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Sub-Saharan African Maize-Based Foods - Processing Practices, Challenges and Opportunities

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ABSTRACT

In vast swathes of Sub-Saharan Africa, maize is the staple food with consumption of up to 450 g/person/day. Additionally, maize is used as a weaning food for infants as well as for special ceremonies, caring for the sick, aged and pregnant women. Malnutrition persists in regions with heavy maize consumption, partly due to compositional maize characteristics, nutrient loss during processing and consumer preferences. This paper reviews the traditional uses and processing of maize, opportunities and necessary improvements to ensure (micro)nutrient security. Better use of maize can enhance its contribution to meeting the dietary needs and livelihood of Africa's growing populace.

KEYWORDS

Maize; maize-based foods; Sub-Saharan Africa; maize processing; maize consumption; maize opportunities

Introduction

Maize (*Zea mays*) accounts for 40% of the cereal production in Sub-Saharan Africa (SSA), where more than 80% is used as food.[1] The crop provides at least 30% of the total calorie intake of people in Sub-Saharan Africa.[2] Maize is consumed as a staple in the African region where intake ranges from 52 to 450 g/person/day and in the Latin American region where it varies from 50 to 267 g/person/day.[1,3] Maize is also considered an important source of nutraceuticals known to enhance health and prevent diseases, including phenolics, carotenoids (yellow maize), anthocyanins (blue maize), phlobaphenes (red maize), insoluble and soluble dietary fiber and polar and nonpolar lipids.[4–6]

Maize can be consumed in several forms: green maize roasted or boiled, steamed products, porridges, beverages, bread, and snacks.[3] Maize-based foods are available in Africa with each country having different processing methods, food products and forms of consumption.[7] Sometimes differences in maize food processing and consumption patterns within the same socio-cultural group exist to communicate individual cultural identity and social class.[8]

Compositional features of maize and local processing techniques affect the nutritional content and bioavailability of nutrients. For instance, the pericarp and germ of maize are usually sieved out as chaff in the preparation of most traditional foods, leading to loss of a large portion of proteins, lipids, minerals and vitamins that are present in those kernel structures.

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Therefore, in addition to the intrinsic nutritional deficiencies of maize, i.e., low lysine and tryptophan, and the presence of an anti-nutrient like phytate, a high amount of nutrients (20–50%) can be lost during maize processing in general.[3] This may contribute to malnutrition in regions where maize is a staple crop and diet diversification is very limited. Efforts to improve the nutritional quality of maize have mainly focused on breeding, by developing biofortified maize with higher protein quality or higher content of provitamin A or zinc.[9] However, the possibility to improve nutrient security by acting on home-based and street vendor processing and formulation aspects have been largely neglected.

Comprehensive maize food reviews by Nuss and Tanumihardjo[2], Suri and Tanumihardjo[10] and Ranum et al.[3] focused on global perspectives while this paper specifically targets Africa, especially Sub-Saharan Africa (SSA), where the population is most in danger of malnutrition and where there is a high rate of maize consumption and untapped opportunities in the value chain. The current paper reviews the most important maize-based foods in Africa and their respective traditional processing techniques, and discusses the constraints of traditional processing and opportunities to improve the nutritional quality and use of maize. The population in Africa is projected to double between 2010 and 2050, with increasing urbanization. To ensure both food and nutrition security, a thorough understanding of the nutritional aspects of traditional processing techniques and identification of important opportunities present on the dynamic continent are crucial.

Traditional food uses of maize in Africa

Maize is commonly consumed as immature or matured whole kernel (i.e., boiled or roasted), freshly ground or parched ground into grits and flour for the production of different kinds of traditional products. Milling is traditionally done through stone grinders (now obsolete), mortar and pestle, steel plate mills, and increasingly by the power-driven hammer mill.[11,12] Light dishes are habitually served as a breakfast, while thick dishes are served as lunch or as dinner and others are reserved for special ceremonies, rituals or caring for ill or aged people, pregnant women or infants.[8,11] Consumer preference for maize in Africa is changing as many recipes use it in a combination with other grains such as wheat, sorghum, millet, barley and legumes/nuts. However, despite the recent trends, maize remains a major contributor to the daily diet of Africans. Different categories of maize-based foods are discussed in the following sections.

Maize-based foods: whole maize cob and kernel

Consumption of green maize is a significant part of the whole maize food intake in Africa. To prepare fresh maize foods, the ears are harvested in the milky to the doughy stage (i.e., three to five weeks after silking), boiled in water, steamed, or roasted and eaten with herbs, spices, condiments and vegetables depending on the socio-cultural group.[13] At the milky stage, kernels are high in sugar content and quantities of other nutrients may be lower than at harvest maturity.[14] Street vendors sell boiled and roasted maize at many places in the major maize-producing countries and it is a common snack for children at schools.[13,15] During harvest season, roasted and boiled maize is eaten on a daily basis by more than 50% of the people in Nigeria[15] and in Zimbabwe, 48% consume boiled/roasted maize at least once a day.[16]

Freshly harvested maize is cooked or boiled in salted water until the kernels are soft, while roasting is through hot charcoal over a wire gauze, beside a fire or in hot ashes until

the maize turns brownish; both types are eaten on the cob with all kinds of spices and vegetables. The charcoal gives the kernels a unique odor and flavor. Boiling is usually with the husk to denote freshness and to retain nutrients and flavor. On the contrary, roasting with the husk is not practiced as it results in decreased sensory attributes such as poor aroma, chewiness, poor taste and appearance.[13]

Apart from the fresh maize eaten on the cob, it can be shelled into the constituent kernels for different dishes. Usually, the kernels are spiced and cooked with legumes or vegetables (Table 1). In Kenya, 17% and 23% of consumers prefer *githeri* (maize cooked with beans) as first choice lunch and dinner, respectively.[11] A similar maize food known as *mutakura* is consumed at least once a day by 40% Zimbabweans.[16] The attributes of green whole cob and kernel maize that are preferred by consumers have not been defined clearly for African consumers. However, freshness seems to be crucial.[11] Harvest time and variety have a significant effect on physical properties of maize; very mature maize (27–34 DAP) is not suitable to prepare roasted or boiled green maize foods.[13] Generally, green maize attributes of interest are soft endosperm, soft or thin hull, sweet taste and not easily burst/pop or burn during roasting.[11,13,17,18] Green maize is a very important form of maize consumption during harvest season in Africa.[13] Canning of green maize provides an opportunity to make it available all year round and reduce the chance of mycotoxin contamination, which is common to on-farm drying and storage of matured maize, thereby giving farmers more market opportunities.

In East, West, and Central Africa, whole dried grain is commonly cooked with alkaline rock salt (popularly known as *kaun* or *akanwu* or *trona or magadi*) or white wood ash, which reduces cooking time, improves digestibility, increases viscosity of soup, and acts as flavor enhancer, preservative and tenderizer.[22] *Akanwu* is a crystal-like (bi)carbonate salt that is naturally present in many parts of Africa.[23] The traditional use of *Akanwu* in Africa, which is comparable to the lime-cooking process (nixtamalization) in Mexico, has not been well studied yet. In Mexico more than 300 foods are produced by processing methods that include nixtamalization, the most common one being the tortilla.[22] This processing method for maize is not known in Africa; from about 1500 onwards the continent has connected to maize that originates from America through its agronomy but not through its processing technology. Nixtamalization provides nutritional benefits (Fig. 1), including: (1) reduction in pellagra disease risk, due to the improved niacin bioavailability, (2) increasing calcium intake due to its absorption by the kernels during the steeping process with calcium hydroxide, (3) supply of dietary fiber by increasing the content of resistant starch in the food products, (4) significantly reducing mycotoxin levels in kernels by removal of pericarp, and (5) reducing levels of phytic acid, an inhibitor of iron and zinc bioavailability.[4,24] Nixtamalization is reported to be effective in reducing mycotoxin contamination in maize through a combination of extraction and hydrolysis.[25,26] This method can be combined with traditional processing techniques in Africa to mitigate aflatoxin contamination, which remains of grave concern and hinders efforts to attain food and nutrition security. The ancient technology of nixtamalization is simple and cheap, thus conditions to promote its use in Africa should be assessed to enhance the nutritional quality of maize-based foods.

Local wet-ground maize foods

Wet-ground maize foods are produced by steeping maize kernels and grinding or pounding with ingredients such as vegetables, herbs, spices, legumes and nuts. The foods can also be produced from maize flour or the usually imported canned maize when fresh maize is not

Table 1. Maize-based foods: whole maize cob and kernel.

