Chapter

Millets Cereal Grains: Nutritional Composition and Utilisation in Sub-Saharan Africa

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Abstract

Millets are small to medium size cereal grain crops that are cultivated throughout the tropics and subtropical region. The grains are used for food and fodder for feeding animals around the globe. Millets have great economic, health importance, gluten-free, have low glycemic index and are known as "nutra–cereals". The grains are mostly utilised as a food source by population with lower socio-economic factors which are traditional consumers in the farm and village levels. They are rich sources of carbohydrates, protein, crude fibre, phytochemicals, minerals, and vitamins. They are processed by using different traditional processes such as soaking, germination, malting, fermentation, milling or grinding, cooking, roasting and popping. Millet grains/ flours are utilised and consumed as flat breads, biscuits, snacks, beverages, porridges, *chapati*, *dosa*, pastas. There is a need to produce new value-added products from millets which is underutilised crop to improve food security and prevent micronutrients deficiencies.

Keywords: Millets, cereal grains, nutritional composition, health benefits, utilisation

1. Introduction

Millets are cereal crops that belong to the family *Gramineae* and they are small-seeded species [1–3]. Most millets belong to the tribe *Panicoideae* apart from finger millet and teff that belong to the tribe *Eragrostideae* [4–6]. The grains are available in some parts of African countries and they are cheap [7]. They differ from each other by their appearance, grains quality, taste, morphological and biochemical behavior [8]. They are widely grown around the world for food and fodder and are staple food in the West, East, Central and Great Lakes region of Africa as well as in Asia and India [9–11]. The word millet has been derived from the French word "mille" which means thousand, a handful of millet has been referred to contain thousands of grains [12]. Millets are classified with maize and sorghum in the grass sub-family *Panicoideae* [3, 8]. They are the 6th most important cereal grain crop in the world agricultural production after wheat, maize, sorghum, rice, and barley that are regarded as the major economic grains in the world [13–15]. Millets are resistant to pests and diseases as compared to other cereal grains [1, 13]. They are major food sources for millions of people, especially those who live in hot, dry areas of the world, adapt to harsh environment especially drought conditions. Millets are one of the cereal grain crops

that are drought-tolerant and have short growing season [15, 16]. They grow well on poorly fertilised and dry soils with short rainfall periods [1, 17]. The grains are cultivated between February and August while harvested in June or January [18]. About 55–60% of worldwide produced millet grains are cultivated in the sub-Saharan Africa including Ethiopia, Kenya, Malawi, Nigeria, Tanzania, Uganda, Zambia, and Zimbabwe (**Table 1**). Major types of cultivated millet species varieties are finger millet (*Eleusine coracana*), pearl millet (*Pennisetum glaucum)*, Japanese banyard millet (*Ecchinochloa frumentacea*); foxtail millet *(Setaria italica)* and proso or white millet *(Panicum miliaceum)* [20, 21].

The millet grains are gluten-free, non-acid forming, easy to digest, low glycemic index and healthy food diet for people with celiac disease – common disease caused by cereal protein ingestion [1, 2, 19, 22]. Other gluten-free cereal grains are maize, brown rice and sorghum while barley, wheat and rye are gluten rich cereal grains [4]. **Table 2** and **Figure 1** show the major cultivated millet species in the world. Millets are globally grown in different regions from East to West and they are called in different names around the globe which indicate their specific originality such as foxtail millet as Italian millet, proso as French millet and barnyard as Japanese millet [25]. Finger millet originated in East Africa while white fonio (*Digitaria exilis*), black fonio (*Digitaria iburua*) and pearl millet originated in West Africa [26]. **Table 3** shows various characteristics of millet species and their functions are shown in **Table 4**.

Countries	**Yearly production (in tonnes)**				
	2015	**2016**	**2017**	**2018**	**2019**
Angola	43746	42000	70000	69854	51054
Benin	21640	25182	24717	26143	25000
Botswana	555	1264	1099	2462	902
Burkina Faso	946184	905071	828234	1189079	970176
Burundi	9970	10019	9955	9891	9827
Cameroon	95810	99015	101101	103186	105271
Central African Republic	10000	10000	10000	10000	10000
Chad	592124	725677	660175	756616	717621
Congo	13197	13595	13896	14197	14499
Côte d'Ivoire	55200	58300	61600	65000	65000
Democratic Republic of the Congo	43776	41006	40887	40908	40930
Ethiopia	1036444	1017059	1030823	1035630	1125958
Gambia	73420	65073	52000	38000	35000
Ghana	157369	159017	163484	181564	190000
Guinea	224587	238177	241714	214747	223220
Guinea-Bissau	14000	14000	16177	18000	20000
Kenya	99000	54000	54000	72000	135000
Malawi	33512	19510	35121	31315	34479
Mali	1864301	1806559	1492650	1840321	1878527
Mauritania	2790	3145	3277	3247	3218
Morocco	4953	4564	4312	4104	3928
Mozambique	10916	21000	21000	19869	12832

