

Review

Millet in sub-Saharan Africa: a review of the nutritional and bioactive composition, methods of processing and its developed products

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Abstract

Millet grains are essential foods for most people living in rural areas with low socioeconomic status, especially in Asia and sub-Saharan Africa (SSA). The most cultivated millets in SSA are pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), fonio (*Digitaria exilis*), and teff (*Eragrostis tef*). Others from around the world are Japanese Barnyard millet (*Echinochloa frumentacea*); foxtail millet (*Setaria italica*) and proso millet (*Panicum miliaceum*), Kodo millet (*Paspalum scrobiculatum*), and little millet (*Panicum sumatrense*). The main databases used for this review paper were Web of Science and Scopus. Science Direct and Google Scholar were also used for identifying keywords. The total number of articles used were 110. This review paper explored the origin, physical structure, nutritional composition, and phytochemicals of millet grains. The effect of different processing methods on the nutritional, antinutritional and bioactive compounds of millet products was discussed. Moreover, some traditional products made from these grains were reviewed. The challenges that pertain to the migration from major cereals to millet-based products and future perspectives were given. We advocate the need to create value-added products from these underutilised millets species for commercialisation and food security in line with the second sustainable development goal.

Keywords Millets · Cereal grains · Underutilised crops · Nutritional composition · Millet-derived products

1 Introduction

Millets are small-seeded, annual, warm-weather cereal grains grown around the globe for animal feed fodder and human consumption [1–3]. They consist of various species and belong to the family *Poaceae* [4, 5]. Millet ranks as the sixth most vital cereal grain worldwide, sustaining more than one-third of the world's population [6]. They are grouped into major millets such as finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica*), pearl millet (*Pennisetum glaucum*), proso millet (*Panicum miliaceum*), and minor millets namely barnyard millets (*Echinochloa colana*), Kodo millet (*Paspalum scrobiculatum*), and little millet (*Panicum sumatrensemiliare*) [7–10]. There are four millets grown on the African continent. These are pearl millet, finger millet, fonio (*Digitaria exilis* and *Digitaria iburua*), and teff (*Eragrostis tef*). These millets are climate-resilient crops that grow in various soils under harsh conditions such as drought [11, 12]. The grains are cheaper than major cereal grains and can help combat food insecurity, especially in developing and developed countries [13].

The cumulative production index of millets in Table 1 shows that the major countries of millet cultivation in sub-Saharan Africa (SSA), in ranking order, are Niger > Nigeria > Mali > Ethiopia > Senegal over a period of five years [14]. Cultivation

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is higher in semi-arid regions of Western Africa in countries like Nigeria, Mali and Niger (Table 1). In some countries like Kenya, Gambia, Ghana, Malawi, Mozambique, Namibia, Niger, Nigeria, Zambia and Zimbabwe, there was an increase in millets produced over the period reported here. This implies improved cultivation, mostly due to increasing demand for local consumption and exportation. On the other hand, in Guinea, South Sudan, Sierra Leone and Uganda, there was a decrease in production output (Table 1).

Teff (*Eragrostis tef*) is a little millet grain from East Africa. Ethiopia is the only nation in the world that has made teff a staple crop, producing most of it, at least 50 million tonnes per annum [15]. However, Ethiopia's teff production and value chain rely on conventional methods, and the government's export prohibition restricts the teff market. As an alternative, more developed nations, including the United State of America, are entering the teff market. Teff is mostly used for the production of *injera*—a flatbread. Fonio (*Digitaria exilis*) is a small-seeded grain indigenous to the low rainfall regions [16] of West African countries like Nigeria (Table 2). Fonio is regarded as a superior grain and has garnered attention from developing countries regarding agronomic developments and value addition.

Table 1 Production of millets in Sub-Saharan Africa (in tonnes)

Countries	2015	2016	2017	2018	2019	2020
Angola	43,746	42,000	70,000	58,984	56,432	55,000
Benin	21,640	25,182	24,717	26,143	26,250	27,294
Botswana	555	1675	1099	2462	902	7369
Burkina Faso	946,184	905,071	828,234	1,189,079	970,176	957,000
Burundi	9970	10,068	10,090	10,067	10,043	11,000
Cameroon	95,810	96,692	98,432	96,978	97,368	97,593
Chad	592,124	725,677	660,175	756,616	717,621	686,584
Congo	13,197	13,343	13,756	13,432	13,511	13,566
Côte d'Ivoire	55,200	58,300	61,600	63,847	66,248	69,465
Democratic Republic of the Congo	43,776	45,297	45,051	44,708	45,019	44,926
Ethiopia	1,036,444	1,017,059	1,030,823	1,035,630	1,125,958	1,218,582
Gambia	73,420	69,273	52,000	38,000	35,000	80,000
Ghana	157,369	159,017	163,484	181,564	190,000	170,000
Guinea	224,587	238,177	241,714	214,747	223,220	213,420
Guinea-Bissau	14,000	14,000	16,575	18,000	20,000	24,000
Kenya	99,000	54,000	54,000	72,000	135,000	153,000
Malawi	33,512	19,510	35,121	31,315	44,718	48,931
Mali	1,864,301	1,806,559	1,492,650	1,840,321	1,878,527	1,921,171
Mauritania	2790	2855	2490	2712	2685	2629
Morocco	4953	5407	5309	5223	5313	5281
Mozambique	10,916	21,000	21,000	33,464	40,545	22,099
Namibia	42,494	19,428	57,644	83,515	18,700	95,000
Niger	3,404,813	3,886,079	3,790,028	3,856,344	3,270,453	3,508,903
Nigeria	1,485,387	1,552,576	1,500,000	2,119,000	2,000,000	2,000,000
Rwanda	4960	5051	5100	5037	5063	5067
Senegal	749,874	493,340	875,484	897,574	807,044	1,144,855
Sierra Leone	44,000	38,000	39,000	38,000	38,000	32,000
South Africa	6243	6407	6310	6320	6346	6325
South Sudan	8000	6000	5000	5000	5000	6000
Sudan	486,000	1,449,000	878,000	2,647,000	1,133,000	484,960
Togo	38,664	23,838	26,044	26,082	26,806	30,000
Uganda	236,484	193,461	185,517	141,982	196,000	209,671
Tanzania	330,060	314,969	308,897	316,194	385,962	325,000
Zambia	31,967	29,972	32,566	32,278	24,843	45,005
Zimbabwe	17,672	27,461	62,157	38,964	6771	43,411

Source: FAOSTAT (<https://www.fao.org/faostat/en/#search/millet>)

Table 2 Production statistics of Fonio in sub-Saharan Africa

Countries	2015	2016	2017	2018	2019	2020
Benin	1543	1331	1394	6367	4700	4382
Burkina Faso	13,091	10,936	10,068	11,270	10,238	10,355
Côte d'Ivoire	19,300	19,800	20,400	22,749	18,427	18,634
Guinea	496,953	496,953	488,309	477,432	530,227	565,988
Guinea-Bissau	639	734	738	704	725	722
Mali	20,294	16,740	46,189	27,868	40,538	44,014
Niger	5807	6113	6207	6400	6046	5673
Nigeria	83,071	83,747	83,529	83,111	83,308	83,504
Senegal	3228	2317	3857	3921	5151	6761

Source: FAOSTAT (<https://www.fao.org/faostat/en/#search/fonio>)

Millet-based foods are suitable for celiac and diabetic patients as they are gluten-free and have a low glycemic index [17]. They are favourable food grains/ flours for communities with lower socioeconomic strata and traditional consumers, especially in Africa and India [18, 19]. Millets are not commercially used to produce value-added products in SSA because of poor market strategy, which is not favourable to food industries [9]. Millet grains have excellent potential to produce flour and food products. However, the flavour and difficulty of processing millets have limited their use in routine diets [20]. The low awareness of millet-based products, coupled with a lack of commercial-scale production of millet food products, discourages farmers from cultivating millet on a large tier [21, 22].

The worldwide food security challenges have been linked to climate change, resulting in floods, drought, social unrest, food price increases, and high birth rates, especially in SSA [4, 23]. The underutilisation of indigenous crops, food industries' resistance to commercialising those products, and consumer choice of migrating to westernised junk foods have all led to food insecurity [24, 25]. Some studies have been conducted on millet starch varying between 50 and 70 g/100 g of starch (dry weight basis, db). Millet starch has found application in the production of breakfast cereals, muffins, cookies, snacks, pasta, and health foods [5, 13, 26]. This article aims to identify the nutritional, bioactive composition, methods of processing and developed products of different millet grains and flours.

2 Materials and methods

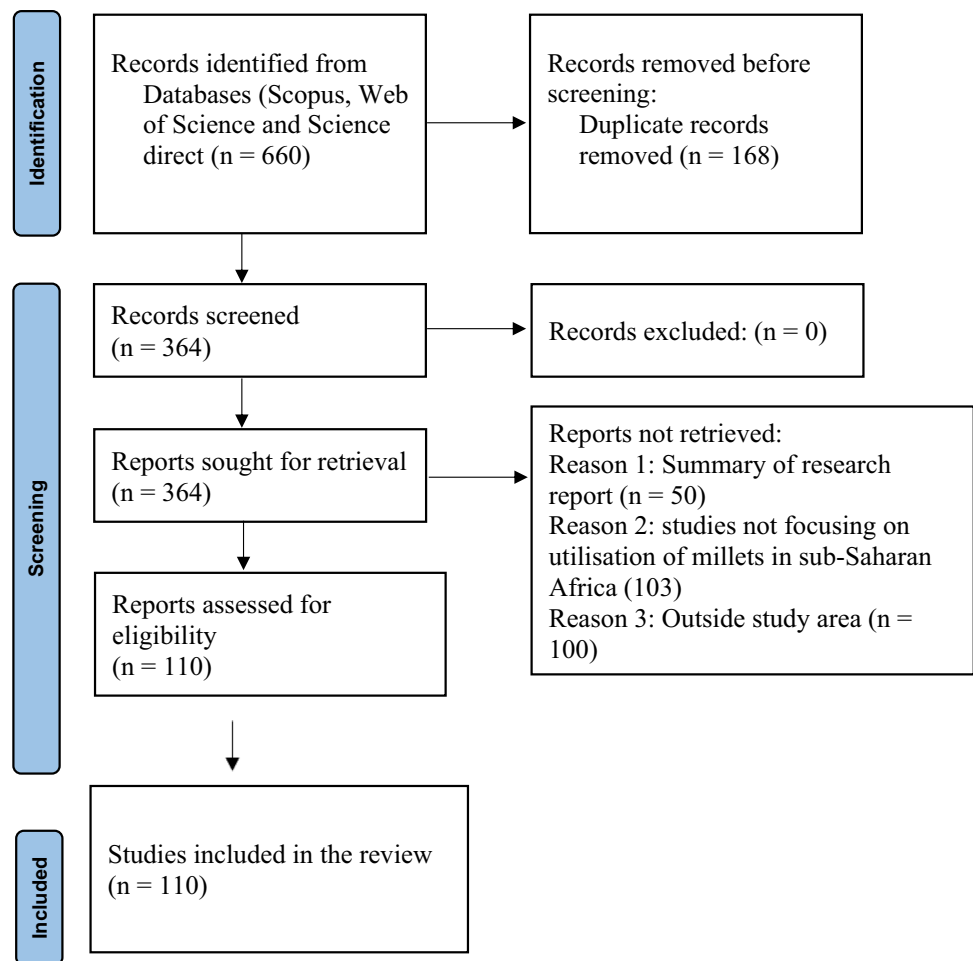
The online literature was searched between February and September 2024 using databases such as Web of Science, Scopus, Science Direct and Google Scholar. Key phrases used were millet, indigenous name, nutritional and health benefits of millet, phytochemicals in millet, and traditional African millet products. Articles published between 1999 and 2024 were selected for this review. More than 90 articles that were found through search engines were cited in this review. Figure 1 shows a PRISMA diagram of the selected articles for the literature synthesis. Data was chosen for inclusion in the review according to its relevance to the title, literature review, and discussion sections. This review was formulated using the following research questions: (i) What body of knowledge is available about the physical structure, nutritional composition and health benefits of millets? (ii) What are the polyphenolic compounds found in millets? (iii) What are the different value-added products produced from millet grains/flour? (iv) What are the effects of processing methods on the nutritional, antinutritional and bioactive compounds of millet products?