Category	Food name	Country	Description	References
Fresh maize: Whole-grain foods	(A) Roasted maize Boiled maize	Available across Africa	(A) Ways of eating differ across regions in Africa. In western Africa, roasted maize is consumed with coconuts, garden egg, nuts or with *ube* (African pears – *Dacryodes edulis*). In eastern Africa, roasted maize is eaten with salt, chilies, and lime.	[11,17,19]
	(B) *Adalu* *Owo-imiyo* *Imiyo ikokodie* *Githeri* *Muthokoi* *Ayibli* *Azibli* *Adibabli* *Mukimo or Irio* *Tchap*	 Nigeria Nigeria Nigeria Kenya Kenya Ghana Ghana Ghana Kenya Cameroon	(B) Whole maize kernels are usually cooked with kidney beans (*Phaseolus vulgaris*) in East Africa or cowpea (*Vigna unguiculata*) in West Africa. *Githeri, adalu and tchap* are prepared with beans, vegetables, oil, meat or fish. *Muthokoi* is prepared like *githeri* using maize from which the germ and part of the testa are removed. *Owo-imiyo* and *imiyo ikokodie* require the use of Akanwu, and other ingredients such as coconut juice, crayfish pepper etc *Ayibli, azibli and adibabli* are maize grains boiled with cowpea, groundnut and pawpaw (*Carica papaya*), resp. *Mukimo* is simply prepared by mashing boiled fresh maize with green peas, potatoes and vegetables.	
Dry maize: Whole-grain or maize meal foods	*Egbo* *Aboda* *Makande* *Manhuchu* *Samp* *Umngqusho* *Nkyekyerewa* *Setampo* *Mangai* *Mutakura* *Lusontfwana, Tinhlumaya-nemphuphu* *Kandy*	Nigeria Benin, Ghana Tanzania Zambia, Zimbabwe South-Africa South-Africa Ghana Lesotho Zimbabwe Zimbabwe Swaziland Tanzania	*Egbo, aboda, makande, manhuchu, samp* and *setampo* have a similar method of preparation and consumption. To enhance cooking, dry maize is soaked overnight and dehulled. *Egbo, manhuchu* and *samp* are made by cooking maize intensely until the kernels burst open. *Samp* is made from dehulled maize grits. *Umngqusho* is a cooked mixture of *samp* or maize meal and cowpeas. *Abode* and *makande* are cooked until the kernels are soft, but *aboda* is first precooked to remove the hull. Generally, they are cooked or eaten with beans, groundnut, coconut, vegetable oil, condiments, spices and meat. *Nkyekyerewa* is cooked dehulled maize and groundnut wrapped in leaves. *Mangai* is boiled dried kernels, *mutakura* is made by boiling maize kernels with peanut and cowpeas. *Lusontfwana* and *tinhlumaya nemphuphu* consist of maize meal cooked with round beans and lentils respectively. *Kandy* is a dish made of maize (sometimes dehulled) and beans boiled with tomatoes, onions and vegetable oil.	[16,17,20,21]

available. The term wet-ground used in this study should not be confused with wet milling, i.e., separation of maize into constituent parts or extraction of components such as oil and protein.[27] Wet milling is typically an industrial process, and hence not a home-based or traditional processing method in Africa. Examples of wet-ground foods are shown in Table 2. The grinding of whole grains to form wet-ground foods ensures optimum utilization of the kernel due to the inclusion of all parts as against many maize-based foods that require dehulling and other refining processes. An important attribute of these foods in West

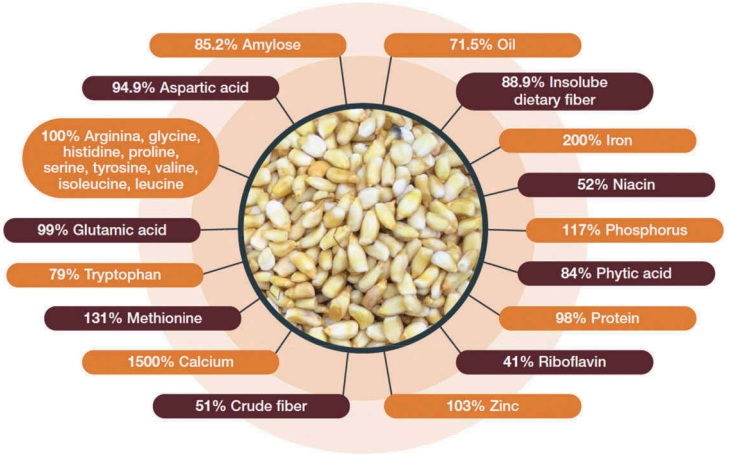


Figure 1. An overview of compound retention in nixtamalized maize. The increase in mineral composition along with a decrease in anti-nutrient as well as high retention of amino acid is beneficial to the fight against the rampant hidden hunger and protein-energy malnutrition (PEM) in Africa.

Table 2. Local wet-ground foods.

Category	Food name	Country	Description	References
Wet-ground maize foods	*Amiwo*	Benin	The major difference is the type of ingredient used, e.g. *kowe* is made with palm nuts, cowpeas, salt, pepper and coconut juice wrapped in banana leaves *sapala* is maize, pepper and salt and wrapped in guineacorn or cocoa leaves and boiled, *ablongo* is ground maize left to ferment for six hours, after which ingredients such as sugar or ground sweet potato, salt and palm-oil are added and wrapped in plantain leaves takes place, and *ofam* requires addition of ripened plantain, onion, ginger, pepper, salt, groundnut and boiled eggs, The unique feature of recipes from Benin is the addition of *Akanwu* and sometimes the use of germinated maize and fermented dough.	[17,24,32,33]
	Avata	Benin		
	Kpo	Benin		
	Kowe	Benin		
	Aboete	Benin		
	Abla	Benin		
	Kanji	Benin		
	Kpome-Klekle	Benin		
	Sapala / Ogidigbo	Nigeria		
	Abari	Nigeria		
	Igbagwu	Nigeria		
	Kokoo Dokono	Ghana		
	Ablongo	Ghana		
	Akakla	Ghana		
	Ofam	Ghana		
	Koga	Cameroon		
	Mohlefe	Lesotho	To make *mohlefe*, green maize is wet ground, shaped into balls, covered with maize leaf and steam.	
	Pate	Nigeria	*Pate* is a soup prepared from coarsely pounded maize, mixed with palm oil, meat, and boiled in water.	

Africa is the method of packaging before or after steaming; the foods are wrapped in leaves of different plants. The type of leaves used for packaging imparts a special flavor to the food, which is the preferred quality attribute among the different socio-cultural groups. Moreover, the leaves used for food wrapping were observed to be protein-rich and contain essential oils, antioxidants and antimicrobial agents that can prevent food spoilage and leaching of nutrients.[28] Leaves of banana, cocoyam, bamboo, uma, cassava and maize husk are commonly used for wrapping foods in Africa. However, considering the cyanogenic potential of cassava leaves (i.e., 5–20 times that of the roots), proper selection and treatment are required to avoid exposure above the safety limit, i.e., 10 ppm.[29] The indigenous custom of using

cassava leaves for wrapping foods such as *egble* or *madadi* and *kenkey* is still common among the Ewe tribe in Ghana.[30] The scarcity of wrapping leaves in urban environments cause urban dwellers to use empty cans, foil and cellophane or polyethene (nylon) bags instead. The use of such materials could result in migration of poisonous chemicals (i.e., dioxin, bisphenol A and heavy metals) into the food.[31]

Maize-based bread and snacks

Maize mixed with ingredients (e.g., groundnut, salt, sugar, egg, spices and vegetables) is used to produce different kinds of snacks and bread (Table 3), which are usually consumed in between meals and sometimes as the main meal. Unlike Mexico and Central America with different kinds of bread and snacks that can serve as a main meal,[22] only a few are found in Africa. However, northern African countries such as Egypt have different kinds of maize bread that serve as main meal, included in this paper to serve as an example (Table 3). The reduced use of maize in bread production is due to the unavailability of local technology, dominance of substitute grains (e.g. wheat), susceptibility to staling, storability issues (e.g., lipid in maize is more than two times higher than in wheat so relatively it becomes rancid faster during storage) and a lack of functional gluten, which is needed to produce an elastic dough and bread with characteristic light and spongy properties.[4,37] To minimize rancidity issues, heat treatment is used to inactivate lipase; local users commonly grind maize for short-term use and in some communities, maize bread is eaten during winter months. In general, the higher the proportion of polar lipid, the better the baking properties (e.g., increase in loaf volume); the ratio of polar to nonpolar lipid in cereal flour decreases in the order wheat > rye > maize.[38] Maize bread has a low volume and a heavy, dry, fibrous and brittle crumb with a relatively strong malty and fermented flavor.[37] At times, in local communities, water is sprinkled on it, after which it is covered with a cloth to keep it fresh. In most cases, maize bread contains wheat flour as a source of gluten. One of the outstanding properties of wheat is its ability to provide a viscoelastic dough that can hold and retain air to form a spongy structure. Maize does not have this ability due to the absence of gluten, thus making bread production difficult. Gluten-free bread has poor texture and flavor, a short shelf-life, low volume and stales rapidly.[39] The functional properties, commercial and nutritional value of maize flours can be improved by inclusion of protein from decorticated and defatted flours of crops like peanut, sesame seed, sunflower seed, soybeans, cowpea, melon seed, winged bean, bambara groundnut, chick pea, lentil seed, shea nut and sweet potato flour. Traditional Indian foods, such as *dosai* or *idli*, use fermentation of the mixture of rice and a legume to produce a gluten-like paste.[40] A nonwheat based composite flour with the ratio of sweet potato flour 40%, maize starch 40%, soybean flour 19.5% and xanthan gum 0.5% was observed to yield acceptable breads.[41] In another study, addition of 2% hydrocolloid hydroxypropyl methylcellulose (HPMC) significantly improved the quality of maize bread, mimicking wheat bread qualities.[42] With the use of appropriate additives – hydrocolloids, emulsifiers and binding agents and suitable flour milling properties, the viscoelastic and sensory properties can be improved. Furthermore, pre-gelatinized cereal flour and composite flour made by inclusion of malted grains have been shown to improve dough and bread qualities.[37,43,44] Composite flour made from pre-gelatinized starch or alkaline treated maize exhibit improved rheological properties

Table 3. Maize based bread and snacks.

