

Millet-based Traditional Processed Foods and Beverages—A Review

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Millet is a general term used for a wide range of cereals that describes seeds from several taxonomically divergent species of grass. These grasses are grown mostly in marginal agricultural areas and under agricultural conditions in which major cereals fail to produce substantial yields (22). Millet is thought to be among the first cultivated crops and has been a staple food ingredient in Central and Eastern Asia, Europe (mainly Russia), China, India, and some parts of Africa since ancient times (12). Millet is grown extensively in India, although it is not of major importance as a food crop. In contrast, millet is the major source of energy and protein for millions of people in Africa. It is an important food in many developing countries because of its ability to grow under adverse weather conditions such as limited rainfall. In addition, millet has many nutritious and medicinal properties (51,74).

Millet is related to sorghum and belongs to the Poaceae (formerly known as Gramineae) plant family. There are many varieties of millet, but the four major types are pearl millet (*Pennisetum glaucum*), which comprises 40% of worldwide production;



- Millet is an important food source in many developing countries because of its ability to grow under adverse weather conditions.
- Fermentation is a simple, economical way to improve the nutritional value, sensory properties, and functional qualities of millet products.
- Traditional millet-based foods and beverages and their processing techniques are highlighted.

foxtail millet (*Setaria italica*); proso or white millet (*Panicum miliaceum*); and finger millet (*Eleusine coracana*). Pearl millet produces the largest seeds and is the variety most commonly used for human consumption (23). Minor millets include barnyard millet (*Echinochloa* spp.), kodo millet (*Paspalum scrobiculatum*), little millet (*Panicum sumatrense*), Guinea millet (*Brachiaria deflexa* = *Urochloa deflexa*), and browntop millet (*Urochloa ramosa* = *Brachiaria ramosa* = *Panicum ramosum*). Teff (*Eragrostis tef*) and fonio (*Digitaria exilis*) are also often referred to as millets.

The main components of millet include starch, protein, lipids, vitamins, and miner-

als (69). In addition, minerals such as magnesium, manganese, and phosphorus are present in significantly higher amounts than in other cereals (26). Millet also generally contains significant quantities of essential amino acids, particularly sulfur-containing amino acids (methionine and cysteine). It can contain 6–13% crude protein and 1.9–14% minerals (19). Millet is also higher in fat than maize, rice, and sorghum (51).

Although cereal grains constitute a major source of dietary nutrients worldwide, they are deficient in some basic components (e.g., essential amino acids). Fermentation may be the simplest and most economical way of improving their nutri-

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tional value, sensory properties, and functional qualities (65). As a result, fermented foods have become a very important part of the human diet worldwide. Fermented foods make up between 20 and 40% of the human food supply (15).

Traditional food processing techniques usually involve the use of endogenous enzymes activated by germination or produced by microorganisms during fermentation. Fermentation can be spontaneously initiated without the addition of microorganisms or controlled through the use of specific cultures or starters from a previous batch of fermented product (68). Fermented foods are produced worldwide using various manufacturing techniques, raw materials, and microorganisms. However, there are four main fermentation processes: alcoholic, lactic acid, acetic acid, and alkali fermentation in food systems (63). Alcoholic fermentation (e.g., wines and beers) results in the production of ethanol, and yeasts are the predominant organisms used. Lactic acid fermentation (e.g., fermented milks and cereals) is mainly carried out by lactic acid bacteria (LAB). A second group of bacteria that is important in food fermentation includes acetic acid producers from the *Acetobacter* species. *Acetobacter* spp. convert alcohol to acetic acid in the presence of excess oxygen. Sev-

eral investigations have been performed to determine the role of LAB and yeasts in traditional fermented foods. Different species of LAB and yeasts have been used successfully as starter cultures to ferment traditional cereal products, as well as legume and seed products (8,9,47,58,66,75). Alkali fermentation often takes place during the fermentation of fish and seeds, producing a product popularly used as a condiment (45). Scientists have embarked on extensive studies to isolate and characterize microorganisms associated with production of fermented foods to explore the possibilities for exploiting their industrial potential (1,38).

Cereals, in particular millet-based fermented foods and beverages (Table I), have been extensively studied and form a major part of the diet in most African countries (16). However, published research on millet and its food value and potential is limited. This article highlights some traditional millet-based foods and beverages.