3 Results and discussion

3.1 Indigenous names and country of origin

Different indigenous names of millet species, their country of origin and the major areas of production are shown in Table 3. Other researchers reported that millet species are among the first crops cultivated in Central and Eastern Asia,

Fig. 1 PRISMA diagram of the selected articles for the literature synthesis



China, India, Russia, and some parts of Africa, especially in Ethiopia, where it is essential for their daily diets [12, 17]. The world's largest producers of millets are India [13, 18], Nigeria, Niger, and China [3, 6].

3.2 Some physical structures of millet grain species

The grains are round-shaped cereal grains found naturally in various colours and sizes, depending on the variety or cultivar. Millets differ by appearance, plant, grain type, maturity, and morphological features, as indicated in Figs. 2 and 3 [2]. The grains are composed of the pericarp (outer covering), endosperm (starchy part) and embryo or germ (oil part). The endosperm is the most significant part of the millet grain and acts as a storage tissue [2, 18]. Pearl millet is a caryopsis type with an ovoid, hexagonal, globose shape. It consists of different colours: grey, white, yellow, brown, and purple. Finger millet has a utricle-type grain structure with a globose shape, consisting of yellow, white, red, brown, and violet colours [27].

3.3 Nutritional composition and health benefits of millet species

Millets are beneficial to diabetics as they have relatively low glycaemic index. This implies that when consumed, they will be digested gradually and not cause a sudden spike in postprandial blood glucose level. The nutritional composition of millet species compared to wheat, rice and sorghum is shown in Table 4. They contain a higher amount of fibre, and their protein quality plays a vital role in food and nutrition security. The protein contents of pearl millet (12.7 g/100 g),

Table 3 Indigenous names and origins of millet species

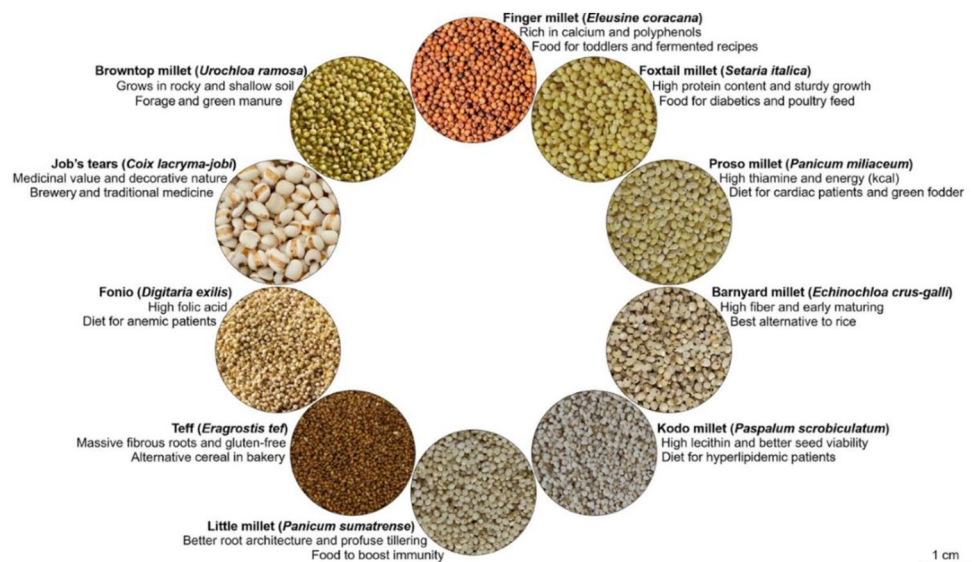
Millet species	Indigenous names	Origin	Major areas of production	References
Finger millet	<i>Ragi</i> and <i>mandua</i> (India); <i>kaddo</i> (Nepal); fingerhirse (Germany); <i>petit mil, eleusine cultivée, coracan, koracan</i> (France), <i>bulo</i> (Uganda); <i>kambale, lupoko, mawele, amale, bule</i> (Zambia); <i>poho, rapoko, zviyo, njera, mazhovole</i> (Zimbabwe); African millet, <i>koracan</i> (England); <i>dagussa, tokoso, barankiya</i> (Ethiopia); <i>mufhofo</i> (South Africa); <i>wimbi, mugimbi</i> (Kenya); <i>Tamba</i> (Nigeria)	Uganda	India, Eastern, Southern Africa and Uganda	[22, 25, 27, 29–31]
Pearl millet	<i>Sajje</i> or <i>cumbu</i> (South Africa); <i>bajra bajri, saje, kambu, kamban, sajalu</i> (India); <i>gero, arum, bulrush millet, milheto, dark millet, bajri, cattail millet or bulrush millet</i> (northeastern Nigeria)	Tropical west Africa Sahel	India, Western, Central Africa	[12, 25, 27, 29]
Fonio	Podgi (Benin), <i>acha</i> (Ghana), <i>sùurù, gashish, weté</i> (Nigeria), <i>Dekolé, efoled</i> (Senegal) <i>apende</i> (Sierra Leone), <i>Entaya</i> (Niger), <i>fénhe</i> (Guinea-Bissau), <i>foundé</i> (Mali).	West Africa	Western Africa	[32]
Teff	Teff, Williams lovegrass or annual bunch grass	East Africa	Ethiopia and Eritrea	[15]
Proso millet	Common millet (USA); broomcorn millet (China); <i>broom tail, kashfi, mijo, Chinese millet, kibi, hog millet, white millet, brown millet, red millet</i> (Spain); <i>panic</i> (France); <i>Gijang</i> (Korea); <i>cheena</i> (India)	Central east Asia	China, Russia, Kazakhstan, Ukraine, India, Japan	[12, 18, 25, 29]
Barnyard millet	Sawa millet, Japanese barnyard millet, Indian barnyard millet, <i>kodisama, bhagar, burgu millet, banti, jhangora, khira, konidhan, kutdirvali, oodalu, Sanwa, shyama, swank, korean, kweichou</i>	Japan, India	India, China, Japan, Malaysia	[12, 18, 25, 29, 33]
Little millet	<i>Gajrao, kuri, kurtki, sama, samalu, sava, suan, swank</i> —India	Southeast Asia, India	India	[18, 25, 29]
Kodo millet	Cow grass, ditch millet, rice grass, native Paspalum, or Indian crown grass <i>Anika, kodon, kodra, kodua, harika, varahu, araku</i> —India	India, West Africa	India	[18, 20, 25, 29]
Foxtail millet	Italian millet, German millet, Chinese millet, Hungarian millet, green millet or <i>harka</i> <i>kakon, kangani, kang, kangni, kangam, kangtzu, kaon, navane, nala, tanai, thena</i> —India	India	China, India, Eastern Europe	[25, 29, 34, 35]

The first four millets are grown on the African continent

Fig. 2 Various types of millet species <https://pristineorganics.com/millet-ancient-grains-for-a-healthier-future/>



Fig. 3 Small millets
DOI:<https://doi.org/https://doi.org/10.1016/j.tplants.2020.08.008>



foxtail millet (12.3 g/100 g) and proso millet (12.75 g/100 g) are comparable to that of wheat (≥ 13 g/100 g). Although millet proteins do not have viscoelastic properties like gluten in wheat, their use in bakery products may be optimised via partial substitution in wheat flour or by using hydrocolloids or natural gums as binders. On the other hand, the high protein content makes these millets a valuable protein source for foods like breakfast porridge, smoothie powder and infant foods. The functionality of foxtail millet protein concentrates was assessed by Mohamed et al. [28]. They observed that foxtail millet species contained two main proteins, viz: albumin and globulin, which were soluble and easily hydrolysed by digestive enzymes. Hence the higher digestibility when compared to soy protein concentrates. Additionally, protein concentrates had higher methionine, threonine, tryptophan and histidine than soy protein concentrate. They concluded that protein concentrates from foxtail millet have the potential to be functional food ingredients. The superior emulsifying and oil absorption capacity of the protein concentrates indicates they can be used in foods such as mayonnaise, salad dressings and sausages [28].