Category	Food name	Country	Description	References
Bread	*Masa*	Nigeria	Maize is pounded, dehulled, soaked, wet ground and fermented overnight. The dough is then mixed with ingredients such as vegetables, akanwu, ochra, salt and fried with vegetable oil or oven baked. The stem of *Grewia mollis*, locally known as *dargaza*, is added to *tsafa*. The stem acts as a remedy for diarrhoea and dysentery due to its antimicrobial and antioxidant effects. *Muufo, muttala* and *injera* are unleavened breads served with stews, sauce, wot and bananas.	[19,33–36]
	Wainna	Nigeria		
	Tsafa	Nigeria		
	Pandaso	Nigeria		
	Kpome-Klekle	Benin		
	Nakia	Nigeria		
	Muufo	Somalia		
	Injera	Ethiopia/Eritrea		
	Dabo	Ethiopia		
	Aish merahra	Egypt	To prepare *chigumu*, maize flour is mixed with mashed banana, salt, vegetable oil, milk and eggs and then baked in the oven. To make *aish merahra*, roasted fenugreek powder (5–10%) is mixed with maize meal followed by addition of water, sugar, salt and yeast to form a dough. The dough is allowed to ferment all night and then baked in the oven. Fenugreek improves the protein content, shelf life and digestibility. *Shamsi* and *fallahi* are prepared in a similar way but with a mixture of wheat and maize, excluding fenugreek. *Monepola oa poone feela* is made by steaming a pre-gelatinized and fermented maize dough. *Mabbotot* and *kabbouri* are balady bread i.e. having loaf with dent middle, two crust and thin crumb, the dough is made with 25% corn flour. *Amh-nashif* is a dry cracker-like bread made from dough with 25% maize flour. *Bettaw* bread contains up to 98% corn flour, while *eokrouk* contains about 55% corn flour. *Bettaw* and *eokrouk* contains fenugreek flour and okra respectively, to improve the nutrient and enhance dough property.	
	Muttala	Sudan		
	Chigumu	Malawi		
	Monepola oa Poone feela	Lesotho		
	Shamsi	Egypt		
	Fallahi	Egypt		
	Chimodho	Zimbabwe		
	Mabbotot	Egypt		
	Kabbouri	Egypt		
	Amh-nashif	Egypt		
	Bettaw	Egypt		
	Eokrouk	Egypt		
Snacks	Popcorn	Available across Africa	*Guguru, azikpeli* and *maputi* are salted or sweetened dry maize roasted and eaten with groundnut or coconut. The snacks in the group (A) are prepared in a similar way as bread but without fermentation except for *tale tale, atififi* and *bamfo-bisi*, which require fermentation (6–72 hours); *tale tale* and *bladzo kaklo* are mixed with ripened banana. The snacks are fried in vegetable oil.	[16,17,19,32]
	Guguru	Nigeria		
	Azikpeli	Ghana		
	Maputi	Zimbabwe		
	(A)			
	Tale Tale	Benin		
	Avoumi Klekle	Benin		
	Kokoro	Nigeria		
	Pandaso	Nigeria		
	Atififi	Ghana		
	Bamfo- Bisi	Ghana		
	Bladzo- Kaklo	Ghana		
	(B)		All snacks in group (B) are dry milled roasted maize mixed with ingredients such as sugar, pepper, palm oil, groundnut and coconut. The difference is in the type of ingredient, i.e. *elekute* is a blend of milled roasted maize and sugar, while *donkuwa* and *dzowee* are blends of roasted milled maize and groundnut. Ginger is by tradition added to *donkuwa* to prevent dysentery, while clove is added to *dzowee. Mamu kaklo* is roasted maize meal with ripe plantain and deep fried. *Kyekyirehetu* is as above with chili, onion, palm oil and grilled. *Kyekyire brofre* is roasted maize meal mixed with paw paw and sugar, while *fiedzowee* is roasted maize and tiger nut ground together. *Potaka* is ground popped grains mixed with salt.	
	Aadun	Nigeria		
	Elekuted	Nigeria		
	Potaka	Nigeria		
	Donkwa	Nigeria		
	Emu	Nigeria		
	Ekaka	Nigeria		
	Dzowee	Ghana		
	Mamu Kaklo	Ghana		
	Kyekyirehetu	Ghana		
	Kyekyire Brofre	Ghana		
	Fiedzowee	Ghana		

that support bread making. Similarly, flours derived from sourdough made by fermentation using selected multiple strains of microorganisms have been shown to improve maize bread quality.[45] Acidification of the sourdough during fermentation (mainly by lactic acid bacteria) or through addition of lactic/acetic acid improves the swelling or water binding properties of starch and the functionality of zein (maize prolamin) to enhance loaf volume and crumb structure of gluten-free bread.[46] Sourdough improves nutritional quality (i.e., increases mineral bioavailability) due to a lower phytate content. Likewise, the low pH helps to improve the shelf life of bread.[45]

Popcorn, as a snack, is found all over Africa due to the introduction of locally fabricated popping technologies and the growing acceptance of the product at cinemas, amusement parks, schools and during travelling.[47] Though affordable foreign and local popcorn machines are now available, popcorn is traditionally prepared using a clay pot or metal dishes. There are different kinds of popcorn-like snacks common in Africa (e.g., roasted maize kernels of any variety with salt/sweetener and roasted popcorn with salt or sweetener – honey or sugar). Though popcorn production still strongly relies on the importation, it is a crucial opportunity in the maize value chain capable of improving the livelihood of street vendors. Generally, consumers prefer popcorn with a soft texture and free from hulls, while the processors prefer high storability, unbroken pericarp and a high popping volume.[47] Ingredients such as fat, sugar and salt are usually added to enhance the flavor of popcorn. It is normally taken with roasted groundnut.

Other maize-based snacks are listed in Table 3. In general, a mildly sour and sweet taste, crispy and brown edge color are desirable for maize-based snacks.[48] To supplement the low nutritional value of maize-based snacks, protein-rich legumes and nuts such as soybean, cowpea and groundnut are usually included in the recipe. For instance, *kokoro*, a common crispy maize snack was observed to have a 54–68% higher protein content due to the inclusion of 30% soybean or groundnut in the recipe.

Maize sourdough and dumplings

Maize sourdough is an uncooked thick fermented cake that is pressed, shaped and ready to use in other dishes like maize dumplings, porridges, snacks, bread and beverages[49,50] (Table 4). Maize sourdough is most common in West Africa. For instance, more than half of the total maize production in Nigeria is used for *ogi*.[50] Maize dumplings, such as *kenkey*, are consumed twice or more often per week by 26–58% of Ghanaians.[53] Traditional preparation of sourdough and dough dumplings is labor intensive and time-consuming (4–6 days); consumers mostly buy such foods from street vendors. Technological improvements, such as a temperature increase, the use of dry-milled maize and pure starter cultures, have shown positive results in reducing preparation time and facilitating industrial processes.[54] Maize sourdough can be derived from either fresh or dried maize. However, dried maize is preferred for its higher starch content and retention of the accustomed flavor.[50] Traditional preparation of maize sourdough in Africa follows a similar process. Dry maize is soaked for 24–36 h; the peak of water uptake is attained at 36 h. The time of water saturation can be reduced to 8 h by increasing the soaking temperature to 60°C or using crushed maize kernels.[54] The soaked kernels are drained, then milled to a slurry and sieved to remove the chaff, followed by dewatering, kneading to dough and fermentation for 1–3 days at room temperature (25–32°C).[50,55],

Table 4. Maize sourdough and dumplings.

Category	Food name	Country	Description	References
Sourdough	*Mawe* *Ogi* *Amo/Mbore* *Mutwiwa/ Mudzvurwa* *Poto-poto* *Fura* *Soy-ogi*	Benin/Togo Nigeria Ghana Zimbabwe Congo Nigeria Nigeria	See the section on sourdough for *mawe, ogi, mutwiwa, poto-poto and Amo. Fura* is a blend of sour milk, maize flour and spices (cloves and ginger). The blend is pounded, cooked for 30 minutes and shaped into balls. *Soy-ogi* is a blend of fermented, dehulled and wet milled maize and soya beans (70:30% w/w) shaped into balls. The soya bean is boiled or roasted to eliminate antinutrients.	[50,51]
Dough dumpling	*Ablo* *Donkunu* *Ga kenkey* *Fanti kenkey* *Sweet kenkey* *Nsihu* *Akassa* *Eko/agidi* *Akple* *Banku* *Abolo* *Amo-yakayake* *Doklu* *Leqebekoane*	Benin Nigeria/Ghana Ghana Ghana Ghana Ghana Benin Nigeria Nigeria/Ghana Ghana Ghana Ghana Côte d'Ivoire Lesotho	*Ablo, donkunu, kenkey, nsihu, akassa, abolo, banku* and *amo-yakayake* are often directly prepared by mashing maize sourdough in salted or sweetened water of different consistencies, and then cooked in water or steam. The unique attribute of *kenkey* is that half or one-third of the fermented dough is first cooked into a thick porridge known as *aflata*, then mixed with the remaining uncooked part. The major differences are: *ga kenkey* (pH 3.7 and moisture 52–55%) is non-salted and half of the dough is used for aflata, *fanti kenkey* (pH 3.7 and moisture 52–55%) is salted and one-third of the dough is used for *aflata, nsishu* -also known as *white kenkey*- (pH 4 and moisture 62–68%) is produced from neatly dehulled maize, and sugar is added to make *sweet kenkey*. These foods can also be differentiated by the type of wrap used, e.g. *ga kenkey* is wrapped in maize sheaths while *fanti kenkey* is wrapped in banana leaves. *Doklu* is similar to *ga kenkey* and eaten with legumes, soup and fried fish. *Akple* is a cooked mix of cassava dough and maize dough (ratio of 1:2). *Eko, omadidi* and *agidi* are gelatinized dough dumplings prepared by excessive heating of pureed sourdough that is poured in leaves and cooled to solidify. *Leqebekoane* is a steamed dumpling eaten with meat stew. Generally, maize dough dumplings are eaten with vegetable soup or stew with fried fish or meat.	[17,20,52]