Traditional Fermented Millet Foods and Beverages

Malt. The malting process, which involves soaking, germination, and drying, transforms grains into malt through high enzyme activity. Millet and sorghum malt production is a traditional practice in Afri-

ca, where malt is used in lactic acid- and alcoholic-fermented beverages and infant food production (10,28,42,70). Malting induces important beneficial biochemical changes in the millet grain. Moreover, soaking generates grain softening and increases water absorption. Enzymes produced during germination are responsible for hydrolysis of starch and proteins, which makes sugar and peptides/amino acids directly available. Furthermore, proteolytic enzymes improve the availability of limiting amino acids such as lysine, methionine, and tryptophan (5,11,41). These attributes depend on the type and quality of grain.

Traditional malting processes in many developing countries involve three main operations: soaking, germination, and drying. The duration and conditions of each operation are highly variable, resulting in highly variable malt and derived product quality. Total aerobic germ, coliform, yeast, and filamentous fungus levels in malt derived from traditional processes can be higher than the limits recommended by the Codex Alimentarius Commission (29). Like other cereals, millets are susceptible to fungal growth and mycotoxin production under certain environmental conditions. Mycotoxins not only threaten consumer health but also are a major threat to malt quality (61).

Table I. Traditional fermented and unfermented millet-based foods and beverages

Product	Microorganisms ^a	Form	References
Fermented			
<i>Ben-saalga</i>	Lactic acid bacteria	Gruel	Rivera-Espinoza and Gallardo-Navarro (60); Songré-Ouattara et al. (62); Tou et al. (67)
<i>Burukutu</i>	<i>S. cerevisiae</i> , <i>S. chavelieri</i> , <i>Leuconostoc mesenteroides</i> , <i>Candida</i> , <i>Acetobacter</i> , <i>G. candidum</i>	Beer	Haggblade and Holzapfel (27); Iwuoha and Eke (32); Nzelibe (50); Songré-Ouattara et al. (62)
<i>Bushera</i>	<i>Lactococcus</i> , <i>Leuconostoc</i> , <i>Enterococcus</i> , <i>Streptococcus</i> , <i>L. brevis</i>	Gruel	Muyanja et al. (48); Prado et al. (59)
<i>Fura</i>	<i>Enterobacter</i> , <i>Bacillus</i> , <i>Staphylococcus</i> , <i>Fusarium culmorum</i> , <i>A. oryzae</i> , <i>A. niger</i> , <i>A. flavus</i> , <i>A. parasiticus</i> , <i>Mucor racemosus</i>	Porridge	Inyang and Zakari (31); Jideani et al. (34,35)
<i>Jandh</i>	Lactic acid bacteria, yeast, mold	Beer	Dahal et al. (17); Karki (36); Tamang and Sarkar (64)
<i>Koko</i>	<i>L. fermentum</i> , <i>L. salivarius</i> , <i>Enterobacter cloacae</i> , <i>Acinetobacter</i> , <i>L. plantarum</i> , <i>L. brevis</i> , <i>S. cerevisiae</i> , <i>C. mycoderma</i> , <i>W. confusa</i>	Porridge	Campbell-Platt (15); Lei and Jacobsen (37)
<i>Kunu-zaki</i>	Lactic acid bacteria, yeast	Paste	Agarry et al. (2); Akoma et al. (6); Efiuvwevwere and Akoma (21); Oranusi et al. (57)
<i>Mangisi</i>	Lactic acid bacteria	Beer	Benhura and Chingombe (14); Gadaga et al. (25); Zvauya et al. (76)
<i>Ogi</i>	<i>L. plantarum</i> , <i>L. fermentum</i> , <i>Leuconostoc mesenteroides</i> , <i>S. cerevisiae</i> , <i>C. mycoderma</i> , <i>Corynebacterium</i> , <i>Aerobacter</i> , <i>Rhodotorula</i> , <i>Cephalosporium</i> , <i>Fusarium</i> , <i>Aspergillus</i> , <i>Penicillium</i>	Paste	Akinrele (4); Banigo et al. (13); Inyang and Idoko (30); Marero et al. (42); Odufa (52)
<i>Togwa</i>	<i>L. plantarum</i> , <i>L. brevis</i> , <i>L. fermentum</i> , <i>L. cellobiosus</i> , <i>W. confusa</i> , <i>P. pentosaceus</i>	Gruel	Mugula et al. (47); Oi and Kitabatake (53); Prado et al. (59)
<i>Uji</i>	Lactic acid bacteria	Porridge	Masha et al. (43); Mbugua (44); Onyango et al. (54–56)
Unfermented			
<i>Dambu</i>	Unknown	Dumplings	Agu et al. (3); Jideani et al. (33); Nkama et al. (49)
<i>Masvusvu</i>	Lactic acid bacteria, yeast	Mash	Efiuvwevwere and Akoma (21); Zvauya et al. (76)
<i>Roti</i>	Unknown	Bread	Dahl (18); Wickramasinghe et al. (73)

^a A. = *Aspergillus*, C. = *Candida*, G. = *Geothrichum*, L. = *Lactobacillus*, P. = *Pediococcus*, S. = *Saccharomyces*, and W. = *Weissella*.