Countries	Yearly production (in tonnes)				
	2015	**2016**	**2017**	**2018**	**2019**
Namibia	42494	19428	57644	83515	18700
Niger	3404813	3886079	3790028	3856344	3270453
Nigeria	1485387	1552576	1500000	2119000	2000000
Rwanda	4960	5021	5083	5140	5195
Senegal	749874	493340	875484	897574	807044
Sierra Leone	44000	38000	39000	38000	38000
South Africa	6243	5950	5683	5424	5160
South Sudan	8000	6000	5000	5000	5000
Sudan	486000	1449000	878000	2647000	1133000
Togo	38664	23838	26044	26082	26806
Uganda	236484	193461	211050	238558	243104
Zambia	31967	29972	32566	32278	24843
Zimbabwe	17672	27461	62157	38964	35000

Source: [19].

Table 1.
Millet production in sub Saharan Africa in thousands per tons from 2015 to 2019.

Common name	Tribes/genus and species	References
Finger millet/*ragi/mandua/nagli/nachani/kurakkan/mufhoho*	*Eleusine coracana*	[2, 20]
Teff	*Eragrostis tef*	[4]
White fonio (*acha*)	*Digitaria exilis*	[22, 23]
Black fonio (*iburu*)	*Digitaria iburua*	
Barnyard millet/*banti/kudiraivali sawan/shama*	*Echinochloa frumentacea*	[1, 2, 24]
Proso millet/*panivaragu/kutki/cheena*	*Panicum miliaceum*	[13, 20]
Kodo millet/*haraka/varagu/kodra/ditch*	*Paspalum scrobiculatum*	[13, 15]
Foxtail millet/*navane/tenia/kauni/kakun*	*Setaria italic*	[2, 13]
Pearl millet/*bajra/cambu/saije/cattail*	*Pennisetum glaucum*	[15, 20]

Table 2.
Major cultivated millet species.

2. Nutritional composition of millet species

Some nutritional values of millets are similar to that of wheat and rice. Millets are staple food for many African countries; however, they are low in macro nutrients such as protein and fat but rich in vitamins and minerals [7]. Millets are a good source of magnesium which reduces the severity of asthma, frequency of migraines, lowers high blood pressure and reduces the risk of heart attacks. These nutrients play important roles in human nutrition [27]. The grains are also a good source of diet for growing children and expectant mothers [28]. They are a good source of phytochemicals such as polyphenols, tannins, and phytic acid which helps to lower cholesterol and reduces cancer risk, high blood pressure, heart disease and diabetes

Figure 1.
Cultivated millet species. A = Foxtail millet; B = Pearl millet; C = Proso millet; D = Banyard millet; E = Teff millet and F = Kodo millet. Source: [25].

Millet	Colour	Shape	Size	Origin
Foxtail millet	Pale yellow to red	Ovoid	2 mm long	China
Finger millet	Light to dark brown	Spherical	1–2 mm in diameter	East Central Africa (Uganda)
Proso millet	White cream, yellow, orange	Spherical oval	3 mm long/ 2 mm diameter	Central and eastern Asia
Pearl millet	White, grey, pale yellow, brown, or purple.	Ovoid	3–4 mm in length	Tropical West Africa (Sahel)
Kodo millet	Blackish to dark brown	Elliptical and oval	1.2 to 9.5 μm long	Mainly in India also in west Africa
Little millet	Grey to straw white	Elliptical and oval	1.8 to 1.9 mm long	Southeast Asia
Banyard millet	White	Tiny round	2–3 mm long	Mainly Japan and India

Source: [18].

Table 3.
Various characteristics of millet species.

[21, 27]. Other potential health benefits and medical function of millets are increasing in time span of gastric emptying and provides roughage to gastro intestine. Millet is also known as an alkaline forming food. Alkaline based diet is often recommended to get better optimal health and prevent illness/ diseases [7, 29].