see Fig. 2. The chaff removed during the sieving process is fed to animals or reserved as a base for the preparation of other foods such as *amala* (i.e., a thick cassava or yam flour food in Nigeria, having a dough-like consistency). Aside from the inherent characteristics of maize, the amount of chaff separated by sieving depends on the nature of the milling technology. Plate mills are commonly used for wet grinding; the sharpness of the plate and the number of milling rounds minimize the chaff yield.[12,50] The use of plate mills has been reported to increase the iron content in dry and wet milled maize by 78–89% and 199%, respectively, due to the wear and tear of the grinding metal plate. The increase was suggested to be an enrichment, but the bioavailability of the extra iron was not established.[12]

Traditional sourdough production uses spontaneous fermentation, which is uncontrolled. Sometimes backslopping is used to achieve a consistent and faster fermentation.[49] The microorganisms involved in natural maize food fermentation in Africa have been well elucidated in the literature.[56–61] The addition of commercially available yeasts as starter culture and the use of backslopping to speed up the fermentation, improve flavor, nutrient and functional properties of fermented food is common in both rural and urban areas in Africa, showing the possibility of adoption of pure microbial starter cultures (optimized mixtures of microorganisms) for traditional maize fermentation, if made available. Since

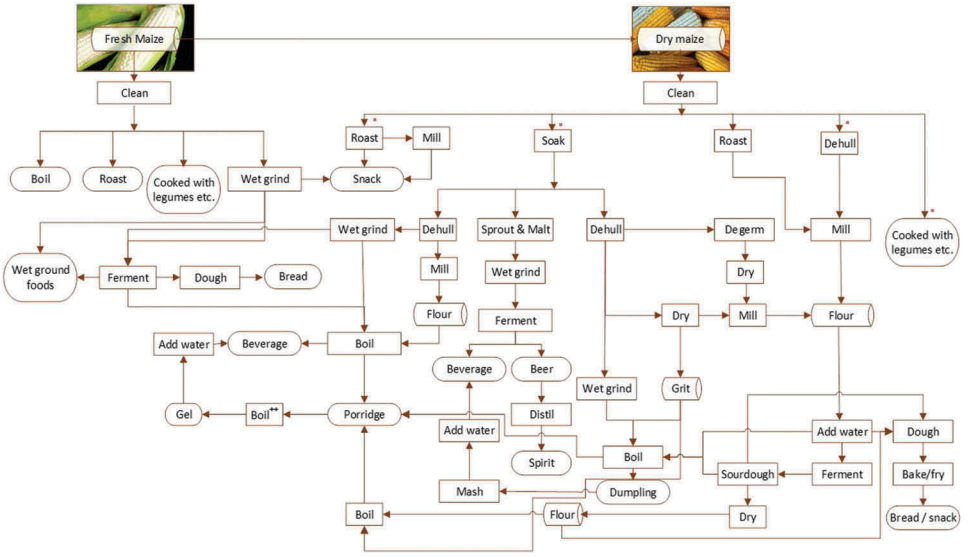


Figure 2. An overview of traditional maize-based foods and beverages processing in Africa. The flow chart shows the outline of the processing steps of about 200 maize-based foods listed in this article. All traditional maize-based foods in SSA can be traced from raw material to the final product using the summarized chart. For instance, dry maize can be dehulled, milled into flour, sieved and boiled in water to make porridge (*ugali*). The flour can also be fermented (usually spontaneous or backslopping method) into sourdough to make porridge (*ogi*) and beverage (*munkoyo*). In some cases, the final product of one step can serve as a starting material for another product e.g. porridge (*ogi*) can be intensely heated to make gel (*agidi*). Dumpling or gel can be mashed with water to make beverage (*ice kenkey*). It is worthy of note that, alkaline cooking which is an important processing method in Mexico recommended in this article for Africa is yet to be introduced in the continent. Proposed inclusion points of the Mesoamerican technique is shown with an asterisk (*) in the flow chart.

fermentation is an age-old, acceptable food processing method in Africa and used for many foods, a sustainable increase in production, commercial and nutritional value of food products can be achieved by optimizing the composition of starter cultures for fermentation. Several biotechnological methods have been developed over the years as a substitute for the costly chemical synthesis of amino acids and vitamins used for fortification.[62–64] For instance, to improve protein quantity and quality of *ogi* (maize sourdough), microbial *in situ* fortification or bio-enrichment, such as the use of high lysine or methionine producing mutant microorganisms, have been used successfully to significantly increase essential amino acids.[65,66] Sybesma et al.[64] isolated spontaneous mutants of *Lactococcus lactis* able to overproduce both folic acid (B11) and riboflavin (B2) during food fermentation. Vitamin overproducing microorganisms such as *A. gossypii, C. famata, B. subtilis, P. freudenreichii* and *Lb. plantarum* have been identified and isolated.[62] Aside from increasing the amount of nutrients, decreasing the amount of anti-nutrients such as phytate is crucial for malnourished societies. Therefore, in the selection of microorganisms for starter cultures, it is important to also consider those able to overproduce the enzyme phytase, because phytate remains a major factor limiting mineral (iron and zinc) bioavailability; deficiencies of both minerals remain a major public

health concern in SSA. Starter cultures containing phytase-active microorganisms will help to degrade phytate and improve mineral bioavailability.[67]

The major variations in sourdough production in Africa are the extent and conditions of fermentation, which determine the degree of sourness/acidity, flavor and physical properties such as color and texture.[55] The degree of sourness of a dough depends on the type of end product and the preference of the respective socio-cultural groups. For instance, relatively sour dough (pH 3.8–4.2 and acidity 1.2–1.4%) is used for the preparation of *eko* and *akassa*, while less sourness is used for thin porridges such as *koko*.[55] Furthermore, the most desirable attributes of *kenkey* are a mild sourness, fruity odor, clear white color and non-sticky texture, which can be achieved by a reduction of fermentation time, modification of inoculant (i.e., using bacteria and yeast starter cultures with higher yeast concentrations to give the desired fruity taste), dehulling the maize, and adjusting the sourdough puree consistency before cooking, respectively.[17]

The moisture content of maize dough ranges from 45% (*amo* and *mawe*) to 55% (*ogi*).[17,50] The high moisture content predisposes it to microbial deterioration. In home-based processing, it is therefore left in source liquor with a steady change of water. The commercial dough is spray dried in the industry to increase stability; drum drying has been reported to be harmful to the heat sensitive components (e.g., amino acids).[68] Sourdough commonly used for making porridge is mainly sold in the wet form, having a short shelf life because of continued fermentation. The current development trends in SSA require a better supply of easily accessible and shelf-stable maize-based foods. Controlled drying methods can be used to reduce the moisture content (below 12%) to enhance storability and ease of distribution.[50] This form of fermented flour can be reconstituted to make paste needed for porridge. It can also serve as an ingredient in other products where consumers desire a sour or fermented flavor (e.g., in Western Africa food and beverages).

Maize-based porridges

Maize porridge is simply a dish made by cooking milled maize or sourdough in water and stirring until thickened. In most parts of Africa, maize porridge is consumed in different consistencies, namely as breakfast when thin or as lunch/dinner when thick. For instance, 46% of consumers in Kenya prefer thin porridge (*uji*) as breakfast while 67–71% prefer thick porridge (*ugali*) as lunch/dinner.[11] For economic reasons, the thick porridge is at times eaten as breakfast to withstand hunger all through the day due to its high energy density.[8] In fact, *ugali* in Kenya is synonymous to 'strength' and in Tanzania, it is termed the '*real food*'.[8] *Ugali* is consumed 5–7 times a week by 64% of the Tanzanians,[69] and a similar pattern of consumption is common across Eastern/Southern Africa.[16] The ratio of flour to water, flour particle size, the method of preparation, the degree of starch gelatinization and enzymatic hydrolysis, the rate of maize meal extraction and sometimes the inclusion of other ingredients determine the consistency of the porridge. Porridges can be classified based on consistency or texture; i.e., *ogi* and *koko* are thin porridges with a water content over 90% whereas *ugali* is a thick or stiff porridge with less than 70% water and *tuwo-masara* is a soft porridge with intermediate thickness.[70] Thick maize porridges in Eastern, Western and Southern Africa have 33%, 22% and 20% total solids, respectively.[70,71] As shown in Table 5, not all porridges are fermented. Hence, they can

Table 5. Maize based porridges.

