Finger millet grain is popular in eastern and northern Uganda as a highly nutritious food. Finger millet bread or hot porridge is eaten with banana juice or sugar [79]. Different processes during the preparation of weaning food, such as roasting, help enhance the bioavailability of iron [8, 45]. Finger millet has special properties which make it an excellent source of nutrients, compared to other grains. It is a rich food due to its malting characteristics. Malted finger millet has been traditionally used to develop infant food and beverages either with milk or lukewarm water with the addition of sugar [51, 69].

Chapatti (roti). Dough is prepared from finger millet flour, water, a pinch of salt, and oil. To make chapatti, the dough is kneaded into small balls, which are flattened and then put over a hot pan. Shobana *et al.* stated that the wheat chapatti had a better digestibility index than the finger millet chapatti [3]. The latter had a resistant starch content of about 4.5%. Sharma *et al.* prepared chapatti from a blend of finger millet and wheat flours (3:1) [82]. The blended flour showed higher levels of phenols and higher antioxidant activity than wheat flour. The chapatti from blended flour had a high level of starch which was slow in digestion.

Panghal *et al.* found that the chapatti prepared from finger millet flour (40%) and wheat flour had poor dough sheeting and handling properties [96]. Moreover, it was low in the level of redness and phenolic content. A 7:3 ratio of finger millet and wheat flours was considered suitable for the preparation of chapatti, although the color of chapatti was still slightly dark. Finger millet flour incorporated into the dough improved the taste of chapatti. In addition, it efficiently controls the level of sugars in diabetic patients. Its fiber content can also help solve the problem of constipation [16].

Papad. According to a report by Verma and Patel, papad is prepared using 60% of finger millet flour in Karnataka [51]. First, the flour is cooked in distilled water until it gets gelatinized. Then, the dough is prepared by adding water. It is rolled, flattened, cut into shapes of a desirable size, and then dried until required moisture. In India, papad is a very popular snack and it is as thin as wafers. Generally, it has a round shape and is consumed roasted. The moisture content of papad is about 14–15%. Papad prepared from a blend of finger millet and soy flours can be stored for up to two months. In a study by Kazi and Auti, finger millet grains were soaked for 16 h and germinated for 48 h. They were then dried at room temperature to reduce moisture and ground into fine powder. To enhance the flavor of papad, malted flour and cumin seeds were added to boiling water. The mixture was stirred until it became thicker in consistency and sun-dried for 2 days [83].

Porridge. Porridge is a staple food mainly consumed in southern India, especially in rural areas. Porridge is prepared by mixing finger millet flour with water to attain a dough-like consistency [47]. Porridge made from different varieties of finger millets had a reduced content of phenolic compounds (by 41%) and tannins (by 35%), while its iron and zinc bio-accessibility was 6 and 13%, respectively [55]. Finger millets were roasted at various temperatures and during different times to prepare porridge. Ambre *et al.* reported that longer time and higher temperature decreased viscosity by 50–60% [16]. Mainly brown and white cultivars were used to prepare porridge [36, 52].

Non-food uses. Finger millet is an unconventional crop that can be used not only to formulate nutritious foods but also as an excellent source of biomass for bioethanol production. Finger millet seeds are mainly utilized in the production of ethanol, while African countries mostly use them for beer production [97]. Finger millet straw and agricultural waste can be converted into bioethanol. The current problems of global warming, turbulent oil prices, and environmental pollution have prompted most of consumers around the world to sharply increase their use of "green" fuels. Bioethanol is commonly derived from the conversion of carbon-based feeds. However, bioethanol from bio-sources is the main alternative to fossil fuels for road transport vehicles [98]. Finger millet straw can be used for feeding Mandya sheep or any other animals [99].

Future prospects for research. Our literature review shows that finger millet is an excellent source of nutrients and health-benefitting properties, which are comparable to those of major cereals such as wheat, rice, and maize. Its edible content and nutritional value can be increased by various processing technologies such as soaking, fermentation, germination, popping, and puffing. The use of finger millet grain is lower in some rural areas compared to urban areas. This is due to the lack of innovative millet-processing technologies to provide easy-to-handle, ready-to-cook, or ready-to-eat products and meals on a commercial scale.

Finger millet is not only used as a coarse grain, but it is also considered a nutrient grain, or a nutrient crop, and a possible solution to food and nutrition security globally. Its high nutritional value and tolerance towards various biological and azotic stresses make it an excellent crop for the currently growing population in the conditions of climate change.

A super grain can be created in the future by genetically combining various agriculturally important traits of the finger millet genus. Advanced finger millet varieties can be cultivated through different types of breeding and genetic modification to enhance the crop's nutritional composition. The production of finger millet can be improved with modern agricultural practices and a timely management of the crop's condition.

CONCLUSION

Finger millet is a promising raw material for obtaining food products with a high nutritional value. In addition to meeting the food requirements of the population, it has a large number of nutritional (vitamins, minerals, fatty acids, calcium, antioxidants) and medicinal properties. Its nutritional and functional properties were found to be superior to those of other cereal grains. Processing and value-addition technologies have made it possible to process and prepare functional products for both rural and urban consumers. In rural areas, the utilization of finger millet as a food product is still limited, so it needs to be widely popularized. Specially formulated region-specific and group-specific foods can help promote millet consumption and thereby improve the nutritional intake of consumers.

CONTRIBUTION

Vaibhav Gaikwad, Jaspreet Kaur and Prasad Rasane designed and planned the research, and wrote the manuscript. Sawinder Kaur and Jyoti Singh created the tables and figures, as well as interpreted the data. Ankit Kumar, Ashwani Kumar, Nitya Sharma, Chandra Mohan Mehta and Avinash Singh Patel reviewed and modified the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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