Table 5 shows the nutritional composition of some millet's species. They have higher amount of minerals such as magnesium, manganese, phosphorus, iron, copper, and potassium when compared with corn, sorghum, and wheat [1, 8, 30]. The main nutrients in millets are starch, protein, lipid, dietary fibre, vitamins, and minerals as shown in **Table 6**. When comparing millet with other cereals, millet contains 75% of carbohydrates and is low in fat (2–5%) content than maize, rice, and sorghum [1, 2, 8]. Other potential health benefits of millets are the development and repair of body tissue, the prevention of gallstones, protection against breast cancer and protection against postmenopausal complications and the reduction of chances of childhood cancer [1, 2]. Millets contain 65–75% of complex

Millet	Functions
Finger millet	It prevents tissue damage and stimulates the wound healing process in diabetic rats. Prevents cardiovascular disease by reducing plasma triglycerides in hyperlipidemic rats.
Proso millet	Gluten-free and can prevent humans from celiac disease. Helpful in reducing the risk of type 2 diabetes in humans due to a low glycemic index.
Foxtail millet	It prevents colorectal cancer in mice models. Reduces cholesterol level & have an antidiabetic effect on impaired glucose tolerance persons. Capable of attenuating acute ethanol-induced hepatic injury in mice.
Pearl millet	Prevention of celiac disease in humans due to gluten-free property. Stimulates the immune system to prevent the Shigella-induced pathogenicity in the mice model.
Banyard millet	Acts as an inhibitor of cancer by inducing apoptotic cell death in HT-29 human colon cancer cell line. Its phenolic content inhibits the protein glycation and glycoxidation, which plays a crucial role in the progression of diabetes.
Little millet	Prevents from modern metabolic disorders due to the presence of polyphenols.
Kodo millet	Reduce glycemic index and prevents diabetes in the human female model, also have antioxidant activities.

Source: [25].

Table 4.
Functions of millet species.

Mineral contents (mg/ kg)	Millet	Wheat	Maize	Rice	Sorghum
Phosphorus	2400	1170	990	1030	350
Potassium	2200	1550	1200	1500	240
Magnesium	1000	250	470	350	188
Calcium	100	170	60	60	27
Sodium	None	20	10	20	5
Zinc	34	8	5	17	3
Iron	48	12	11	12	11
Manganese	7	5	NA	9	1
Source: [30]					
Nutrient compositions (g/100 g)					
Protein	7–12	11.6–11.8	8.1–10.5	6.8–7	7.9
Fat	2–5	1.5–2.0	3.8–4.6	0.5–1	2.8
Minerals	1.0–2.3	1.5–1.8	1.2	0.6	1.6
Dietary fibre	15–20	2.0–12.6	2.8–13.4	4.1	2.3–12.8
Carbohydrates	65–75	71.0–71.2	73.0	78.2–79.0	73.0
Vitamins (mg/100 g)					
Riboflavin	0.25	0.17	0.20	0.06	0.15
Thiamine	0.59	0.45	0.38	0.06	0.38
Niacin	3.2	5.5	3.6	1.9	4.3

NA – not applicable.
Sources: [1, 14, 27, 30–32].

Table 5.
Nutritional composition of whole grains (at 12% moisture).

Contents	Foxtail millet	Kodo millet	Barnyard millet	Pearl millet
Proximate composition (g)				
Moisture	11.2	12.8	11.9	12.4
Protein	11.50–12.3	9.8	6.2	11.6–11.8
Fat	2.38–4.3	1.3	2.2	4.8–5.0
Minerals	0.47–3.3	2.6	4.4	2.2–2.3
Dietary fiber	2.5–8.5	2.47	1.98	11.3
Carbohydrates	60.9–75.2	65.9–66.6	65.5	67–67.5
Energy (kcal)	331	309	307	361–363
Minerals (mg)				
Phosphorus	290	188	280	296
Potassium	250	144	—	307
Magnesium	81	147–228	82	137
Calcium	31	27	20–22	42
Sodium	4.6	4.6	—	10.9
Zinc	2.4	0.7	3.0	3.1
Iron	2.8	0.5–5.0	5.0–18.6	8.0
Manganese	0.60	1.10–3.3	0.96	1.15
Copper	2.4	1.60	0.60	1.06

Sources: [1, 13, 31].

Table 6.
Proximate composition and mineral contents of some millet species.