Koko. *Koko* is a millet porridge that is consumed daily by many people in West Africa as lunch or an in-between meal. *Koko* is produced by steeping pearl millet overnight, discarding the steep water, wet-milling the millet grains together with spices (usually ginger, chili pepper, black pepper, and cloves), and adding water to the milled materials to make a thick slurry. The slurry is then sieved, fermented, and sedimented for 2–3 hr. The liquid top layer is decanted and boiled for 1–2 hr, and finally, the sedimented bottom layer is added until the desired consistency is obtained. The whole process generally starts in the evening with steeping of the millet grain, and the final product is ready for consumption around noon the following day. *Koko* can be sold as porridge in plastic bags or bowls and is normally consumed with added sugar. The predominate microorganisms in *koko* are *Weissella confusa*, *Lactobacillus fermentum*, and *L. salivarius* (15,37).

Fura. Pearl millet is an important food for millions of people inhabiting the semi-arid tropics and is a major source of calories in developing regions of the world (23). The Sahel is a region that borders semi-arid and arid areas of Africa north of the equator. The staple food in the Sahel

region is *fura* made from millet flour. A detailed method of preparing *fura* using pearl millet is diagrammed in Figure 1 (20,31). Millet grain is slightly moistened with water and ground in a locally fabricated disc attrition mill. The hull is removed from the grain after drying in the sun, and the grain is ground using a hammer mill and sieved. Pearl millet flour is mixed with powdered black pepper, powdered ginger, and water (95°C) in a mortar and kneaded into a smooth dough with a pestle. The dough is hand molded into balls, placed inside a cooking pan containing boiling water, and cooked for 30 min at atmospheric pressure. The balls are kneaded again while still hot until a smooth, slightly elastic mass is obtained. The dough is then molded into balls of *fura*. The stiff dough produced is reconstituted to a porridge-like consistency with sour milk (34,35). In recent years a company in Abuja, Nigeria, specializing in the production of powdered (instant) *fura* has made *fura* available in supermarkets (34,35).

Mangisi. Fermented beverages constitute a major part of the diet of rural African families, serving as alcoholic beverages and weaning foods, in addition to their role in social functions and ceremonies (46,71).

Mangisi is a sweet-sour beverage made from naturally fermented millet mash (76). Preparation varies in different regions of sub-Saharan Africa such as Zimbabwe and Uganda. In one variation, finger millet is malted and then milled, and the flour is mixed with water. The mixture is slowly heated for 80 min to near boiling. The resulting product is a mash (*masvusvu*) that is cooled, diluted, strained, and allowed to stand for several hours during which spontaneous fermentation takes place, producing *mangisi* (76).

Another variation involves malting and milling finger millet, mixing the flour with water, and boiling the mixture for 1–2 hr. The *masvusvu* is cooled, diluted, and allowed to stand overnight. On the second day more malt flour is added, and the mixture is left to ferment until the third day, when the coarse solids are strained off. The mixture is returned to the fermentation vessel, and the *mangisi* is then ready for consumption (14). Gadaga et al. (25) reported that the product contains more alcohol due to the addition of extra malt to the brew on the second day, which could serve as an additional source of inoculum, and also to the longer fermentation time.

Jandh. Traditional fermented foods are generally specific to certain geographic

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regions and particular communities. *Jandh* (a type of beer), a slightly acidic and sweet beverage, is a major traditional alcoholic product of Nepal (17). *Jandh* is a fermentation product of finger millet (*koko* or *marua*), which is sometimes supplemented with a small amount of wheat or corn (64).