The millet varieties have not had substantial protein yield with superior lysine content (usually absent in most cereals). In addition, the protein is easily digestible and has, not had high stability, foam, and emulsifying capacities. The wide range of protein concentration denaturation temperatures (84–89 °C) points to their potential utilisation in hot beverages and bakery products. The protein quality of seven proso millet varieties was higher (51%) compared to wheat using the essential amino acid index [36]. The millet grains are a rich source of nutrients such as minerals (2.5–3.5%), fat (1.5–5%) and vitamins B-complex (niacin, folic acid) compared to wheat and rice [37, 38]. They contain a higher amount of dietary fibre (15–20%) and carbohydrates (65–75%) which play a vital role in the energy requirement and nutrient

Table 4 Selected nutritional composition of millet species as compared to wheat, rice and sorghum (per per 100 g edible portion)

Millet	Protein (g)	Carbohydrates (g)	Fat(g)	Dietary fibre (g)	Minerals (g)	Calcium (mg)	Phosphorus (mg)	Riboflavin (mg/100 g)	References
Finger millet	7.3	72.0	1.3	18.8	2.7	344	283	0.21	[39, 40]
Pearl millet	10.3-12.7	67.0-68	5.6-5.9	2.3	1.9-2.2	25	339	0.21	[39, 41]
Fonio	7.5-12.19	74-81.2	0.6-0.98	1.03-3.38	8.22	20-30	289	0.41	[7, 42]
Teff	13.3	73-85.6	2.4-4.4	8-9.8	2.8	180	429	0.27	[43-45]
Proso millet	12.5	70.4	3.1	14.2	1.9	14	5206	0.11	[39, 40]
Barnyard millet	6.2	65.5	2.2	13.7	4.4	11	280	0.09	[39, 40]
Little millet	7.7	67.0	4.7	12.2	1.5	17	220	0.28	[39, 40]
Kodo millet	8.3	65.0	1.4	15.0	2.6	2.7	188	0.10	[39, 40]
Foxtail millet	12.3	60.9	4.3	14.0	3.3	31	290	0.19	[39, 40]
Sorghum	10.82	73	3.23	1.97	1.70	27.60	306	0.15	[8, 39]
Wheat	10-13	71.2	1.5	12.9	1.5	41	306	0.10	[39, 40]
Rice	6.8	78.2	0.5	5.2	0.6	45	160	0.04	[39, 40]
Oats	16.9-17.3	66.2	7.03	15.4	-	58	734	0.14	[46, 47]
Barley	9.9	15.6	1.2	15.6	-	29	221	0.11	[46, 47]
Maize	9.4	7.3	4.7	7.3	-	7	210	0.2	[47]
Amaranth	13-18	65.5	2.5-8	12.5	-	162	374-455	0.1-0.2	[47]
Quinoa	13.1-14.1	53.7-57.2	4.7-5.5	7-14.7	-	54	212-527	0.2-0.3	[47]

intake of humans [12, 17]. Millets contain calcium and magnesium, reducing the heart attack risk. The manganese, iron, and zinc content of millet may assist in decreasing high blood pressure and preventing anaemic disorders. Phosphorus is essential for the development of body tissue and energy metabolism. Millet grains have the highest calcium content of 344 mg compared to other cereal grains, which play a crucial role in repairing bones and teeth.

The grains are also rich in phytochemicals such as phytic acid, flavonoids, lignans, phenolic acids and polyphenols, which provide potential health benefits like antioxidant, antidiabetic, antimicrobial effects, and protection from diet-related chronic diseases such as diabetes & cancer, to regular consumers of millets [10, 11, 18]. The grain consists of phenolic compounds in the pericarp and testa, especially flavonoids, which reduce tumour production. Shi et al. [48] confirmed through in vitro and in vivo assay that the bound polyphenols from foxtail millet caused the death of tumour cells (HCT-116) and demonstrated a substantial prooxidative effect against colon cancer cells. They also contain essential amino acids such as methionine and cysteine [12, 38].

In terms of nutrigenomics, pearl millet grains are highly nutritious because they are rich sources of iron (0.002–0.15%) and zinc (0.001–0.02%) with relatively higher amounts of the iron and zinc than staple cereal such as wheat (0.001%), rice (0.003%), and maize (0.002%) [49, 50]. In SSA, the gene bank of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a promising source of iron and zinc rich genotypes. A total of 41 and 42 genotypes were richer in iron (> 0.08%) and zinc (> 0.06%), respectively. On the other hand, 33 genotypes were found to be a rich source of both minerals [51]. The analysis of 297 Iniadi germplasm from Western Africa has demonstrated extensive variability for grain iron and zinc content [50]. Various studies at ICRISAT demonstrated a wide range of variability for grain iron and zinc densities in different breeding materials such as Iniadi germplasm accessions (0.005–0.012% Fe; 0.005–0.009% Zn), population progenies (0.002–0.014% Fe; 0.002–0.009% Zn), inbred parents (0.003–0.010% Fe; 0.003–0.008% Zn), etc. [52]. Analysis of 281 advanced breeding lines exhibited substantial variability for Fe (0.004–0.012%) and Zn (0.002–0.008%) [53].

3.4 Polyphenolic compounds in millets

Millets are rich in polyphenolics such as phytic acid, flavonoids, phenolic acids, and tannins that provide potential health benefits such as antioxidant, antidiabetic, hypocholesterolemic, antimicrobial effects and protection from diet-related chronic diseases such as diabetes & cancer (Table 5) to regular consumers of millets [10]. The grain consists of phenolic compounds in the pericarp and testa, especially flavonoids, which reduce tumour production. The millets primarily contain 60% of phenolic acids in the bound forms, while 40% are free molecules [54]. Millets with dark colour pigment testa and pericarp have a higher content of soluble phenolic fractions than light-coloured millets such as white or yellow testa [55]. Hydroxycinnamic acids and their derivatives are the most prevalent phenolic acid available in the insoluble-bound fractions of the phenolic acids in millet grains. A study by Kumari et al. [56] found that the soluble extracts of finger millet have a high amount of total phenolic content compared to foxtail and proso millets. The main phenolic compound in finger millet is catechin, although epicatechin has also been identified [55, 57].

Flavonoid is a vital antioxidant contributing to a low risk of chronic diseases. In terms of flavonoid content, finger millet has a higher range than foxtail and proso millets, with flavanols being the principal subclass [58]. Other phenolic compounds that belong to various flavonoid subclasses include flavones, isoflavonoids, flavonols, and dihydroflavonols, including their glycosides. The same flavonoid subclasses have been identified in barnyard millet soluble extract [59]. Watanabe [60] reported that Japanese barnyard millet contains two flavonoids: luteolin and tricetin.

Barnyard millet contains phenolic compounds like formononetin, kaempferol, apigenin, isorhamnetin, and 3,7-dimethylquercetin [59]. Millets such as pearl, Kodo and foxtail have lower condensed tannin compared to that of finger millet [57]. Furthermore, condensed tannins have pharmaceutical properties such as antibacterial, antioxidant, antiviral, and anti-inflammatory, and consist of flavan-3-ol units. Coloured millet varieties contain considerable amount of tannin, and condensed tannin contributes to the colour of finger millet grain. Brown finger millet has greater antioxidant capacity than white finger millet. Therefore, grains rich in condensed tannin exhibit higher antioxidant properties [61].

With the evidence from the literature of the multiple nutrient streams of nutrients from the various millet varieties, the production of nutrient-rich millet-based foods is not implausible. The stakeholders in the African food value chain from farm to fork (botanists, farmers, agro-processing industries, millers, researchers, product developers, food producers, advertisers, retailers, and consumers) are all needed to change the false narrative that millet is a poor man's crop. The new narrative should be that millets are a sustainable nutrient powerhouse in the face of the current climate and economic changes in SSA.

Table 5 Phytochemicals of millet species and their health benefits

Millet species	Phytochemicals	Health benefits
Finger millet	Apigenin, catechin, diadzein, epicatechin, epigallocatechin, gallocatechin, kaempferol, luteolin, myricetin, procyanidin B ₁ , procyanidin B ₂ , quercetin, tricin, vitexin	Anti-tumorigenic effect, antidiabetic, antioxidants, antimicrobial
Pearl millet	Apigenin, flavonoids, lignin, myricetin	Anti-fungal, prevent ulcer, breast cancer and coronary heart diseases
Proso millet	Apigenin, myricetin, kempferol	Anti-diabetic, anti-cancer, anti-inflammatory
Barnyard millet	Luteolin, N-(p-coumaroyl), tricin, serotonin	Anti-diabetic, anti-cancer, anti-inflammatory
Little millet	Apigenin	Anti-diabetic, anti-cancer, anti-inflammatory
Kodo millet	Apigenin, isovitexin, kempferol, leutolin, quercetin, vitexin	Anti-diabetic, anti-cancer, anti-inflammatory
Foxtail millet	Apigenin, catechin, kaempferol, quercetin	Physiological removal of toxic substances from the body, anti-tumor, prevention of contagious disease

Sources: 12, 59

3.5 Effect of processing on nutritional, antinutritional and bioactive compounds of millet products

Like other cereal grains, millets must be processed into edible food products for palatability and easy digestion. Over the years, millet grains have been subjected to processing methods such as fermentation, germination, malting, roasting, and hydrothermal treatment to create new and improved existing products. The effect of some of these processing methods is discussed subsequently. Some of the studies cited in this section were done in Africa.

3.5.1 Fermentation

From time immemorial, fermentation has been a favoured traditional technique for processing and preservation of food products in most parts of Africa [62]. Fermentation is a process where certain microorganisms (yeasts and lactic acid bacteria) hydrolyse the sugars in the grains, producing an array of metabolites beneficial to human health and food preservation [62]. Aside from its preservative effect, fermentation imparts unique taste and flavour to foods and improves cereal grains' nutritional properties and digestibility. During fermentation, the action of enzymes leads to a breakdown of the proteins into amino acids. Hence, a 1.5- to twofold increase in amino acids was reported in fermented pearl millet flour and biscuits [73]. Traditionally, spontaneous fermentation is standard, and several research studies have been carried out to investigate the effect of spontaneous fermentation on the nutrient retention and sensory profile of millet products.

Mutshiyani et al. [22] reported an increasing impact of spontaneous fermentation (0–96 h) on flavonoids, polyphenols, antioxidant activity, dietary fibre, and finger millet flour moisture content. Sensory panellists analysed porridge produced from these flours, and the one from the 24 h fermentation flour batch had the best organoleptic characteristics. Another study reported an increase in the proximate composition, mineral content and antioxidant activity of biscuits produced from fermented finger millet flour [10]. The effect of fermentation on the increase in mineral content may be attributable to cell wall solubilisation and synthesis, thereby increasing the mineral extractability. On the other hand, Nami et al. [64] used four *Lactobacillus* spp to produce sourdough pearl millet bread via controlled fermentation. They concluded that sourdough technology prolonged the shelf-life of the bread compared to the conventional dough. Other fermented millet products are mentioned in Table 6.

3.5.2 Germination and malting

Germination is a simple process in which grains are sprouted for a brief period. The grains are steeped in water for ten to twenty-four hours, then transferred to a germination bed (usually on cloth) and moistened intermittently until the grains sprout. Malting is a processing method that entails steeping, germination, and kilning (drying) of cereal grains to reduce bitterness and rancidity and enhance the flavour of the resulting flour [65]. During germination, the hydrolytic enzymes in the grains induce biochemical transformations, structural alteration and synthesis of new compounds that boost the nutritional content and stability of the cereal grains [66].

Research has shown that germination increases the bioavailability of the bioactive compounds, minerals, vitamins, protein, and fibre while reducing the anti-nutritional factors, such as phytic acid. Laxmi et al. [67] reported increased moisture, protein, fibre, carbohydrates, iron and vitamin C contents and reduced fat, ash, calcium, and phosphorus in malted foxtail millet. In vivo studies on the effect of germination on pearl millet flour showed anti-inflammatory and antioxidant action in high-fat and high-fructose-fed rats and reduced fat adiposity and liver inflammation [66]. Germination increased the lightness, titratable acidity, solubility, and water and oil absorption capacity of the finger millet flours. The sensory panellists accepted the porridge produced from the germinated flour at 24 and 48 h [68].