Phenolic compound	Foxtail millet	Kodo millet	Barnyard millet	Pearl millet
Hydroxybenzoic acid and derivatives				
Methyl vanillate	—	—	—	19.8
Protocatechuic acid	10.2	39.7	—	11.8
p-Hydroxybenzoic acid	5.63	10.5	—	22
Vanillic	22.1	4.01	—	16.3, 7.08
Syringic	93.1	—	—	17.3
Gentisic acid	21.5	—	—	96.3
Hydroxycinnamic acid and derivatives				
Caffeic acid	34	276	—	21.3
p-Coumaric acid	848	767	—	268.9
Trans-ferulic acid	631	1844	—	637
Cis-ferulic acid	101	100	—	81.5
8,8′-Aryl ferulic acid	19.6	94.8	—	—
5,5′-Di ferulic acid	62.2	173	—	57
Flavonoids	169	173	—	71

Source: [27].

Table 7.
Phenolic compound content (μg/g defatted meal) of some millet species.

carbohydrates, 5.6–12% protein, fat, 2–5%, 15–20% crude fibre and 2.5–3.5% minerals.

Millets are rich source of antioxidant activity such as phenolic compounds that contains phenolic acids, flavonoids, and tannins. Phenolic acids are sub-divided into hydroxybenzoic acids, hydroxycinnamic acids, hydroxyphenylacetic acids and hydroxyphenylpropanoic acids (**Table** 7). The phenolic compounds of millets phenols are reported to have antioxidant, anti-mutagenic, anti-oestrogenic, anti-inflammatory, antiviral effects, and platelet aggregation inhibitory activity [18]. The antioxidant activities of foxtail and proso millets are high because of their high total carotenoid and tocopherol content which range from 78 to 366 and 1.3–4.0 mg/100 g. The grain has good nutritional value however it is mostly consumed by traditional consumers in a tribal community. Its products are scarce in the urban areas as compared to rice ready-to-eat products [7, 29]. The major challenge with millet grains is that the commercial industrial method of processing the grains are not well-known or developed as compared to other cereal grains [29].

3. Processing and utilisation of millet grains/flours

Processing is a technology which is used to convert the cereal grains into an edible form of food products. Millet grains are prepared using modern and traditional technologies such as soaking, germination, malting, fermentation, milling or grinding, cooking, roasting, compositing flour, fortification, irradiation and popping or puffing mostly widely used in rural areas [13, 33, 34]. Traditionally, millet grains are spread and dried in the sun for a period of one week and are stored inside the bags for future use or processing. The grains can be stored for 5 to 10 years. These processes improve the consumption, nutritional composition, and sensory attributes of food products. Various studies has been conducted and the researchers have tried to produced millets products like puffed, popped, flaked, extruded and

Current	**Emerging**
Foods • Flours and meals (Africa and India) • Dumplings, porridges, and gruels (Africa and India) • Rice (Africa and India) • Couscous (Africa) • Malt (Africa and India)	Foods • Gluten-free baked products (USA) • Ready-to-eat breakfast cereals (USA) • Noodles (Japan) • Instant porridges (Africa) • Instant infant foods (South Africa) • Expanded snack foods (Africa)
Beverages • Non-alcoholic fermented beverages (Africa, Europe, and Asia) • Cloudy opaque beers (Africa and Asia) • Spirits (China)	Beverages • Lager beers and stouts (Africa, USA and Australia)
Animal feeds • Processed cattle feed (USA and South America) • Bird food (Asia and Africa) • Poultry feed (Australia)	Animal feeds • Formulated dog food (South Africa)
Industrial uses • Starch (USA and Africa)	Industrial uses • Bioethanol from starch (USA)
Source: [35].	

Table 8.
Current and emerging uses of millets in the world.

Uses	References
Traditional opaque beer, Busa	[36]
Bread, porridge, soup, cake, beer and distilled liquors	[37]
Light and thick porridge; Beer called *pito*	[9]
Weaning and infant food preparations, dumpling, porridge and roti	[38]
Food products: *mathri, sevain, kachari, kachauri, laddu, cheela, cheela,* biscuits and *halwa*	[39]
Polenta, couscous, medicinal herb, folk remedy for leprosy, liver diseases, measles. Pneumonia and smallpox	[40]
Flour- based foods such as *roti, mudde* and *ambli*	[1, 41]

Table 9.
Uses of millets.

roller dried products; fermented, malted and composite flours; weaning foods. Some of the recent studies are promising to produce popped and milled products [7]. Current and emerging food products produced from millet grains/ flours are shown in **Tables 8** and **9**.