Jandh is prepared as follows. Millet seeds are softened using steam and then spread on leaves (preferably banana leaves). *Murcha*, the starter culture, is powdered and sprinkled on the boiled and cooled seeds. After thorough mixing, the seeds are piled in a heap and kept for 24 hr at ambient temperature. Next, they are usually placed in an earthen pot and covered with leaves and straw. (In urban areas, the seeds are allowed to ferment in polyethylene bags.) If air leaks into the fermentation substrate, the product becomes sour (36). In the case of millet, after fermentation the seeds are kneaded to remove the seed coats. The grits are then placed in bamboo vessels with water (cold or hot depending on the season). After 10 min, the beverage is ready to drink. This liquor is believed to be a beneficial tonic, especially for postnatal women (17,36).

Uji. *Uji* is a thin, lactic acid-fermented porridge that is widely consumed in East Africa (Kenya, Uganda, and Tanzania) and is referred to as *togwa* and *obusera* in Tanzania and Uganda, respectively. It is pre-

pared by lactic acid fermentation of cereal (maize, finger millet, or sorghum) and cassava flours mixed in different combinations and proportions. The fermentation inocula are derived by a technique referred to as backslopping. The most popular 1:1 combinations are maize and sorghum, maize and finger millet, cassava and finger millet, and cassava and sorghum (54,56). Adults consume *uji* as a refreshing beverage, and children consume *uji* as their principal weaning food (55).

Lactobacillus plantarum is the predominant species of lactobacilli in typical *uji* fermentation and is responsible for the high lactic acid levels and subsequent sour flavor of *uji*. Other species present include *Pediococcus acidilactici*, *P. pentocaceus*, *L. paracasei* subsp. *paracasei*, *L. fermentum*, *L. cellobiosus*, and *L. buchneri* (43,44).

Burukutu and Pito. In many countries millet has been used successfully as a substitute for barley. For example, grains such as finger millet have been used in sub-Saharan Africa and India as major ingredients in the traditional manufacture of malt (50,62). Traditionally, African beers differ from Western beer types in several ways: they are often sour, less carbonated, and have no hops. African beers are consumed unrefined, including unfermented substrates and microorganisms (27). *Pito* and

burukutu are brewed concurrently by fermenting malted or germinated single cereal grains such as millet or a mixture of cereal grains into a brownish suspension or liquor (10,32). *Burukutu* is a popular alcoholic beverage among the peoples of sub-Saharan Africa.

Kunu-zaki. *Kunun-zaki* is a fermented nonalcoholic cereal-based beverage. It is a popular refreshing beverage in areas of the Sahel such as northern Nigeria, Niger, and Tchad. *Kunun-zaki* production is essentially a home-based industry, and at present, there is no large-scale factory production. Efiuvwevwe and Akoma (21) studied the microbiology of the *kunun-zaki* fermentation process and reported that *Lactobacillus fermentum* and *L. leichmannii* were predominant at the end of the fermentation period.

Akoma et al. (6) described the production of four types of *kunun-zaki* using combinations of millet or millet and wheat, with or without the addition of ground malted rice, fermented for 6 hr. Agarry et al. (2) outlined how *kunun-zaki* could be produced using developed starter culture (controlled fermentation), natural (uncontrolled) fermentation, and different combinations of millet, wheat, malted rice, and starter culture. For the control experiment, uncooked cereal starch (previously sterilized) was mixed thoroughly with hydrolyzed cereal starch before addition to gelatinized cereal starch. This mixture was incubated at ambient temperature (without addition of starter culture) for 6 hr to establish whether fermentation could take place. The authors claimed *kunun-zaki* produced with the addition of starter culture to either millet and malted rice or millet, wheat, and malted rice had several advantages (flavor, aroma, appearance, and overall acceptability) over other products. However, in the Sahel, the quality of traditional food products such *kunun-zaki* has always depended on the skill of local producers and the season in which a product is made (57). Other fermented millet beverages include *braza* and *darassum*, which are made in Romania and Mongolia, respectively (72).

Ogi. *Ogi* is a porridge prepared from fermented millet, sorghum, or maize paste or cake in West Africa. *Ogi* is often sold as a wet cake wrapped in leaves or polyethylene bags. Gelatinized *ogi* is called *pap* and is mainly used as a traditional infant weaning food, as well as a breakfast meal for many adults. In many parts of Africa, children are fed mashed adult foods or gelatinized cereal flour slurries to complement breast milk from 4 to 6 months of age.