3.5.3 Roasting

Roasting is a process of subjecting millet grains to dry heat by using a high-temperature short-time treatment, leading to the browning of the grains and enhancement of their flavour [25]. The grains can be roasted in a conventional oven, microwave oven, or pan on a stovetop. When a pan is used, sand is put in the pan to ensure even distribution of heat [69]. During roasting, the sugars and amino acids in the aleurone layer undergo a Maillard reaction, thus increasing the array of aroma compounds in the grains, giving them desirable and distinct aromas [70]. In the study by [70], roasting increased the protein digestibility, phenolics, minerals, and dietary fibre of millet grains. Roasting also reduced the phytates and

Table 6 Effect of millet processing on the quality characteristics of selected food products

Millet species	Processing method	Type of food product	Effect of processing on quality characteristics	Reference
Finger millet (FM)	Germination (0–72 h)	Porridge	Germination increased the lightness, titratable acidity, solubility, and water and oil absorption capacity of the FM flours. Sensory panellists accepted porridge from germinated for 24 and 48 h	# [68]
	Spontaneous fermentation (0–96 h) (0–72 h)	Porridge	The dietary fibre, moisture, carbohydrates lipids, total polyphenols, and flavonoids of the fermented flours increased. Porridge from flour fermented at 24 h had the most acceptable sensory properties	# [22]
		Gluten-free biscuit	Fermentation increased the carbohydrates, protein, energy values, antioxidant activity, and mineral content of biscuits. The lightness, thickness and hardness of the biscuits increased due to fermentation. Consumers preferred biscuits from flours fermented for 24 h	# [10]
	Fortification (partial substitution with wheat flour at 10–40%)	Bread	The water and oil holding capacity of flours increased with increasing FM amount. The colour difference of the bread crumb and crust, ash, fibre, fat, carbohydrate contents and weight increased significantly	# [37]
	Fortification (partial substitution with wheat flour at 25–75%)	Biscuit	Fortification increased biscuits' calcium, iron, zinc, and crude fibre. Biscuits were desirable for up to 50% replacement of wheat flour and slightly desirable at a 75% level of replacement	[71]
	Malting and hydrothermal treatment	FM seed coat-wheat flour composite biscuit	The biscuits exhibited higher protein, dietary fibre, and calcium content. The sensory evaluation of the biscuits showed that 10% of hydrothermally processed millet and 20% from malted millet could be used in composite biscuit flour	[72]

Table 6 (continued)

Millet species	Processing method	Type of food product	Effect of processing on quality characteristics	Reference
Pearl millet	Malting and fermentation	Gluten-free biscuits	Malting and fermentation increased the moisture, crude protein, crude fibre, the essential and non-essential amino acids, and energy value of biscuits. Malted biscuits had the best aroma, taste, and overall likeness, while fermented biscuits had the best acceptable texture	# [73]
	Steaming and addition of preservatives (cloves, ginger, red pepper, sorbic & citric acid)	<i>Dambu</i> (steamed pearl millet mash)	The combination of steaming and the addition of preservatives increased the total titratable acidity and improved the shelf life of <i>dambu</i> during storage for up to two months	# [74]
	Malting, extrusion, and combination	Instant beverage	Combining processing methods increased carbohydrates, calcium, iron, starch digestibility, and most amino acids	# [75]
	Fermentation with four <i>Lactobacillus</i> spp.	Sourdough gluten-free bread	Sourdough fermented with <i>L. brevis</i> improved the loaf height, specific volume, porosity, and moisture content. The sensory evaluation showed that the sourdough-based bread was more palatable than conventional or chemically acidified ones	[64]
Foxtail millet	Fermentation with <i>Bacillus natto</i>	Bran	Soluble dietary fibre was significantly increased. Fermentation improved the water and oil holding and swelling capacities and cholesterol, bile salts, nitrite ion and glucose adsorption capacity of the bran. The total phenolic content and DPPH free radical scavenging capacity of millet bran were improved by fermentation	[76]
	Roasting	Millet flour and porridge	Roasting improved the aroma of the flour and porridge samples. Some pyrazine compounds were newly detected in roasted millet samples. The dieanal and pyrazine compounds were responsible for aromas, such as the "boiled rice and popcorn" odour in the flour and porridge samples	[70]
*Millet	High-temperature, high-pressure, and ultrasonic treatment	Bran dietary fibre	Processing improved the water/oil-holding, swelling, fat-binding, and cation exchange capacities of millet bran. Enhanced thermal stability and fibre accumulation were observed. The total antioxidant capacity of the ultrasound-treated fibres was higher than those of high-temperature and pressure-treated fibres	[77]

Table 6 (continued)

Millet species	Processing method	Type of food product	Effect of processing on quality characteristics	Reference
*Millet	Acrylate-grafting, carboxymethylation, heat-assisted with cellulase hydrolysis, and enzymatic hydrolysis combined with acrylate-grafting	Bran dietary fibre	The soluble dietary fibre content, water absorption capacity and α -amylase-inhibition activity improved. Oil, cholesterol, sodium cholate, copper ion and nitrite ion adsorption capacities all increased. Enhanced polyphenol content, sodium cholate-adsorption capacity, and hypoglycemic properties were reported	[78]

Studies carried out on the African continent to exploit millets for new product development.

*Millet species not mentioned



Fig. 4 Traditional food products from millet grains/ flours (Google, accessed date 15 September 2024)

protein. Furthermore, foxtail millet grains were oven-roasted for 35 min at 150 °C, and the volatile compounds were appreciably higher in the roasted millets than in the raw millets. These compounds include aldehydes (54.43–68.11%), hydrocarbons (5.70–10.17%) and pyrazines (9.67–25.46%), of which the latter such as 2-ethyl-3,5-dimethylpyrazine, 2-ethyl-5-methylpyrazine, and methylpyrazine were newly found in the roasted millet [70].

3.6 Products made from millet grains/flours

Products such as stiff porridge, thin porridge, cooked grains, sweet and savoury products and popped products are primarily consumed in Asian and African countries. These products are called by different names depending on the ethnic groups, such as alcoholic beverages [opaque beer or Dogon millet beer, *cipumu*, *malwa*, *kimpumu*, *chibuku* shake, *mbege*, *merissa*], flatbread (*roti*). Other products included are *laddoo*, chips, wadi, bread, cake, injera and non-alcoholic drink (*pombe*, *pito*, *boza*, *kunun Zaki*, *bushera*, *mahewu*, *oskikundu*, *marewa*) [63, 79] as some of the examples are shown in Fig. 4.

In Ethiopia, finger millet is used to make *injera*, local beverages, porridge, bread, soup, and *chechebsa*, a traditional breakfast, and the straw is used as animal feed. *Injera*, a fermented pancake-like, soft, circular flatbread, can be made with or without tef (*Eragrostis tef*), the best crop for *injera* production. Ethiopian traditional beverages *tella* and *areki* are made from cereal grains, including finger millet. Feyera et al. [80] suggested mango-flavoured finger millet juice in North Ethiopians Hailu. According to the authors, drinking juice is a great way to acquire all the crop's nutritional benefits. The seeds can be eaten as a cooked grain, used to brew the traditional beer or ground into flour to produce porridge. Pearl millet is grown to make silage, hay or directly grazed when green; thus, it is used as animal feed. As fodder for animals, the seeds feed poultry, and the green plant is used for grazing or silage and hay production [21].

3.6.1 Some traditional African millet products

3.6.1.1 Injera *Injera* is an Ethiopian unleavened fermented flatbread characterised by honeycomb appearance, thin and rollable texture, and sour taste—a result of natural fermentation. In appearance, *injera* resembles pancake and tortilla [58]. Where pancake is made from wheat flour and tortilla from corn flour, *injera* is made from teff flour. *Injera* is prepared by mixing teff flour, water, and a starter from a previously fermented batch [81]. The production process of *injera* begins

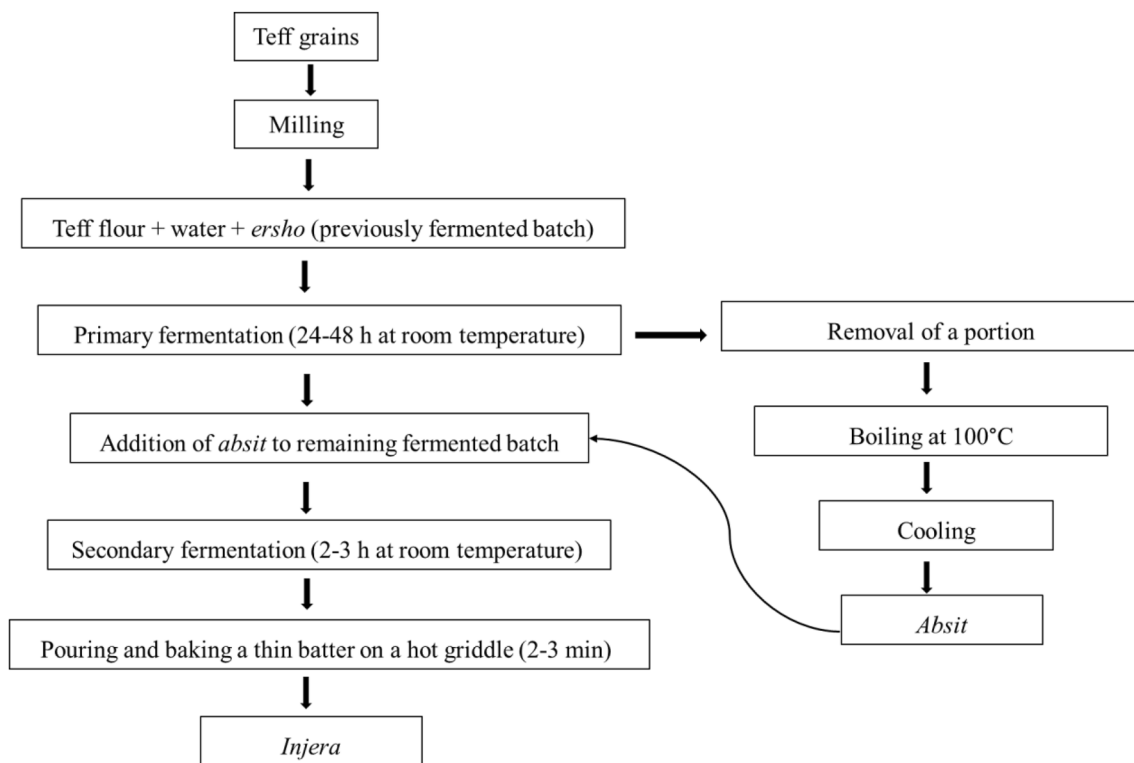


Fig. 5 Production flow chart of *injera*

with sorting and cleaning the grains and milling them. The flour is mixed with water and a back-slopping starter from a previous batter batch. The mixture is allowed to ferment for 24–48 h at room temperature, removing a portion mixed with water and boiled to gelatinise the starch. The gelatinised mixture is called *absit* (Fig. 5). The *absit* is reintroduced and incorporated into the fermented batch. The batter is fermented for about three hours, after which the batter is poured thinly onto a hot griddle and baked for 2–3 min producing the flatbread *injera* [81, 82].