Category	Food name	Country	Description	References
Unfermented porridges	**Thin porridges**		(Un)roasted maize meal is cooked in water (usually >90% water content) and stirred to prevent lumps. *Mgaiwa phala* is maize meal porridge mixed with milk and sugar and sometimes cinnamon. *Dzudzuwo* is produced from roasted maize meal, *tombrown* is the same but with the addition of ginger and peanut, while CSB is an infant food with a blend of roasted maize-soya bean meal. They are served with sugar, milk and snacks.	[17,70]
	Mgaiwa phala	Malawi		
	Dzudzuwo	Ghana		
	Tombrown	Ghana		
	Maize-Soy Blend (CSB)	West Africa		
	Thick or stiff porridges			
	Tuwo	Nigeria	The thick porridges are prepared as above but with less water (usually <70% water content) and they are served differently, usually with vegetable stew or soup, meat and fish. The distinctive attributes found in some of the thick porridges are as follows: • *Phutu* is made by steaming maize meal to form a crumbly texture. • *Wokple* can also be prepared by mixing cassava flour with maize meal (1:2) • *Lakiri*: dry maize is soaked, milled then dried. The meal is blended with peanut, boiled, sweetened with sugar and served with milk. • *Ayikple*: roasted maize meal is cooked with cowpeas, shrimps, vegetables and condiments. • *Asida* can be made with either milk or water	
	Phutu/krummel-pap/ Stywe/Oshifima	Lesotho/ South Africa, Botswana/Namibia		
	Owo	Benin		
	Ugali	Kenya,Tanzania, Uganda,Burundi, Rwanda		
	Chima	Mozambique		
	Tuo Zaafi	Ghana		
	Sadza/Isitshwala	Zimbabwe		
	Tô	Mali, Burkina Faso		
	Nsima,Bogobe,Upshwa	Zambia/Malawi, Bostwana, Mozambique		
	Asida	Sudan, Libya		
	Lakiri	Ghana		
	Ayikple	Ghana		
	Wokple	Ghana		
	Mielie or *Slap pap*	South Africa		
	Phaletshe	Botswana		
	Papa	Lesotho		
	Soor	Somalia		
	Akoume	Togo		
	Granulated porridges			
	Goungoumbe bouillie	Benin	*Goungoumbe bouillie* is prepared by boiling crushed maize grits with *citronella* leaves and served with peanut. *Dumbun masara, buboche,* and *zijjo-zaa-Gelle* are course ground maize (grits) mixed with ingredients such as oil, vegetables, salt, and cooked. *Yeke-Yeke* and *gwate* are steam-cooked course ground maize in the form of couscous, eaten with sauce, meat and vegetables.	
	Dambun-masara	Nigeria		
	Buboche	Nigeria		
	Zijjo-zaa-Gelle	Somalia		
	Yeke Yeke	Benin		
	Gwate	Nigeria		
	Ekuegbeemi	Ghana		
	Eburow	Ghana		

(*Continued*)

Table 5. (Continued).

Category	Food name	Country	Description	References
Fermented porridges	**Thin porridges**			[50,91–94]
	Mutwiwa pap	Zimbabwe	In making *mutwiwa pap*, the maize is dehulled, soaked and left to ferment until gas production stops. The fermented maize is then dried, milled and used to make porridge. *Ilambazi lokubilisa* and *sekhakabolo* are prepared by fermenting maize meal in water for 2–4 days then use to prepare sour porridge. In *sekhakabolo*, the maize meal is course and sorghum is used as inoculant. *Koko* and *akluiyonou* are like *ogi* or *uji* but contain tiny lumps and less total solids (5–6%) while *kunu* is like *koko* but has lesser total solid and tastes spicy due to the addition of chili, cloves, black pepper and sugar. To make *ice kenkey, kenkey* dumplings are mashed in cold water with evaporated milk and sugar. *Fura de nunu* is prepared the same way but with *fura* dough and addition of sugar.
	Ilambazi – lokubilisa	Zimbabwe	
	Sekhakabolo	Lesotho	
	Fura de nunu	Nigeria	
	Ice kenkey	Ghana	
	Koko	Benin/Ghana/ Nigeria	
	Akluiyonou	Benin	
	Ogi	Nigeria	
	Uji	Kenya, Uganda, Tanzania	
	Ting	Botswana	
	Ohu/Afiata	Ghana	
	Koklui	Ghana	
	Kokompampa	Ghana	
	Totodzogbe	Ghana	
	Olor	Ghana	
	Nasha	Sudan	
	Thick porridges		
	Sour sadza	Zimbabwe	*Ting* is made from a blend of fermented maize and fermented sorghum meal with or without the addition of salt. *Ohu/afiata/ dzogbo* is an intermediate product from the production of *kenkey*, i.e. it is not consumed directly. *Kokompampa* is a gruel mixed with ripened plantain, salt, pepper and onions while *totodzogbe* is the same but with ripened pineapple instead of plantain. *Totodzogbe* is served during fever. *Aklui* is made by sieving *mawe* into pellets and boiling in water. *Ikii* is prepared like *ogi* but from maize grits. It can be stored up to seven days at room temperature (<30°C) without spoilage.
	Granulated porridges		
	Aklui	Benin	
	Ikii	Kenya	

be classified on that basis as well. In Eastern Africa, the main maize flour preparation is for porridges (mostly unfermented).[8,11] This is also true for Western Africa, except that maize porridges are mostly derived from soaked maize or fermented dough.[32]

In general, fermentation is not a common practice for thick maize porridge in Africa (except in countries like Nigeria, Benin and Ghana); it is largely used for thin porridges.[70] West Africans preserve the traditional porridge processing; i.e., preparation of soaked wet ground maize or sourdough followed by cooking in water, Fig. 2. Nche et al.[76] & Teniola and Odunfa[77] attempted to accelerate traditional porridge preparation by using maize flour instead of the usually soaked kernels as starting material. They observed a decrease in processing time from 6 days to 24 hours but produced porridge with an inferior and undesirable textural quality, namely poor pasting properties and flow behavior. This clarifies the significance of the soaking step in the production of West African maize dishes. Sourdough from steeped whole maize gives a more preferred aroma, taste, smoothness, and better pasting and setback viscosities than dehulled steeped maize and fermented maize flour.[77] Bolade[78] observed the lowest pasting temperature (i.e.,

faster gelatinization) in flour produced from soaked maize, possibly due to the breakdown of the matrix around the starch granule.

The most popular maize porridges in Eastern and Southern Africa are the thick textured foods known as *ugali/nsima/sadza*, all of which are derived primarily from unfermented dry milled maize generally with no ingredient added but with differences in thickness and maize meal type. For example, *nsima* from Malawi and Zambia is relatively soft compared to *sadza* from Zimbabwe and *ugali* from Kenya, Tanzania, Rwanda and Uganda. Properties such as moldability and mouthfeel are most desirable in thick porridges.[70,78] While the urban areas depend on ready-made flours (i.e., packaged maize meal from the industrial mill), the rural areas sort and clean maize then mill at home or in a local mill that generally uses a hammer mill. The classification of maize meal can be based on color, extraction rate, particle size and the type of maize kernel texture used (i.e. soft (dent) or hard (flint) endosperm).[79] For instance, three types of maize meal are found in Africa: whole maize meal, dehulled maize meal and dehulled & degermed maize meal, see Table 6. Although the preparation of refined maize flour is laborious and results in excessive loss of nutrients, it is the most preferred quality for the preparation of *ugali/nsima*, and it is perceived as "rich people" food. Unrefined flour such as *dona* (whole kernel maize flour) is classified as "food for the poor" in some communities.[8] The soaking process and a fine particle size of maize flour enhance water absorption, pasting properties, starch breakdown, cohesiveness, bulk density, taste and appearance.[70] Similarly, degermed maize flour was observed to require 10 times less energy and less time to cook as well as having a longer shelf life compared to whole maize flour. In a survey in urban Kenya, 64% of refined maize meal consumers indicated ease of cooking as the major reason for purchasing this type of flour.[80] From a nutritional point of view, dehulling, removal of maize germ, several rounds of soaking and drying during maize refinement indeed result in high nutrient losses.[10,81] *Ashanti* and *nsihu kenkey*, usually made from degermed flour, were confirmed to have low mineral contents[82]; up to 20% protein and more than half of the vitamins and minerals could be lost during maize meal refinement. The nutrient lost from the industrial meal may be replenished through exogenous fortification but this is unlikely for the majority of meals processed at home. Therefore, children depending on ingestion of foods produced from refined flours might have nutrient deficiencies.

About 70% of thin porridge consumers are infants, but the low dry matter content (6–10 g/100 ml) makes it nutritionally inadequate. For instance, maize pap in Nigeria was reported to contain 0.5% protein and 1% fat; thin porridge provides an energy density of less than 0.40 Kcal/ml, which is much lower than breastmilk (0.68 Kcal/ml).[83,84] The energy, protein density and protein quality can be improved by using, for instance, quality protein maize with addition of legumes and sprouted maize to achieve a viscosity favorable for infant foods.[49] To correct for the essential amino acids deficient in maize, a soybean enriched sourdough known as *soy-ogi* and *weanimix* was developed.[85] *Soy-ogi* was compared to nine commercial weaning foods and found to be relatively low cost and nutritionally adequate. Other maize – legume/nut (groundnut, melon, bambara groundnut and cowpea) combinations tested were found to be superior to any available single protein source.[85–88] However, the acceptability of legumes in weaning food might be low due to problems associated with difficulties in digestion and the flavor when it is not properly processed.[89] The acceptability test carried out on *soy-ogi* showed that 66%

Table 6. Major maize meal types and nutrient composition.