These slurries absorb a large quantity of water and swell greatly when mixed either

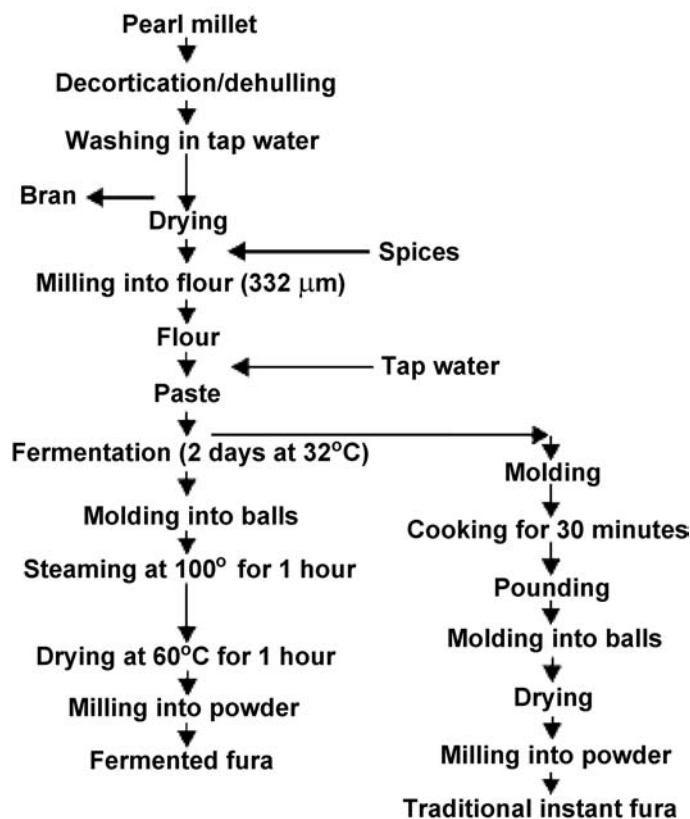


Fig. 1. Production of traditional and fermented instant fura (31).

with cold or hot water. Traditional and industrialized methods for manufacturing *ogi* have been reported (13). Malting and fermentation techniques can be used to modify the starch content of the cereals so they do not thicken and, therefore, do not require dilutions. Other benefits from good manufacturing processes include the inhibition of pathogens throughout the fermentation process (42). Akinrele (4) showed that *Lactobacillus plantarum*, *Corynebacterium* spp., *Aerobacter* spp., *Candida mycoderma*, *Saccharomyces cerevisiae*, *Rhodotorula* spp., *Cephalosporium* spp., *Fusarium* spp., *Aspergillus* spp., and *Penicillium* spp. are the major organisms responsible for the fermentation and nutritional improvement of *ogi*. Odunfa (52) identified *Lactobacillus plantarum* as the predominant organism in *ogi* fermentation responsible for lactic acid production (30). Lactic, acetic, butyric, and formic acids give *ogi* its characteristic aroma and sour flavor (8,30). Light colored *ogi* with a mild sour flavor is reportedly preferred by consumers (4,30).

Ben-saalga. *Ben-saalga* is a millet-based fermented gruel that is made in a large number of traditional production units in Burkina Faso (West Africa). Traditional cereal-based fermented foods are frequently used as complementary foods for infants and young children in Africa (60,67). The daily quantity of millet usually processed into *ben-saalga* in a traditional production unit is around 7 kg. Processing includes the following main steps: washing and soaking of grain (pearl millet), grinding, kneading, sieving, settling, and cooking. Aromatic ingredients, such as ginger, black pepper, pepper, and mint, usually are added in small quantities prior to grinding depending on the tradition of the *ben-saalga* producer (62,67).

During final cooking, the supernatant resulting from the settling step is collected and heated for 40 min to near boiling. Afterward, the paste is added to the supernatant and boiled for 7 min. Tou et al. (67) reported that the sour *ben-saalga* resulting from cooking the sour paste had inadequate nutritional characteristics with respect to the requirements for infants and young children.

Bushera. *Bushera* is the most common traditional beverage prepared in the western highlands of Uganda, where sorghum and millet are important staple and commercial crops. The product is consumed by both young children and adults. Numerous methods are used to prepare *bushera*. Flour made from germinated sorghum or millet grain is mixed with boiling water and left to cool to ambient temperature. Germinated millet or sorghum flour is then added,

and the mixture is left to ferment at ambient temperature for 1–6 days. The lactic acid bacteria isolated from *bushera* generally are from five genera: *Lactobacillus*, *Lactococcus*, *Leuconostoc*, *Enterococcus*, and *Streptococcus*. *Lactobacillus brevis* is more frequently isolated than other species (48,59).