3.6.1.2 Pombe beer The millet grains are first malted to produce traditional beers such as *pombe*. Malting starts with soaking the millet grains in warm water for 24 h to initiate the sprouting process. The goal of sprouting is to increase the maltose content in the grain. After that, the germination is stopped by drying the sprouted grains. The malted grain is then milled into powder and mixed with water [83]. This mixture is known as wort. The wort is later boiled for 24 h to kill any pathogenic bacteria. The wort is cooled down, and brewing yeast is added. The mixture is then allowed to ferment aerobically for another 24 h until it is frothy, giving rise to *pombe* beer which is consumed immediately [84]. The process flow diagram is shown in Fig. 6.

3.6.1.3 Millet noodle Millet noodle explained in this section is of Chinese origin but can be adopted by African consumers. Noodles are usually produced using wheat flour because of the viscoelasticity of the gluten protein present in the wheat. Millet grains, however, are gluten-free and, as such, have little or no extensibility. Millets have been supplemented with other flour such as cornflour [85], rice flour and wheat flour to produce noodles. Dissanayake and Jayawardena [86] developed noodles from finger millet and rice flour. The sensory properties from 100% finger millet had equal acceptable sensory values with the composite flour noodles. Based on the archaeological excavation of a 4000-year-old millet noodle in China, Lü et al. [87] were able to replicate the production process, evincing that we could learn a lot from the indigenous production process. Millet noodle is hinged on the production of viscous matter for starch noodles as opposed to wheat noodles made from glutinous protein (Fig. 7).

This traditional method of millet noodle making is based on modifying starch's viscosity by fermentation, resting the dough, repeated pounding and gentle. The process begins by deshelling the millet to remove the husks, followed by soaking at room temperature for 12 h. In addition, the soaked grains are pounded in a mortar to produce dough

Fig. 6 Processing flow chart for traditional *pombe* beer production

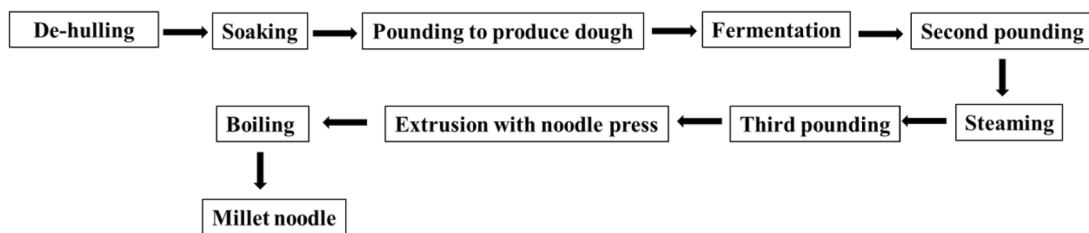
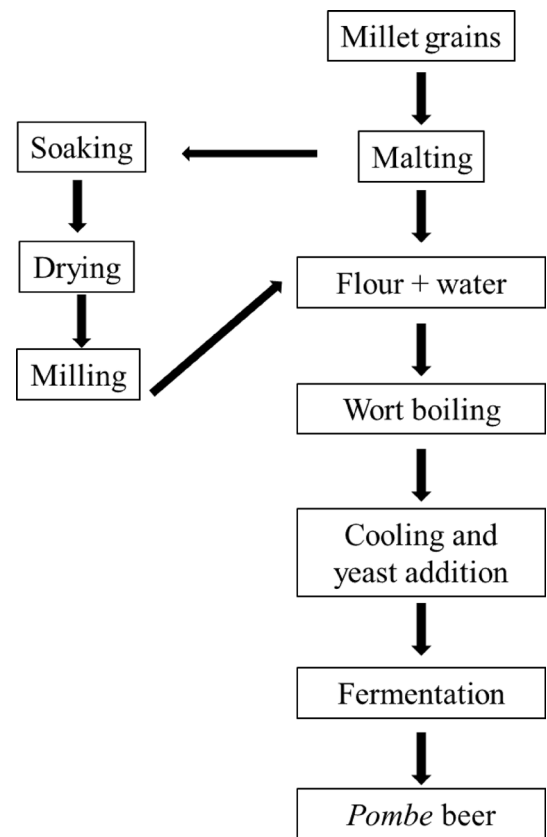


Fig. 7 Traditional processing of millet noodles

fermented for one hour. The dough is pounded again between two to three hours. The dough is steamed for 15 min and pounded again before being extruded through a noodle press and boiled in water [87].

3.7 Breeding and utilisation of millets as animal feed in sub-Saharan Africa

The millet research in SSA is behind compared to commodities such as maize, sorghum and cotton. However, plant breeders have successfully diffused different types of new millet cultivars onto farmers' fields. For example, the millet research programmes has resulted into twelve countries producing 16 millet cultivars in the last two decades [88]. The principal breeding strategies are those that focus on developing hybrids, synthetics, and composites. Hybrids have been used commercially to significantly improve pearl millet performance in recent decades. The iniadi pearl millet germplasm, which is indigenous to the west African countries of Benin, Togo, Ghana, and Burkina Faso has been widely used to improve the crop [89]. On the other hand, Indo-African crosses have been crucial for achieving breakthrough in yield performance for small millets, particularly finger millet, as well as for enhancing characteristics associated with blast resistance, early vigor, size of panicle, branching, number of fingers, and the density of the grain [90]. More than 95% of the global sorghum production is in developed countries, and most millets are used to feed animals [91]. Nevertheless, the amount of millet used for animal feed in SSA remains very low. The low usage of millet as animal feed might be

because it has lower yield levels than maize and other cereal grains. Moreover, millet cultivation in SSA is dominated by a subsistence farming system characterised by a low surplus for marketing [92]. To evaluate the nutritional value of seven types of pearl millet grown in Mali, Cisse et al. [93] fed laying hens or broilers diets that contained 0, 14, 28, or 43% whole pearl millet. Results showed that chickens fed varying amounts of millet over 16 weeks did not exhibit a significant change in egg weight or production. However, weight was lower in broilers fed the highest level (43%) of pearl millet between 1 and 42 days of age than in broilers fed the control diet. Furthermore, there was no discernible difference in the body weight gains of the broilers fed the control diet compared to those fed diets that contained 14 or 28% whole pearl millet. The findings suggest that pearl millet grown in Mali might be introduced whole to the diets of broilers and laying hens and would be a useful feed alternative for poultry production.

3.8 Migration from wheat, rice and maize commercialised to value-added millet food products

Most communities are now moving from the traditional way of producing millet food products to value-addition products such as malted flour, composite flour, multigrain, baked products, beverages, noodles, extruded products, etc. [18, 21]. People are moving to consume commercialised food products from wheat, rice and maize to traditional foods processed from millet which are a rich source of nutrients. Cereal grains primarily consumed are maize, rye, wheat, barley, and sorghum. These crops have been traditionally and commercially explored into functional foods as ready-to-eat products [94].

In contrast, millet grains and their processed products are not consumed in SSA as the grains mentioned earlier. With the drastic surge in the triple burden of malnutrition in the past two years (an outcome of the global pandemic and recent wars), coupled with the importation of wheat, millet is a valuable alternative to overcome malnutrition and food security in developing countries. For instance, Prakash et al. [95] developed a protein-rich extruded maize-based



Fig. 8 Millet value-added products in sub-Saharan Africa (Google, accessed date 15 August 2024)

breakfast cereal by adding 18% finger millet powder to the formulation. The chemical composition of the final product had 9.6% protein and higher lysine and tryptophan contents than the maize product without finger millet.

Diversification of millet food products needs to be promoted at a national and household level, especially in producing value-added food products. The grains have essential parameters such as resistance to drought, resistance to pests and diseases, and a short growing season as compared to other major cereals [12, 18, 19]. Encouraging the cultivation of millets at the commercialisation level will provide farmers in rural communities with a source of income. There is a need to utilise new advanced technology for post-harvest processing of millet grains. New value addition is given priority in urban areas as well as in rural areas. The development of food processing technologies is required, which may help to retain the nutritional quality of millets, which offers potential health benefits [38].

Various food products such as biscuits, flour, noodles, bread, pasta, flour, snacks, porridge, and others are produced from refined millets flours, but these products are predominant in Asian countries. However, in recent years, some processed, value-added products are now visible in the SSA region (Fig. 8), although these products are not yet as prominent as products from other major grains like wheat, maize and rice. For instance, the *Yolele* fonio products are produced outside Africa, but the grains are sourced from Africa, thereby increasing grain cultivation and livelihoods of the farmers through gains on exportation. As stated on its website, the company was founded “to create economic opportunity for smallholder farming communities, to support their biodiverse, regenerative, and climate-resilient farming systems, and to share Africa’s ingredients and flavours with the world (<https://yolele.com/about>).” In addition, the company is already taking root to produce these products locally in West Africa. These are the initiatives that Africa needs to improve the value-added products of her ancient grains. Rathore et al. [19] reported that millet grain could be used to produce composite flour, baked items, extruded products, and other gluten-free cereal-based foods. Foods made from finger millet vary from country to country and area to region, and most of the items made in underdeveloped countries are not commercialised. Spaghetti, macaroni, pasta, noodles, vermicelli, and flakes are commercially accessible and widely consumed finger millet-based goods in affluent countries [21]. Instead of maize and wheat, millet is combined with buckwheat and amaranth to produce extruded snacks [19].

3.9 Challenges of utilising millet in value-added food products and future perspectives for sub-Saharan Africa

The food and nutritional security of the world’s population are impacted by an overreliance on major grains like wheat, oat, rice, and maize. The first challenge with millet utilisation in SSA is low commercial production. Despite their high nutritional composition and agronomic advantage, millets are mostly cultivated on a subsistence scale and sold in local markets. Ironically, millets are widely grown in countries with the highest malnutrition rates [39], which shows that their potential as a food source is significantly underutilised [96]. This problem can be mitigated by implementing improved agricultural techniques and streamlining supply and storage networks. The economy of SSA may experience tremendous growth due to the processing of millets into value-added food products.

Secondly, there is a paucity of shelf-ready, millet-based products in SSA. Millet is unavailable in the market in the form of refined or processed food products, making it challenging to get ready-to-use products. For instance, some consumers in SSA countries such as Zimbabwe are reportedly not keen on using millet as a staple food source. They ascribed this to the millet’s flavour, taste, and colour to the basic customs and way of life of some families. This has resulted in the farmers and processors not having an interest in producing more value-added millet products. Therefore, millet is commonly utilised to produce traditional beer [97]. The traditional millet food products that are primarily found in the African countries are produced from grains/flours such as alcoholic beverages (*pito*, *burukutu*) and non-alcoholic drinks (*kunu Zaki*); millet ball “*fura*”, *tuwo*, porridge and flatbread (*injera*). A great way to break ground into the ready-to-eat market is by making products such as biscuits, pasta, instant breakfast powders and infant foods. Another breakthrough will be making the flour shelf-ready so consumers can use it in traditional recipes for puffed pastry, bakery, and instant food mixes.