Maize flour	Examples	Description	Nutritional value (per 100 g)	References
Whole maize meal	*Dona, mugayiwa, posho, farinha corn farelo, ufawa m'gaiwa, straight run meal, hammer meal*	Milled whole kernels with all components retained. The flour extraction rate is 96–99%.	Calories (Kcal): 343 Protein: 10% Carbohydrate: 73.4 Fat: 3.8% Ash: 1.3% Iron(mgs): 2.5 Thiamin (mgs): 0.35 Riboflavin (mgs): 0.13	[8,78,79]
Dehulled maize meal	*Sembe, sifted meal, roller meal, Farinha Sem Farelo, number 1*	Flour made from dehulled maize kernels, parts of the germ is removed along with the bran. The flour extraction rate is 75–95%.	Calories (Kcal): 341 Protein: 9.3% Carbohydrate: 75.1 Fat: 2.4% Ash: 0.7% Iron(mgs): 2.0 Thiamin (mgs): 0.3 Riboflavin (mgs): 0.08	[19,70,78,79]
Dehulled & degermed maize meal	*Kiwerege, ufa-woyera, extra super or super-sifted meal, farinha matabicho, breakfast meal, Tz flour*	Very fine, soft and white flour made from dehulled, soaked, degermed and dried maize, leaving only the starchy endosperm. The flour extraction rate is 60–70%. The flour is less prone to rancidity due to the removal of the germ containing the oil. It has the highest shelf life and shortest cooking time.	Calories (Kcal): 334 Protein: 7.9% Carbohydrate: 78.4 Fat: 1.2% Ash: 0.5% Iron(mgs): 1.1 Thiamin (mgs): 0.14 Riboflavin (mgs): 0.05	[8,70,78,79]

preferred the usual *ogi*.[89] However, *kenkey* enriched with cowpea showed high acceptability by consumers.[88] A substantial improvement in the nutritional composition of sourdough has been reported from the addition of vegetables, leaves and fruits (e.g., okra seed,[90] mango mesocarp,[91] *Moringa oleifera* leaves,[92] and paw paw (*Carica papaya*) fruit).[93] In an unconventional approach, *Cirina forda* (an edible insect) and maize dough were blended to achieve a significant improvement in the protein, minerals, amino acid and fatty acid contents.[94] Information on home-based production or use of legume/nut supplemented maize food is scanty. However, Bankole[84] reported that 49% of *ogi* consumers were aware that the food can be fortified with fruits and legumes but adoption was only 5.8%, namely with soybean (2.9%), groundnut (1.9%) and cowpea (1%).

Maize based beverages

The use of locally available cereal-based beverages is common practice in Africa, serving as a well-accepted alternative to industrial brews or drinks. They consist of alcoholic and nonalcoholic beverages such as *akpan* in Benin,[32] *kunu zak*i in Nigeria,[95] *togwa* in Tanzania,[96] see Table 7. The nonalcoholic beverages serve as thirst-quenchers and energizers. *Akpan* from maize is consumed 2–3 times a week by 34% of the Beninese.[102] The type of technology used and the preference for cereal grains for making beverages depend on the product, socio-cultural group and consumer preference. Gaffa et al.[95] reported that in the production of *kunu* in Northern Nigeria, 33% prefer millet and 20% maize while 36% of all the respondents prefer to combine grains. Likewise, 49% of *cheka* producers in Ethiopia uses a mixture of cereals; exclusive use of maize is believed to yield a too sour product.[103] Most beverages are derived from combinations of maize with other grains (e.g., wheat, barley, millet, sorghum, legumes).[95,104] Traditional methods of beverage production (soaking, germination, wet grinding, sieving, and fermentation) are preferred in Africa, Fig. 2. The mechanism of these methods in producing the desired quality attributes has been well studied. Soaking softens the texture of the grain, triggers germination and activates endogenous enzymes such as amylases, proteases and lipases, which release sugar, amino acids and fatty acids, respectively; these are essential for the fermentation process.[59] Phytase is also activated during soaking and degrades phytate.[105] Though mainly the endogenous amylase produces fermentable sugars, which serve as energy for the fermenting organism, some molds and lactic acid bacteria are also capable of producing amylolytic enzymes for starch hydrolysis.[106]

An alcoholic beverage is obtained using a malting process followed by fermentation, primarily by lactic acid bacteria (LAB; predominantly the genera – *Lactobacillus, Lactococcus, Leuconostoc* and *Pediococcus*), yeast (e.g., *Saccharomyces*), and fungi (e.g., *Aspergillus*), while nonalcoholic beverages basically use soaking and a slight fermentation.[95] The preparation of nonalcoholic beverages involves soaking (sometimes with malting), grinding followed by filtration and overnight fermentation. The fermented filtrate is boiled and sweetened or salted.[95] In a nonalcoholic beverage such as *munkoyo*, the alcohol content is less than 0.5% but can increase to more than 2.5% with continued fermentation, thereby turning it into an alcoholic beverage.[97] This practice is not unusual since most traditional beverages are consumed while they are actively fermenting. Prolonged fermentation could also result in a bitter taste, off odor and spoilage.[107] Many adults in Zambia drink an average of one liter *munkoyo* per day.[108]

Table 7. Maize based beverages.

Category	Food name	Country	Description	References
Non-alcoholic beverages	*Akpan* *Mahewu* *Munkoyo* *Kunnu zaki* *Kunun akamu* *Kirario* *Borde* *Togwa* *Wotadi* *Bladzodidiwo* *Gowe* *Aliha*	Benin South Africa Zambia, Zaire Nigeria Nigeria Kenya Ethiopia Tanzania Ghana Ghana Benin Ghana	Grains are soaked, drained, sometimes allowed to germinate and wet ground followed by spontaneous fermentation at ambient temperature. *Akpan* is made from diluting *mawe* porridge in water and boil. It is consumed with sugar and milk. *Mahewu* is prepared by adding maize meal to 9 parts of water, cook and then inoculating with wheat flour to ferment. It does not require additional cooking prior to consumption. *Munkoyo* is made by fermenting cooked maize meal with *Rhynchosia heterophylla* root extract. *Borde* is made from a thick paste of roasted maize meal mixed with malt flour. After addition of water, it is allowed to ferment overnight at room temperature. *Borde* has a whitish-grey to brown colour and a sweet-sour taste. *Kirario* is produced from a mixture of green maize and sorghum/millet. *Kunun zaki* is made from maize or combined grains (maize/sorghum) with paste of sweet potato tubers or extracts of *Cadaba farinosa* or malted rice or sorghum, ginger, clove, red pepper. *Kunun akamu* is made from maize, ginger and sugar. *Togwa* is made by boiling maize flour to a porridge, after which malted millet flour is added and the product is left to ferment overnight. The malt flour serves as an amylase source. *Wotadi*: roasted maize mixed with pepper and ginger. The mixture is milled and water is added to taste. It is believed to enhance ulcer healing *Bladzodidiwo*: roasted maize mixed with plantain and pepper. The mixture is milled and water is added to taste. Served in cold weather *Gowe* is made from malted maize, which is ground and fermented to form a sweet dough. The dough is mashed in water, with ice and milk added. It serves as a thirst quencher during warm periods. *Aliha*: malted maize is dried and milled. Next water and sugar are added.	[32,95–98]

(*Continued*)

Table 7. (Continued).

Category	Food name	Country	Description	References
Alcoholic beverages	**Beers**			
	Obiolo	Nigeria	*Obiolo* is made from grinding a mixture of soaked maize and sweet potatoes. The paste is left to ferment overnight, boiled and filtered. To make *pito* and *chakpalo*: soaked grain is allowed to germinate then ground and boiled followed by filtration. The filtrate is fermented using backslopping. *Kaffir beer* is produced in a similar way but using malted wheat flour as an inoculant. *Tella* is produced like beer but using *gesho* leaves instead of hops. Germinated maize is milled and mixed with bread darkened by roasting. *Gesho* leaves are added to the mixture and allowed to ferment in a sealed container then filtered. It has a smoky flavour due to the decontamination of the *tella* jar using hot smoke. *Umqombothi* is made from the combination of maize and sorghum. Both grains are soaked and milled then cooked to a porridge. Malted sorghum flour is added and a small portion of a previous batch of *Umqombothi* is added and allowed to ferment for 18 h then filtered. *Kweete* is made from roasted maize flour and sundried germinated millet. Both are mixed together with water and allowed to ferment for 1–2 days and filtered with a cloth. *Kidongo* is made from the fermentation of the leftover from *kweete* production. Water and brown sugar are added to the mixture and fermented overnight. *Chikokivana* is made from mixing maize meal and malted millet with water, then fermented overnight using commercial yeast as a starter culture. *Cheka* is made by mixing fermented *taro* and cabbage leaves with maize flour to form a dough, which is then cooked. Malted flour is added, followed by fermentation for 16 h then cooked to porridge. The porridge is further fermented for 12 h to form *cheka*. *Busaa* is made by mixing maize flour with water and yeast, and then allowed to ferment for 3–4 days. The mixture is then filtered to give *busaa*. *Chang'aa* is made using the leftover from *busaa* production. Sugar and water are added and left to ferment for 3–4 days. The mixture is distilled by boiling over a flame, followed by condensation using cold water.	[19,32,99–101]
	Pito, Burukutu	Ghana, Nigeria		
	Chakpalo/ chakpalo/dolo	Benin, Côte d'Ivoire, Burkina Faso		
	Busaa	Kenya		
	Pombe	Zambia		
	Talla	Ethiopia, Egypt		
	Malawa	Uganda		
	Kaffir beer	South Africa		
	Umqombothi	South Africa		
	Kwete	Uganda		
	Kidongo	Uganda		
	Doro	Zimbabwe		
	Chikokivana	Zimbabwe		
	Cheka	Ethiopia		
	Chibuku	Zimbabwe, Zambia, Malawi and Botswana		
	Sekete	Nigeria		
	Spirits			
	Chang'aa			
	Kachasu		*Kachasu* is made the same way as *chang'aa* but with maize meal as substrate. Finger millet meal, fruits and banana peels can be used instead of maize. Sugar and water are added, after which the mixture is left to ferment for 4–7 days then distilled.	
	Areke	Kenya		
	Lukutu	Zimbabwe Ethiopia Zambia		

Nonalcoholic beverages are cherished for their sweet and slightly sour taste, smooth texture, low acidity and characteristic local aroma. The type of ingredient gives each beverage its desired local flavor. Ingredients such as ginger, clove, red pepper, black pepper and tamarind (*Dialium guineense* L.) fruits are used for *kunu zaki*,[95] ripened plantain and pepper are added to *bladzodidiwo*,[17] see Table 7.