Togwa. *Togwa* is a lactic acid-fermented traditional beverage consumed in Africa. In southern Tanzania, *togwa* is usually made from maize flour and finger millet malt. In this region, it is consumed by both adults and young children and is used as a refreshment as well as a weaning food (53,59). *Togwa* is prepared by cooking the cereal or cassava flour in water. After cooling, the starter culture (old *togwa*) and cereal flour from germinated grain are added. Fermentation is spontaneous and uncontrolled, resulting in a product with variable quality (40,60).

The bacteria isolated from *togwa* include *Lactobacillus plantarum*, *L. brevis*, *L. fermentum*, *L. cellobiosus*, *Weissella confusa*, and *Pediococcus pentosaceus*. All of them are present throughout fermentation. The *L. plantarum* group is the predominant organism at the end of *togwa* fermentation and has been identified as the predominant organism at the end of several natural lactic acid fermentations (7,47).

Nonfermented Millet Foods and Beverages

Dambu. *Dambu* is a steamed, granulated dumpling generally made from millet, maize, or sorghum depending on availability. Moistened millet flour is blended with spices and steamed 30 min. The coarse particles are sprinkled into fermented milk, and sugar may be added to taste (49). *Dambu* is produced both at home and commercially. Most *dambu* producers use a traditional method involving a wooden mortar and pestle to dehull and mill the grain. The traditional pounding process is time-consuming, which limits production in most African countries (34). Moreover, because the cereal flour spoils quickly and cannot be stored, it has to be milled daily as needed for use in *dambu*. Like *fura*, *dambu* (3,33) has a limited shelf life (2 days) at tropical temperatures and due to a lack of proper packaging. Refrigerated storage conditions could prolong shelf life (3).

Masvusvu. *Masvusvu* is a sweet beverage traditionally made from malted finger millet in many villages in Zimbabwe. As reported earlier (76), *masvusvu* is unfermented *mangisi*. A mixture of water and malted millet meal is heated in an earthen pot and stirred slowly at intervals for 80 min until near boiling. The slurry mixture thickens, and the light-brown product is

consumed as either a food or beverage. Released reducing sugars impart a sweet flavor. *Masvusvu* is also used as an adjunct during opaque beer brewing (76). The preparation of *masvusvu* differs from that of either *kunun-zaki*, which is made from unmalted wet millet flour (21), or *gowé*, which is prepared from wet-milled malted sorghum flour (71).

Roti. There are many different variations of flatbreads found in many cultures across the globe. *Ragi roti*, known as finger millet *roti*, is an unleavened flatbread made from *ragi* flour (18). Other *rotis* made from different grains are part of the daily diet of people in northern and central India. The most popular flatbread is *roti* made from *atta* flour (Indian whole-wheat flour) (40). The preparation of *roti* consists of mixing the *ragi* flour, chopped onions, chili, coriander leaves, grated coconut, and salt in a bowl. Water is added little by little until a dough ball is formed (it should not be too soft). The dough is divided into two parts and cooked on a griddle. The dough is patted into round on the griddle, a few drops of oil are added, and then the griddle is placed over a medium flame. The *roti* is covered with a lid, cooked for 4–5 min on one side, and then flipped to cook the other side for another 2–3 min (73).

Commercial Utilization of Millet

The emerging principal uses of sorghum and millet as raw materials include commercial production of biscuits and confections, beverages, weaning foods, and beer. Grits, flour, and meals from cereals such as millet, sorghum, and corn are now common items in the market. Soft biscuits and cookies are being made using combinations of sorghum, maize, and wheat, and cakes and nonwheat breads are being studied (16,39). Progress in the infant weaning-foods sector is limited by production capabilities. Many brands of beer in the market contain substantial amounts of local millet, as well as sorghum and maize. The storage quality of the grain, nutritional losses after processing, high cost of imported equipment, and variation among cultivars are some of the challenges to increasing use of millet in developing countries (22,24,34).

Conclusions

Cereals, particularly millet, have great potential as raw materials for use in commercial products. However, it is necessary to shift processing and equipment from traditional to modern methods and optimize processing conditions to make quality products that are affordable. Further research is needed to develop high-yield millet varieties with high protein, diastatic power, and other desired malting proper-

ties. Policies also are needed to encourage local production, reduce equipment and processing costs, and reduce product prices.

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