Millets have been reported to boost the overall acceptability of the food product when blended with other cereals, pulses, or legumes [98]. However, the utilisation of millets as food is very limited since they contain anti-nutritional factors such as phytic acid, tannins, and phenols. Moreover, pearl millet-based biscuits have been found to contain a high amount of phytic acid [99]. Improved processing technologies can be used to mitigate the technological and functional challenges with millet processing and produce value-added products such as multigrain flour. These technological methods include extrusion, malting, popping, or puffing, soaking, malting and fermentation, grinding,

cooking, and roasting, and they increase the nutritional composition and sensory properties of millets products [100, 101]. The lack of innovative processing technologies such as High-pressure processing (HPP) negatively influences the production and processing of convenient millet-type products. High-pressure processing has been applied to cereal grains such as rice, sorghum starch, corn starch and buckwheat starch and the technology showed positive results. For example, HPP improved the vitamin B and E in germinated rough rice and the degree of crystallinity of normal and waxy corn starches, thereby modifying the content of resistant starch [102, 103]. These studies suggested that HPP can improve cereal grain's techno-functional properties, such as starch solubility, foaming and gelling properties and small particle size. Another area of interest is extrusion technology. Millets can be used to produce extruded products like pasta and breakfast cereals since it is affordable, convenient and has a longer shelf life [104]. The millet products can be fortified with other plant-based nutrient-rich materials such as legumes, fruit flour and vegetable powder to improve its utilisation as a carrier of bioactive substances [105].

Lastly, diversification of end-use products is needed to make millet products appealing to consumers. Most of the baked products available in the market are mainly produced from wheat flour or millet flour [4, 19, 33]. However, current studies on millet product development focus on supplementation with other cereal grains such as wheat, maize, and rice to improve the nutritional health benefit and livelihoods [106]. This is a good start towards less reliance on wheat and may help to reduce chronic diseases such as high blood pressure, sugar, diabetes, cardiovascular diseases, and obesity [107, 108]. Production of value-added millet products can help to reach the goal of the United Nations' commitment to end malnutrition by 2030. The functional components of millets are concentrated when milled into flour—which can subsequently be utilised effectively in the large-scale production of ready-to-eat products, including baby foods and snack foods [109]. Millets contain no gluten, and their flours can be used to partially replace wheat flour in food products and thus can be consumed by people suffering from coeliac disease. Moreover, incorporating millets in value-added products is beneficial since the risk of constipation, duodenal ulcers and anaemia is reduced [110]. Providing millet-based products is needed to boost the consumption of millet food products and change diets for therapeutic purposes. Millet product development research is on the rise in Africa, but much ground still needs to be covered until the products are available on the shelves for consumers.

4 Conclusion

Millets are still considered a common food source for poor communities who cannot afford expensive food products that are rich sources of antioxidants. The results of this study show that millet grains contain many health-promoting components such as dietary fiber, minerals, vitamins, and phytochemicals. Traditional and novel processing methods are needed to improve micronutrients' bioavailability and modify the quality of millet products. Millet food products that deliver convenience, taste, texture, colour, and shelf-stability at an economical cost for poor people are needed. Furthermore, there is a need to bridge the gap of commercialising millet-based products in SSA because they are only traditionally prepared for home consumption.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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References

1. Durgad AG, Joshi AT, Hiremath GM. Consumer preference for foxtail and little millets in the Northeastern Region of Karnataka. *Econ Aff*. 2021;66(1):101–8.
2. Twinomuhwezi H, Awuchi CG, Rachael M. Comparative study of the proximate composition and functional properties of composite flours of amaranth, rice, millet, and soybean. *Am J Food Sci Nutr*. 2020;6(1):6–19.
3. Ransumithila C, Saravanakumar R. Millets can be a source of value-added healthy food products with different varieties for traditional and non-traditional millet users. Development of value-added millet-based nutritious “Instant Dhokla Mix.” *Int J Chem Stud*. 2019;7(3):4878–82.
4. Ambre PK, Sawant AA, Sawant PS. Processing and value addition: a finger millet review. *J Pharmacogn Phytochem*. 2020;9(2):375–80.
5. Ramashia SE, Gwata ET, Meddows-Taylor S, Anyasi TA, Jideani AIO. Processing, nutritional composition, and health benefits of finger millet in sub-Saharan Africa. *Food Sci Technol*. 2019;39(2):253–66. <https://doi.org/10.1590/fst.25017>.
6. Das S, Khound R, Santra M, Santra D. Beyond bird feed: Proso millet for human health and environment. *Agriculture*. 2019;9(3):64. <https://doi.org/10.3390/agriculture9030064>.
7. Babarinde GO, Adeyanju JA, Ogunleye KY, Adegbola GM, Egun AA, Wadele D. Nutritional composition of gluten-free flour from blend of fonio (*Digitaria iburua*) and pigeon pea (*Cajanus cajan*) and its suitability for breakfast food. *J Food Sci Technol*. 2020;57(10):3611–20. <https://doi.org/10.1007/s13197-020-04393-7>.
8. Kumar, A., Tomer, V., Kaur, A., Kumar, V., and Gupta, K. (2018). Millets: a solution to agrarian and nutritional challenges. *Agric. Food Secur*, 7, 31. <https://doi.org/10.1186/s40066-018-0183-3>
9. Mahajan P, Bera MB, Panesar PS, Chauhan A. Millet starch: a review. *Int J Biol Macromol*. 2021;180:61–79.
10. Mudau M, Mashau ME, Ramashia SE. Nutritional quality, antioxidant, microstructural and sensory properties of spontaneously fermented gluten-free finger millet biscuits. *Foods*. 2022;11:1265.
11. Ramashia SE, Gwata ET, Meddows-Taylor S, Anyasi TA, Jideani AIO. Some physical and functional properties of finger millet (*Eleusine coracana*) obtained in sub-Saharan Africa. *Food Res Int*. 2018;104:113–8. <https://doi.org/10.1016/j.foodres.2017.09.065>.
12. Saini S, Saxena S, Samtiya M, Puniya M, Dhewa T. Potential of underutilized millets as nutri-cereal: an overview. *J Food Sci Technol*. 2021;58(12):4465–77. <https://doi.org/10.1007/s13197-021-04985-x>.
13. Kaur P, Purewal SS, Sandhu KS, Kaur M, Salar RK. Millets: a cereal grain with potent antioxidants and health benefits. *J Food Meas Charact*. 2019;13(1):793–806. <https://doi.org/10.1007/s11694-018-9992-0>.
14. FAOSTAT (2022). <https://www.fao.org/faostat/en/#search/fonio>. Accessed 20 Sep 2024.
15. Lee H. Teff, a rising global crop: current status of teff production and value chain. *Open Agric J*. 2018;12:185–93. <https://doi.org/10.2174/1874331501812010185>.
16. Omaji GO, Osibemhe M, Orji BO, Ilouno LE, Abdulrahman BO, Ajadi AO. Antioxidant potential of crude powder, methanol and aqueous extracts of fonio millet (*Digitaria exilis*) grains. *Niger J Biotechnol*. 2021;38(1):91–7. <https://doi.org/10.4314/njb.v38i1.11>.
17. Annor GA, Marcone M, Bertoft E, Seetharaman K. Physical and molecular characterization of millet starches. *Cereal Chem*. 2014;91(3):286–92. <https://doi.org/10.1094/CCHEM-08-13-0155-R>.
18. Birania S, Rohilla P, Kumar R, Kumar N. Post-harvest processing of millets: A review on value-added products. *Int J Chem Stud*. 2020;8(1):1824–9.
19. Rathore S, Singh K, Kumar V. Millet grain processing, utilization, and its role in health promotion: a review. *Int J Nutr Food Sci*. 2016;5(5):318–29.
20. Patil PB. Rejuvenating millets through value addition. *Food Sci Res J*. 2018;9(2):431–3.
21. Jaybhaye RV, Pardeshi IL, Vengaiya PC, Srivastav PP. Processing and technology for millet-based food products: a review. *J Ready Eat Food*. 2014;1(2):32–48.
22. Mutshinyani M, Mashau ME, Jideani AIO. Bioactive compounds, antioxidant activity and consumer acceptability of porridges of finger millet (*Eleusine coracana*) flours Effects of spontaneous fermentation. *Int J Food Prop*. 2020;23(1):1692–710.
23. Jideani IA. (2012). *Digitaria exilis* (acha/fonio), *Digitaria iburua* (iburu/fonio) and *Eleusine coracana* (tamba/finger millet). Non-conventional cereal grains with potential. *Review Sci Res Essays*. 7(45), 3834–3843
24. Ramashia SE, Gwata ET, Meddows-Taylor S, Anyasi TA, Jideani AIO. Nutritional composition of finger millet (*Eleusine coracana*) flours fortified with vitamin B2 and zinc oxide. *Food Res*. 2021;5(2):456–67.
25. Yousaf L, Hou D, Liaqat H. Millet: a review of its nutritional and functional changes during processing. *Food Res Int*. 2021;142:110197. <https://doi.org/10.1016/j.foodres.2021.110197>.
26. Marak NR, Malemnganbi CC, Marak CR, Mishra LK. Functional and antioxidant properties of cookies incorporated with foxtail millet and ginger powder. *J Food Sci Technol*. 2019;56(11):5087–96. <https://doi.org/10.1007/s13197-019-03981->
27. Hassan ZN, Sebola NA, Mabelebele M. The nutritional use of millet grain for food and feed: a review. *Agric Food Secur*. 2021. <https://doi.org/10.1186/s40066-020-00282-6>.
28. Mohamed TK, Zhu K, Issoufou A, Fatmata T, Zhou H. Functionality, in vitro digestibility, and physicochemical properties of two varieties of defatted foxtail millet protein concentrates. *Int J Mol Sci*. 2009;10(12):5224–38. <https://doi.org/10.3390/ijms10125224>.
29. Gaikwad V, Rasane P, Singh J, Idate A, Kumthekar S. Millets: nutritional potential and utilization. *The Pharm Innov J*. 2021;10(5):310–3.
30. Pragma UD, Pradesh VE, Singh TK. Chemical composition of finger millet of food and nutritional security. *Rev Adv Food Sci Technol*. 2017;5(8):001–8.