Traditional alcoholic beverages account for the highest percentage of alcohol consumption in Africa, possibly because of its cultural connotations (e.g., regular use in traditional ceremonies) and low cost. In Zambia, for instance, in the Copperbelt as well as in Southern Province, farmers drink more than 60 liters of *chibuku* per year.[108] Depending on the season, sorghum, millet, and maize beer contribute 6–12% of adult calories intake in countries like Burkina, Gambia, Guinea-Bissau, Togo, Cameroon, Sudan, Burundi, Rwanda, Kenya, Tanzania, Botswana, Lesotho, Swaziland, Malawi, and Zambia.[50] The preparation of the alcoholic beverage entails soaking maize for 2–3 days or for 5–7 h in warm water of 60–70°C (commonly maize serves as starchy adjunct while other grains such as wheat, sorghum and millet are malted), followed by draining and leaving the grain to germinate in a well-aerated container covered with leaves or cloth. The germinated maize is wet ground, boiled, cooled and filtered. The filtrate is allowed to ferment until the desired sour flavor is obtained and then boiled to a concentrate.[97,109] The beverage contains lactic acid, alcohol, sugar, and amino acids, which have an antimicrobial effect on pathogens, such as *Campylobacter, Salmonella, Shigella* and *E. coli*.[110]

In both alcoholic and nonalcoholic beverages, local starch liquefaction agents are often added (e.g., *Rhynchosia heterophylla* for *munkoyo; Cadaba farinosa*, malted rice/sorghum and sweet potato extract for *kunu zaki*; malted millet flour for *togwa*; and wheat flour and/or sorghum malt for *mahewu)*.[95–97,111] These ingredients contain amylolytic enzymes, which break down large starch molecules into substrate for fermentation and result in the characteristic beverage with a low viscosity and relative density. A bittering and antimicrobial agent such as the *gesho* plant (*Rhamnus prinoides*) is added to *tella* drink in Ethiopia. Similarly, wood ash can be added to neutralize the excessive acid in the drink.[112] The alcohol content of local beverages is unstandardized and varies widely within the same locality and sometimes even for the same type of production; e.g., *pito* is 3%, *tella* is 2–4% and *busaa* is 2–4%.[61,109] The variation can be ascribed to differences in spontaneous fermentation or starter culture, the concentration of liquefaction agent, the duration of the fermentation, the homogeneity of the filtrate and whether or not distillation takes place.

Studies on beverages in Africa usually neglect their health-supporting potential. For instance, sour liquor such as the one derived from *ogi* production has been reported to possess probiotic and antimicrobial effects.[113] In fact, maize sourdough solutions were observed to be as effective as WHO/UNICEF oral rehydration salts (ORS) for treatment of children having diarrhea and abdominal discomfort.[114] The sour liquor has long been effectively used in local communities for managing acute diarrhea in children and for soaking or dilution of local herbal medicines, especially in rural areas where they may not have access to medical facilities. The production and packaging of sour liquor is inexpensive (fully derived from a liquid waste stream) and culturally accepted in most communities, especially in West Africa. To the best of our knowledge, it is only used at household level and not commercialized in any form. Similarly, microorganisms extracted from sourdough in traditional African foods have shown to exhibit probiotic properties.[113,115] However, heat treatment during cooking destroys the predominant

lactic acid bacteria present, and therefore nullifies all probiotic effects. To use the probiotic potential of the sourdough, it could be positioned as an uncooked beverage drink like *pozol* in Mexico and *sobia* in Saudi Arabia. *Pozol* and *sobia* are refreshing beverages made from suspensions of fermented dough in water and consumed cold[116]; similar to the consumption of ice *kenkey* (in Ghana) and *fura de nunu* (in Nigeria).

General evaluation of maize value chains and opportunities

Maize-based street food production serves as a major avenue for consumption of maize in Sub-Saharan Africa. An increase in patronage of street food has been recorded in Africa in the past two decades, consequent to urbanization (movement of people into towns in pursuit of opportunities – 'greener pastures'), which usually leaves a large number of the immigrants jobless. As a result, many embark on street food vending for livelihood. Likewise, the demand for street food increased because city-dwellers spend most time at work or commuting. Thus, they prefer to buy convenient, fast, easily accessible and inexpensive food.[7] This trend will continue since the population of Africa is expected to double, with urbanization levels rapidly expanding to more than half. A large portion of street foods in Africa is maize-based, for instance *banku* (a cooked fermented corn dough) is 44% of the menu list of street food vendors in Ghana.[117] Therefore, it is important to pay more attention to maize-based street food vending as a means of increasing maize utilization and creating opportunities through a value chain approach. The long list of maize-based foods in the previous sections presents many opportunities that can benefit street vending, help to lift many people out of poverty as well as improve nutrition, especially for women (and their children), who are the predominant stakeholder. Other opportunities in maize value chains are presented in Fig. 3.

To ensure food and nutrition security, value chains of major staple crops like maize have to become more efficient and diversified, thereby creating inclusiveness and innovations to feed the current and future population. Although value creation is often viewed exclusively in monetary terms, nonmonetary value creation (enhancing quality, safety, sensory properties, food diversity, as well as the nutritional value of the end product) is critical to ameliorating the current poor performance and untapped potential of staple crops. Value addition of staple crops has been long neglected or received little attention over the years resulting in loss of foreign exchange and employment opportunities and contributing to prevailing malnutrition. Although this study emphasizes opportunities for street food vendors, upscaling food production by small and large scale enterprises is also highly feasible and should be encouraged.

Effects of traditional maize processing on nutritional quality

Traditional maize processing has been used for centuries to improve food quality – functionality, texture, flavor, shelf life, safety and nutritional value. Processing methods include roasting, smoking, dehulling, drying, soaking, malting and fermentation. Maize-based foods are often characterized by a low nutritional quality as a result of the removal of some kernel structures like pericarp or germ, damage due to processing and/or the natural nutritional deficiencies of the grain.[86] Besides, the presence of antinutrients, like phytate in maize, decreases the bioavailability of the minerals. Studies on the effects of

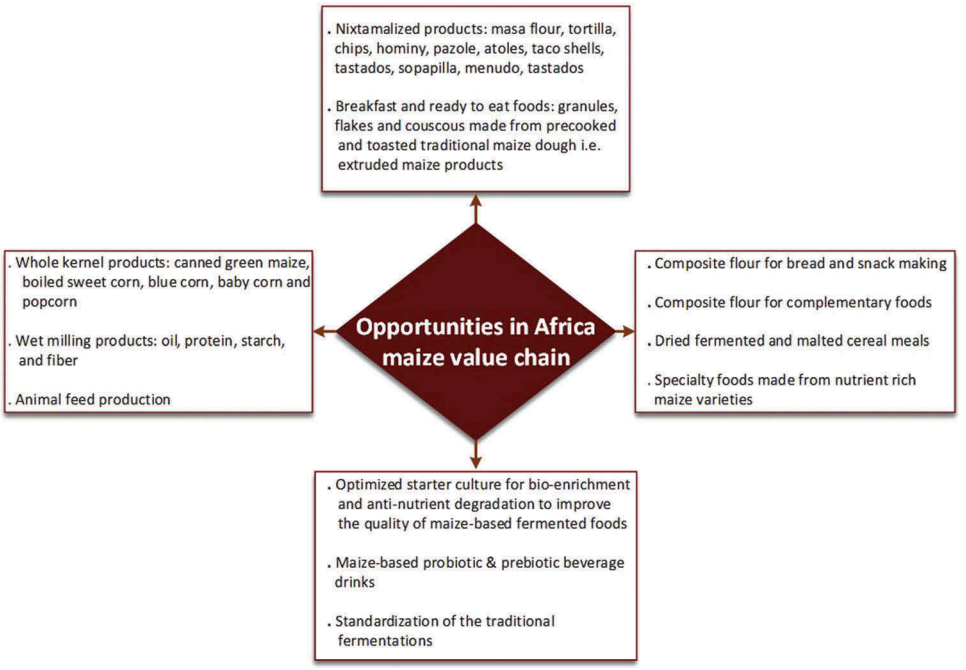


Figure 3. Framework of opportunities in Africa's maize value. Nixtamalization technique in Mexico generates about 300 products [22]. The vast amount of product from this technique coupled with its nutritional and food safety benefits shows that it could make a significant impact in Africa and can serve as a driver for the nutrient-dense varieties currently having low adoption. The close similarity of this technique with the examples of the traditional processing methods in Africa shows a strong possibility for incorporation and acceptance. Green maize and popcorn currently not sufficiently grown in the country are a huge gap of opportunities to be filled. And since fermentation is a critical processing step in Africa, local bio-enriched techniques can generate nutrient-rich products and probiotics/prebiotics from maize. The underutilization of maize for breakfast meal and composite flour could be overturned to drive the acceptance of improved maize varieties.