Traditional processing of millet products has received poor scientific applications especially in the developing countries and the use of the modern processing technology has been restricted which can help to produce commercialised products in a large industrial volume [13, 42]. The development of value-added and convenient food products in urban areas may be a possible solution for promoting consumption of millets products. Most of the research have been conducted on the development of composite flour and extruded products which also increase the availability of millet products in the urban areas [1, 43]. Presently, food scientists are more interested in neglected small grains such as finger millet to reduce food shortage and hunger in the developing countries such as Nigeria, Uganda, Kenya, Tanzania, and South Africa. People who are living in the developing countries have limited access to animal food products so it is better to consume healthy millet foods that are rich in minerals and vitamin B complex. Animal food products contain high amount of minerals such as iron and zinc [44–46].

4. Traditional millet-based products

Millet grains/flours are consumed as flat bread, porridge, roasted and alcoholic and non-alcoholic beverages. They are utilised to bake different baked products (cookies, biscuits, bread and muffins) and weaning food. Composite flours are utilised to make chappati, puti and *murukul*, supplementary foods for feeding babies or infants. Some traditional products produced from millets are *burfi*, *baddis*, *halwa* and *papad*. They are also utilised to replace commonly used cereals in local community dishes like *idli*, *dosa, puttu*, *adai* [27], *khichdi*, millet ball "*fura*" and *tuwo*. Other products that are produced from millet grains/ flours are traditional foods and beverages such as snack, fast foods, millet wine roti, bread (fermented or unfermented), porridge and millet powder [7]. **Table 10** shows the most common indigenous millet based fermented food and beverage products produced around the world in which liquid drink is the most popular product and microorganisms associated with each product.

Products	Microorganisms	Regions
Busa (liquid drink)	*Lactobacillus, Sacchromyces*	Egypt
Chikokivana (Alcoholic beverage)	*Sacchromyces cerevisiae*	Zimbabwe
*Dalaki (*thick porridge)	Unknown	Nigeria
Doro (colloidal, thick, alcoholic drink)	Yeast and bacteria	Zimbabwe
Bogobe (solid dough)	*Lactobacillus* sp., yeast	Botswana and Ghana
Kenkey (solid dough)	*Lactobacillus sp., yeast*	Botswana and Ghana
Kwanu-Zaki (liquid drink)	LAB, Yeast	Nigeria
Ogi (liquid porridge)	*Lactobacillus* sp., *Aerobacter*	Nigeria
Merissa (alcoholic drink)	*Sacchromyces*	Sudan
Mahewu (liquid porridge)	*Lactobacillus delbrukii, L. bulgarius, Streptococcus lactis*	East African Countries
Munkoyo (liquid drink)	Unknown	Africa
Uji (porridge as staple foods)	*Leuconostoc mesenterodes*	Uganda, Tanganyika
Other fermented products		
Traditional opaque beer (*Kaffir* beer) and *Isidudu Imbila* (fermented thin porridge)		South Africa
Commercial brewing, opaque beer, *mangisi (*sweet–sour non-alcoholic drink).		Zimbabwe
Nasha or *madida* (thin porridge).		Sudan/Kenya

Sources: [47–51].

Table 10.
Most common indigenous millet-based fermented foods and beverages.

5. Non-alcoholic beverage products

Some other non-alcoholic beverage products that are produced form different millet species include *appalu, samaipayasam* and *korramurukulu. Appalu* is a food product made from pearl millet and Bengal gram flours. The mixed dough is divided into small balls and flattened into round shape. The dough is fried in a hot cooking pan, then fried and served hot with some vegetables or meat. *Samaipayasam* is a little millet which is also known as *samai* and it means little millet while *payasam* means *kheer*. The food product is prepared by milling roasted groundnuts into fine powder or flour. Little millet is added to boiling water while stirring constantly. After stirring, the jaggery solution is mixed and cooked for a few minutes on low temperature and served hot. Any millet can be used to make this recipe instead of little millet. *Korramurukulu* is prepared from foxtail millet and Bengal gram flour. The mixed dough is placed by using hand extruder and *murukulu* extruded is deep-fried until they turn brown [26]. Millet flour can be utilised to produce breakfast meals that are also known as gruels such as "*og*i" and "*akamu*". They can be consumed with various animal and vegetable products like meat and leafy vegetables that can nourish the human body by providing good nutritional value [52].

6. Conclusion

In general, this book chapter covered the nutritional composition of millets, processing and utilisation of millets grains or flour into traditional based products and non-alcoholic beverages. Different types of millet such as pearl millet, proso millet, kodo millet, finger millet, foxtail millet and little millet) are currently being utilised for different purposes (bread, cookies, muffins, chapatti and biscuit. The availability of gluten free value-added millet products globally may help mitigate the incidence of celiac disease and obesity. Therefore, there is a need for commercialisation and development of value-added gluten-free food products from millets.

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