31. Karki A, Chandra A, Joshi S, Rawat P, Shilpa Sharma S. An overview of Finger millet (*Eleusine coracana* L.). J Pharm Phytochem. 2020;9(4):866–9.
32. Jideani IA, Jideani VA. Developments on the cereal grains *Digitaria exilis* (acha) and *Digitaria iburu* (iburu). J Food Sci Technol. 2011;48(3):251–9. <https://doi.org/10.1007/s13197-010-0208-9>.
33. Sadhu VJS, Naidu S. A study on functional and nutritional characteristics of barnyard millet and foxtail millet. Food Nutr J. 2021;6:234.
34. Sharma N, Niranjana K. Foxtail millet properties, processing, health benefit and uses. Food Rev Int. 2018;34(329–363):10. <https://doi.org/10.1080/87559129.2017.1290103>.
35. Zhang L, Li J, Han F, Ding Z, Fan L. Effects of different processing methods on the antioxidant activity of 6 cultivars of foxtail millet. J Food Qual. 2017;9(8):8372854. <https://doi.org/10.1155/2017/8372854>.
36. Kalinova J, Moudry J. Content and quality of protein in proso millet (*Panicum miliaceum* L.) varieties. Plant Food Human Nutr. 2006;61(1):43–7. <https://doi.org/10.1007/s11130-006-0013-9>.
37. Mudau M, Ramashia SE, Mashau ME, Silungwe H. Physicochemical characteristics of bread partially substituted with finger millet flour. Braz J Food Technol. 2021;24(e2020123):10. <https://doi.org/10.1590/1981-6723.12320>.
38. Sirigeri HU, Veen BM, Reddy PV. Study on the acceptability and functional properties of millets incorporated fryums. Int J Pharm Sci Res. 2022;13(3):1285–90.
39. Muthamilarasan M, Prasad M. Small millets for enduring food security amidst pandemics. Trend Plant Sci. 2021;26(1):33–40. <https://doi.org/10.1016/j.tplants.2020.08.008>.
40. Habiyaremye C, Matanguihan JB, D'Alpoim Guedes J, Ganjyal GM, Whiteman MR, Kidwell KK, Murphy KM. Proso millet (*Panicum miliaceum* L.) and its potential for cultivation in the Pacific Northwest, U.S.: a review. Front Plant Sci. 2017;7(1961):10. <https://doi.org/10.3389/fpls.2016.01961>.
41. Krishnan R, Meera MS. Pearl millet minerals: effect of processing on bioaccessibility. J Food Sci Technol. 2018;55(9):3362–72. <https://doi.org/10.1007/s13197-018-3305-9>.
42. Jocelyne RE, Béhiblo K, Ernest AK. Comparative study of nutritional value of wheat, maize, sorghum, millet, and fonio: some cereals commonly consumed in Cote d'Ivoire. Eur Sci J. 2020;16(21):118–31. <https://doi.org/10.19044/esj.2020.v16n21p118>.
43. Awulachew MT. Teff (*Eragrostis Abyssinica*) and teff-based fermented cereals. J Health Environ Res. 2020;6(1):1–9.
44. Zhu F. Chemical composition and food uses of teff (*Eragrostis tef*). Food Chem. 2018;239:402–15. <https://doi.org/10.1016/j.foodchem.2017.06.101>.
45. Gebru YA, Sbhathu DB, Kim KP. Nutritional composition and health benefits of teff (*Eragrostis tef* (Zucc) Trotter). J Food Qual. 2020. <https://doi.org/10.1155/2020/9595086>.
46. Chen O, Mah E, Dioum E, Marwaha A, Shanmugam S, Malleshi N, Sudha V, Gayathri R, Unnikrishnan R, Anjana RM, Krishnaswamy K, Mohan V, Chu Y. The role of oat nutrients in the immune system: A narrative review. Nutrients. 2021;13(4):1048. <https://doi.org/10.3390/nu13041048>.
47. Jha R, Zhang K, He Y, Mendler-Drienyovszki N, Magyar-Tabori, K, Quinet M, Germ M, Kreft I, Megli V, Ikeda K, Chapman MA, Dagmar Janovska D, Podolska G, Woo S-H, Bruno S, Georgiev MI, Chrungoo N, Betekhtin A, Zhou M. Global nutritional challenges and opportunities: Buckwheat, a potential bridge between nutrient deficiency and food security. Trends Food Sci. Technol. 2024;145:104365. <https://doi.org/10.1016/j.tifs.2024.104365>.
48. Shi J, Shan S, Li Z, Li H, Xinfeng Li X, Li Z. Bound polyphenol from foxtail millet bran induces apoptosis in HCT-116 cell through ROS generation. J Function Foods. 2015;17:958–68. <https://doi.org/10.1016/j.jff.2015.06.049>.
49. Mahendrakar MD, Parveda M, Kishor PK, Srivastava RK. Discovery and validation of candidate genes for grain iron and zinc metabolism in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Scientific Rep. 2020;10(1):1–16. <https://doi.org/10.1038/s41598-020-73241-7>.
50. Srivastava RK, Satyavathi CT, Mahendrakar MD, Singh RB, Kumar S, Govindaraj M, Ghazi IA. Addressing iron and zinc micronutrient malnutrition through nutrigenomics in pearl millet: Advances and prospects. Front Genet. 2021;12:723472. <https://doi.org/10.3389/fgene.2021.723472>.
51. Yadav OP, Upadhyaya HD, Reddy KN, Jukanti AK, Pandey S, Tyagi. Genetic resources of pearl millet: Status and utilization. Indian J Plant Genet Resour. 2017;30:31–47. <https://doi.org/10.5958/0976-1926.2017.00004.3>.
52. Govindaraj M, Rai KN, Cherian B, Pfeiffer WH, Kanatti A, Shivade H. Breeding biofortified pearl millet varieties and hybrids to enhance millet markets for human nutrition. Agriculture. 2019;9(5):106. <https://doi.org/10.3390/agriculture9050106>.
53. Pujar M, Govindaraj M, Gangaprasad S, Kanatti A, Shivade H. Genetic variation and diversity for grain iron, zinc, protein and agronomic traits in advanced breeding lines of pearl millet [*Pennisetum Glaucum* (L.) R. Br.] for biofortification breeding. Genet Resour Crop Evol. 2020;67:2009–22. <https://doi.org/10.1007/s10722-020-00956-x>.
54. Zhang AX, Liu XD, Wang GR, Wang HJ, Liu JK, Zhao W, Zhang YZ. Crude fat content and fatty acid profile and their correlations in foxtail millet. Cereal Chem. 2015;92(5):455–9. <https://doi.org/10.1094/CCHEM-12-14-0252-R>.
55. Chandrasekara A, Shahidi F. Content of insoluble bound phenolics in millets and their contribution to antioxidant capacity. J Agric Food Chem. 2010;58(11):6706–14. <https://doi.org/10.1021/jf100868b>.
56. Kumari J, Bag MK, Pandey S, Jha SK, Chauhan SS, Jha GK, Gautam NK, Dutta M. Assessment of phenotypic diversity in pearl millet [*Pennisetum glaucum* (L.) R. Br.] germplasm of Indian origin and identification of trait-specific germplasm. Crop Pasture Sci. 2016;67(12):1223–34. <https://doi.org/10.1071/CP16300>.
57. Xiang J, Apea-Bah FB, Ndolo VU, Katundu MC, Beta T. Profile of phenolic compounds and antioxidant activity of finger millet varieties. Food Chem. 2019;275:361–8. <https://doi.org/10.1016/j.foodchem.2018.09.120>.
58. Chandrasekara A, Shahidi F. Determination of antioxidant activity in free and hydrolyzed fractions of millet grains and characterization of their phenolic profiles by HPLC-DAD-ESI-MS. J Funct Foods. 2011;3:144–58. <https://doi.org/10.1016/j.jff.2011.03.007>.
59. Ofosu FK, Elahi F, Daliri EB, Chelliah R, Ham HJ, Kim JH, Han SI, Hur JH, Oh DH. Phenolic profile, antioxidant, and antidiabetic potential exerted by millet grain varieties. Antioxidants. 2020;9(3):254. <https://doi.org/10.3390/antiox903025>.
60. Watanabe M. Antioxidative phenolic compounds from Japanese barnyard millet (*Echinochloa utilis*) grains. J Agric Food Chem. 1999;47:4500–5. <https://doi.org/10.1021/jf990498s>.