maize processing on nutritional quality are scarce in Africa, and in many cases the available studies have contrasting results.[90,118]

In general, traditional processing in Africa involves uncontrolled drying, removal of the bran and sometimes the germ, either intentionally or not, and also excessive washing of grits, decanting of soaked or fermented water and sieving out chaff, all of which can result in loss of nutrients.[10] Maize starch derived from sediments in water or repeated rounds of draining is normally used in the preparation of traditional foods (e.g., *ogi)*. This infers that the nutrients in the supernatant are discarded. Improved nutrient retention was reported in modified sourdough processing methods such as in the use of a pure starter culture, reuse of steep water and a proper milling and sieving method to minimize loss of maize germ and other components.[119,120] In addition to the impact of these mechanical processes, other treatments such as heating may result in denaturation of the heat sensitive components like proteins and possibly, crosslinking of amino acids to form lanthionine or lysinoalanine or Maillard browning products.[121] Maize-based foods serve as weaning food for infants and staple foods for adults. Consequently, understanding the nutrient

retention and the amount available for body functions as a result of maize processing is critical to optimize maize use.

Effect of processing on anti-nutrient – phytic acid

Phytic acid (PA) negatively influences the bioavailability of minerals due to the high chelating ability of its reactive groups with positively charged cations such as Fe^{2+}, Zn^{2+}, Ca^{2+} and Mg^{2+} to form insoluble metal-phytate complexes.[122] Breakdown of PA can occur by (1) an endogenous enzyme (e.g., phytase in maize), (2) an exogenous enzyme (e.g., biotechnologically produced phytase or addition of crops with high phytase activity like wheat), (3) intestinal mucosal phytase, (4) microbial (e.g., bacteria, fungi, yeast) phytase released during fermentation or digestion in the gut, and (5) processing activities (e.g., boiling, roasting, milling, etc.).[123,124] As the mucosal phytase activity in humans is very low (i.e., 1000-fold lower than that of alkaline phosphatase), its role in the breakdown of PA is negligible.[125]

Traditional processing and preparation methods, such as drying, milling, soaking, heating/roasting, cooking (e.g., with water or an alkaline solution), sprouting or malting and fermentation can degrade phytic acid (PA) to enhance the bioavailability of nutrients.[24,124,126] The efficiency of these methods in reducing PA can be influenced by its location in the maize kernel.[127] About 90% of PA is located in the maize germ. This is the same structure where 26% of the kernel protein, 78% of the kernel minerals and 83% of the total kernel lipids are present.[111] Thus the removal of the germ where PA is concentrated, deprives consumers of essential nutrients. An efficient maize processing method needs to optimize the reduction of PA to its lowest phosphorylated form (<IP3), and thus maintain a maximum amount of nutrients.[127] Breakdown of PA increases upstream processing (i.e., from raw maize to finished product); hence, it is important to systematically combine different processing methods to achieve a significant reduction of PA.[127]

All forms of heat treatment have a positive impact on PA degradation at different rates. The degradation is higher in fresh maize than in dried maize.[124] Heat treatments such as boiling, cooking in hot powdered charcoal, roasting in sand and roasting on charcoal of fresh maize resulted in PA losses of 18.1, 29.2, 46.7 and 15–41.9%, respectively, while a much lower reduction was observed in dried maize. For example, boiling in water and roasting in sand resulted in 19 and 24–37% PA reductions, respectively.[122,124] Milling or pounding exposes PA to enzymatic hydrolysis, thermal degradation, and faster absorption. For instance, a 47–51% PA reduction was observed in soaked pounded maize, with a much higher reduction in finer flour.[105,128] Reduction of PA during soaking is largely due to diffusion of water-soluble PA (e.g., Na, K, or Mg – phytate), which can then be drained out.[127] Approximately 90% of PA in maize is soluble in water,[129] which makes soaking a reliable method for reducing PA. The soaking of grain also results in activation of endogenous phytases, which break down PA.[130] In general, the extent of PA reduction during soaking depends on the level of granulation of maize, pH, variety (i.e., hardness of the endosperm and hull) and duration.[126] Amoa and Muller[82] observed a 5.9% phytate reduction (with an additional 1.9% in steeping water) in samples from Ghana while 2.2% was reported for samples from Malawian maize. Other researchers, Greffeuille et al.[12] and Mitchikpe et al.[128] reported 3 –14% PA reduction during soaking of maize grains.

The use of unmalted maize flour as a starting material for traditional maize-based food processing deprives the processor of the PA breakdown ability of sprouting since it

requires whole maize. This can be mitigated by adding sprouted maize flour since it contains endogenous phytase.[127] However, Amoa and Muller[82] observed that addition of wheat flour is more efficient than malted maize flour. The addition of 1% wheat flour during the production of *kenkey* resulted in a 99% phytate reduction after 36 h of fermentation.[82] Wheat has a phytase activity of 1565 (U/kg) compared to 24 (U/kg) in maize; the addition of wheat flour increased the phytase concentration thereby causing phytate breakdown.[131] The sprouting process significantly increases phytase activity (more than 80%) in maize along with a decrease in PA. Egli et al.[126] and Mitchikpe et al.[128] reported a 9–74% PA reduction after maize sprouted for 48 h – 72 h. The PA reduction reported from sprouted maize is not sufficient to influence mineral bioavailability but it is an important step to complement successive degradation processes.[127]

The reduction of PA during fermentation of maize is possibly due to the growth of microorganisms rather than by the endogenous enzyme because normal maize has a low phytase activity.[132] An enzyme activity of up to 3 IU/g of maize seed has been reported in a transgenic maize line containing *Aspergillus* phyA (encoding phytase), with about 95% degradation of the endogenous PA in a maize flour paste.[133] Microorganisms break down PA through the production of microbial phytase. The enzyme hydrolyzes PA into myoinositol and inorganic phosphate through the intermediate myoinositol phosphates (i.e., IP1 to IP5).[105,130,134] Amoa and Muller[82] observed 16.9% and 2.7% phytate reductions during the production of *kenkey* from Ghanaian and Malawian maize, respectively. Similarly, Hotz and Gibson[105] reported a 12% reduction of phytate during spontaneous fermentation and a 39% reduction using a starter culture. A larger reduction was observed after the addition of malted maize flour. Microbial phytase is released from the natural microorganisms on maize or starter cultures. The production and activity of phytase are influenced by pH, temperature, species, available nutrients, and the presence of inhibiting agents.[123,130] Optimum degradation of PA requires an understanding of the constituent microorganisms and the released microbial phytase since different phytase sources show differences in heat stability and pH optimum. Most bacteria and fungi produce phytase at an optimum pH range between 5.0 and 7.0; the released phytase is active at a pH optimum between 4.5 and 5.5 for fungi and 6.5 to 7.5 for bacteria.[123] Similarly, most microorganisms produce phytase at an optimum temperature ranging from 25 to 37°C; the released phytase is active at a temperature between 25 to 80°C.[123,130] Stability of microbial phytase decreases as pH drops below 4.5 and increases above 7.5.[134] The pH of the maize food ranges from an average of 6.5 (initial) to 3.1 (final product), with the temperature at an average of 28°C. *Lactobacillus plantarum*, which is the most predominant LAB in fermented maize-based foods and has the highest phytase activity, was found to produce phytase with a single pH optimum of 5.5, and to be inactive at pH <3.5/>6.5. Therefore, to achieve the optimum degradation of PA, fermentation processes need to be maintained at conditions that favor the activity of the predominant microbial phytase.[12]

Conclusion

The traditional uses of maize, especially for snacks, drinks and bread, in African countries are limited when compared to Mexico and Central America, where maize originates. Given the right technology, maize variety, process and awareness, many high potential maize foods localized in some communities can be scaled up across the continent and

beyond. The introduction of local processing technologies or techniques, like nixtamalization, at both household and commercial level, would enhance the use of maize to meet consumer needs and preferences, and reduce nutrient wastages. Rapid population growth and urbanization in combination with increased disposable income is bound to induce dietary change. If dietary change follows comparable patterns as elsewhere in the world, this implies more reliance on semi-processed and processed foods. Promoting processing techniques that will reduce nutrient loss and make food preparation more convenient for consumers can enable enhanced food and nutrition security.

Traditional fermented foods will continue to gain acceptance in SSA; research into technologies to improve nutritional properties, shelf life and baking properties is necessary. Studies on more effective ways to enhance the nutritional quality of maize-based foods through blending with the commonly available nutrient-rich crops, vegetables and possibly through microbial fortification (e.g., fermentation with high amino acid secreting microorganisms) and other novel approaches should be encouraged. Advanced knowledge in biotechnology could be applied to develop microorganisms that can be used in fermentation to enhance nutritional components and quality of maize-based foods. Additionally, there is a need to embark on research to improve the bioavailability of essential nutrients as influenced by the maize food matrix and the different traditional processing methods.

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