61. Siwela M, Taylor JRN, de Milliano WAJ, Duodu KG. Occurrence and location of tannins in finger millet grain and antioxidant activity of different grain types. *Cereal Chem*. 2007;84(2):169–74. <https://doi.org/10.1094/CCHEM-84-2-0169>.
62. Adebisi JA, Obadina AO, Adebo OA, Kayitesi E. Fermented and malted millet products in Africa: Expedition from traditional/ethnic foods to industrial value-added products. *Crit Rev Food Sci Nutr*. 2018;58(3):463–74. <https://doi.org/10.1080/10408398.2016.1188056>.
63. Kubo R. The reason for the preferential use of finger millet (*Eleusine coracana*) in eastern African brewing. *J Inst Brew*. 2016;122(1):175–80. <https://doi.org/10.1002/jib.309>.
64. Nami Y, Gharekhani M, Aalami M, Hejazi MA. Lactobacillus-fermented sourdoughs improve the quality of gluten-free bread made from pearl millet flour. *J Food Sci Technol*. 2019;56(9):4057–67. <https://doi.org/10.1007/s13197-019-03874-8>.
65. Murungweni KT, Ramashia SE, Mashau ME. Effect of malting on physicochemical, antioxidant, and microstructural properties of finger millet (*Eleusine coracana*) flours. *Food Sci Nutri*. 2024;12:547–63. <https://doi.org/10.1002/fsn3.3790>.
66. Theodoro JMV, Martinez ODM, Grancieri M, Toledo RCL, Martins AMD, Dias DM, Martino HSD. Germinated millet flour (*Pennisetum glaucum* (L.) R. Br.) reduces inflammation, oxidative stress, and liver steatosis in rats fed with high-fat high-fructose diet. *J Cereal Sci*. 2021;99:103207. <https://doi.org/10.1016/j.jcs.2021.103207>.
67. Laxmi G, Chaturvedi N, Richa S. The impact of malting on the nutritional composition of foxtail millet, wheat, and chickpea. *J Nutr Food Sci*. 2015;5(5):1–3. <https://doi.org/10.4172/2155-9600.100040>.
68. Nefale FE, Mashau ME. Effect of germination period on the physicochemical, functional, and sensory properties of finger millet flour and porridge. *Asian J Appl Sci*. 2018;6(5):360–7.
69. Pradeep SR, Guha M. Effect of processing methods on the nutraceutical and antioxidant properties of little millet (*Panicum sumatrense*) extracts. *Food Chem*. 2011;126(4):1643–7. <https://doi.org/10.1016/j.foodchem.2010.12.047>.
70. Bi S, Wang A, Wang Y, Xu X, Luo D, Shen Q, Wu J. Effect of cooking on aroma profiles of Chinese foxtail millet (*Setaria italica*) and correlation with sensory quality. *Food Chem*. 2019;289:680–92.
71. Kaur A, Kumar K, Dhaliwal HS. Physico-chemical characterization and utilization of finger millet (*Eleusine coracana* L.) cultivars for the preparation of biscuits. *J Food Process Preserv*. 2020;44:e14672.
72. Krishnan R, Dharmaraj U, Manohar RS, Malleshi NG. Quality characteristics of biscuits prepared from finger millet seed coat-based composite flour. *Food Chem*. 2011;129(2):499–506.
73. Adebisi JA, Obadina AO, Adebo OA, Kayitesi E. Comparison of nutritional quality and sensory acceptability of biscuits obtained from native, fermented, and malted pearl millet (*Pennisetum glaucum*) flour. *Food Chem*. 2017;232:210–7.
74. Agu H, Badau M, Usman A, Jideani V. Effects of steaming duration and preservatives on storage stability of pearl millet based instant Dambu. *Aust J Eng Res*. 2014;1:50–60.
75. Obilana, A.O., Odhav, B., and Jideani, V.A. (2018). Nutritional, biochemical, and sensory properties of instant beverage powder made from two different varieties of pearl millet. *Food Nutr Res*. 62: 1524. <https://doi.org/10.29219/fnr.v62.1524>
76. Chu J, Zhao H, Lu Z, Lu F, Bie X, Zhang C. Improved physicochemical and functional properties of dietary fibre from millet bran fermented by *Bacillus natto*. *Food Chem*. 2019;294:79–86.
77. Wei C, Ge Y, Liu D, Zhao S, Wei M, Jiliu J, Hu X, Quan Z, Wu Y, Su Y, Wang Y, Cao L. Effects of high-temperature, high-pressure, and ultrasonic treatment on the physicochemical properties and structure of soluble dietary fibres of millet bran. *Front Nutr*. 2022;8:820715. <https://doi.org/10.3389/fnut.2021.820715>.
78. Zheng Y, Wang X, Tian H, Li Y, Shi P, Guo W, Zhu Q. Effect of four modification methods on adsorption capacities and in vitro hypoglycemic properties of millet bran dietary fibre. *Food Res Int*. 2021;147:110565. <https://doi.org/10.1016/j.foodres.2021.110565>.
79. Rai KN, Gowda CLLR Abah CR, Ishiwu CN, Obiegbuna JE, Oladejo AA. Nutritional composition, functional properties, and food applications of millet grains. *Asian Food Sci J*. 2020;14(2):9–19. <https://doi.org/10.9734/afsj/2020/v14i230124>.
80. Feyera M, Dasa F, Kebero K. Formulation and quality evaluation of finger millet-based composite food products. *Int J Nutr Food Sci*. 2021;10(3):59–65. <https://doi.org/10.11648/j.ijnfs.20211003.11>.
81. Neela S, Fanta SW. Injera (An ethnic, traditional staple food of Ethiopia): a review on traditional practice to scientific developments. *J Ethn Foods*. 2020;7(1):1–15. <https://doi.org/10.1186/s42779-020-00069-x>.
82. Tamene A, Kariluoto S, Baye K, Humblot C. Quantification of folate in the main steps of traditional processing of tef injera, a cereal-based fermented staple food. *J Cereal Sci*. 2019;87(225–230):10. <https://doi.org/10.1016/j.jcs.2019.04.005>.
83. Hlangwani E, Adebisi JA, Doorsamy W, Adebo OA. Processing, characteristics, and composition of umqombothi (a South African traditional beer). *Processes*. 2020;8(11):1451. <https://doi.org/10.3390/pr8111451>.
84. Hlangwani E, Doorsamy W, Adebisi JA, Fajimi LI, Adebo OA. A modelling method for the development of a bioprocess to optimally produce umqombothi (a South African traditional beer). *Sci Rep*. 2021;11(1):1–15. <https://doi.org/10.1038/s41598-021-00097-w>.
85. Ma DY, Zhang J, Lou XY, Wang XN, Wang CY, Guo TC. Colour, cooking properties and texture of yellow alkaline noodles enriched with millet and cornflour. *Int Food Res J*. 2014;21(3):1151.
86. Dissanayake BDMPB, Jayawardena HS. Development of a method for manufacturing noodles from finger millet. *Procedia Food Sci*. 2016;6:293–7. <https://doi.org/10.1016/j.profoo.2016.02.058>.
87. Lü H, Li Y, Zhang J, Yang X, Ye M, Li Q, Wu N. Component and simulation of the 4000-year-old noodles excavated from the archaeological site of Lajia in Qinghai, China. *Sci Bull*. 2014;59(35):5136–52. <https://doi.org/10.1007/s11434-014-0663-1>.
88. Orr A, Weltzien E, Rattunde F. Research and development for sorghum and millets in Sub-Saharan Africa: What have we learned? *Outlook Agric*. 2022;51(4):435–47. <https://doi.org/10.1177/00307270221133127>.
89. Upadhyaya HD, Reddy KNM, Ahmed I, Gowda CLL, Haussmann BIG. Identification of geographical gaps in the pearl millet germplasm conserved at ICRISAT genebank from West and Central Africa. *Plant Genet Resour-Charact Util*. 2009;8(1):45–51. <https://doi.org/10.1017/S147926210999013X>.
90. Mbinda W, Masaki H. Breeding strategies and challenges in the improvement of blast disease resistance in finger millet. A current review. *Front Plant Sci*. 2021;11:602882. <https://doi.org/10.3389/fpls.2020.602882>.
91. ICRISAT and Food and Agriculture Organization of the United Nations. The world sorghum and millet economies. Hyderabad, India: ICRISAT.1996.

92. Masenya TI, Mlambo V, Mnisi CM. Complete replacement of maize grain with sorghum and pearl millet grains in Jumbo quail diets: Feed intake, physiological parameters, and meat quality traits. *PLoS One*. 2021;29,16(3):e0249371. <https://doi.org/10.1371/journal.pone.0249371>.
93. Cisse RS, Hamburg JD, Freeman ME, Davis AJ. Using locally produced millet as a feed ingredient for poultry production in Sub-Saharan Africa. *J Appl Poult Res*. 2017;26(1):9–22. <https://doi.org/10.3382/japr/pfw042>.
94. Mushtaq BS, Waleed AA, Dhungle A, Haq F, Mahdi AA, Walayat N, Manzoor MS, Nawaz A, Fan M, Qian H, Jinxin L. Influence of pretreatments combined with extrusion on γ -aminobutyric acid, nutritional composition, and physicochemical properties of foxtail millet (*Setaria italica*). *J Cereal Sci*. 2021;102:103359. <https://doi.org/10.1016/j.jcs.2021.103359>.
95. Prakash O, Jha SK, Rudra SG, Jha GK, Sinha JP, Hossain F. Development of quality protein maize-based breakfast cereal. *Ind J Agric Sci*. 2021;91(2):300–4.
96. Sharma N, Keshavan Niranjan K. Foxtail millet: Properties, processing, health benefits, and uses. *Food Rev Int*. 2018;34(4):329–63. <https://doi.org/10.1080/87559129.2017.1290103>.
97. Phiri K, Dube T, Moyo P, Ncube C, Ndlovu S, Buchenrieder G. Small grains “resistance”? Making sense of Zimbabwean smallholder farmers’ cropping choices and patterns within a climate change context. *Cogent Soc Sci*. 2019;5:1. <https://doi.org/10.1080/23311886.2019.1622485>.
98. Deshpande HW, Poshadri A. Physical and sensory characteristics of extruded snacks prepared from Foxtail millet-based composite flours. *Int Food Res J*. 2011;18(2):751–6.
99. Devi NL, Shobha S, Tang X, Shaur SA, Dogan H, Alavi S. Development of protein-rich sorghum-based expanded snacks using extrusion technology. *Int J Food Prop*. 2013;16(2):263–76. <https://doi.org/10.1080/10942912.2011.551865>.
100. Abah D, Oraka EO, Ochoche OC. Trend analysis of millet production and agricultural output in Nigeria (1981–2018). *Int Res J Innov Eng Technol*. 2021;5(3):5.
101. Atuna RA, Ametei PN, Bawa AA, Amagloh FK. Traditional processing methods reduced phytate in cereal flour and improved nutritional, functional and rheological properties. *Sci Afr*. 2022;15: e01063. <https://doi.org/10.1016/j.sciaf.2021.e01063>.
102. Kim HS, Lee EJ, Lim S, Han JA. Self-enhancement of GABA in rice bran using various stress treatments. *Food Chem*. 2015;172:657–62. <https://doi.org/10.1007/s13562-021-00761-2>.
103. Li W, Tian X, Liu L, Wang P, Saleh ASM, Luo Q, Zheng J, Ouyang S, Zhang Q. Recrystallization characteristics of high hydrostatic pressure gelatinized normal and waxy corn starch. *Int J Biol Macromol*. 2016;83:171–7. <https://doi.org/10.1016/j.ijbiomac.2015.11.057>.
104. Nilusha RAT, Jayasinghe JMJK, Perera ODAN, Perera PIP. Development of pasta products with nonconventional ingredients and their effect on selected quality characteristics: A brief overview. *Int J Food Sci*. 2019. <https://doi.org/10.1155/2019/6750726>.
105. Michalak-Majewska M, Teterycz D, Muszyński S, Radzki W, Sykut-Domańska E. Influence of onion skin powder on nutritional and quality attributes of wheat pasta. *PLoS One*. 2020;15(1):e0227942. <https://doi.org/10.1371/journal.pone.0227942>.
106. Cordelino IG, Tyl C, Inamdar L, Vickers Z, Marti A, Ismail BP. Cooking quality, digestibility, and sensory properties of proso millet pasta as impacted by amylose content and prolamin profile. *LWT Food Sci Technol*. 2019;99(1–7):10. <https://doi.org/10.1016/j.lwt.2018.09.035>.
107. Diarra M, Torres-Aguilar P, Hayes AMR, Cisse F, Nkama I, Hamaker BR. Malian thick porridges (to) of pearl millet are made thinner in urban than rural areas and decrease satiety. *Food Nutr Bull*. 2022;43(1):35–43. <https://doi.org/10.1177/03795721211047435>.
108. Kumar RR, Singh N, Singh S, Vinutha T, Krishnan V, Goswami S, Kumar B, Jat SL, Yogeesh LN, Singh SP, Mishra GP, Satyavathi CT, Praveen S. Nutritional supremacy of pearl- and foxtail millets: assessing the nutrient density, protein stability and shelf-life of flours in millets and cereals for developing nutri-stable foods. *J Plant Biochem Biotechnol*. 2022. <https://doi.org/10.1007/s13562-021-00761-2>.
109. Devisetti R, Yadahally SN, Bhattacharya S. Nutrients and antinutrients in foxtail and proso millet milled fractions: evaluation of their flour functionality. *LWT Food Sci Technol*. 2014;2014(59):889–95. <https://doi.org/10.1016/j.lwt.2014.07.003>.
110. Nambiar VS, Dhaduk JJ, Sareen N, Shahu T, Desai R. Potential functional implications of pearl millet (*Pennisetum glaucum*) in health and disease. *J Appl Pharm Sci*. 2011;1:62–7.

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