CHAPTER

10

Modern Convenient Sorghum and Millet Food, Beverage and Animal Feed Products, and Their Technologies

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1. INTRODUCTION

The use of "alternative grains," also known as ancient grains, climate-smart grains, nutrigrains, or traditional grains, like sorghum and millets in modern food products, is becoming common across the world. This is taking place in order to address several socioeconomic trends, especially changing lifestyles (e.g., urbanization, working mothers, and single-parent families) and also consumer nutrition, health, and ethical concerns about obesity and type 2 diabetes, allergies, and environmental sustainability (Taylor and Awika, 2017). For example, sorghum and millets are increasingly being explored in gluten-free applications targeting consumers who suffer from celiac disease and intolerances to wheat and related cereals. Another perceived advantage of sorghum and millets is their completely genetically modified organism (GMO)-free nature that can allow them to be used in specialty products such as organic foods and humanitarian aid for countries with GMO restrictions.

This chapter is structured with the purpose of providing innovative ideas to enable mainstreaming of sorghum and millets in modern foods, against this background of prevailing socioeconomic trends, all of which provide opportunities for creating a sustained "demand pull" for these crops. Opportunities for creation of sustainable business enterprises to address the consumer demand for nutritious value-added products from these climate-smart, hardy crops (see Chapter 1) are discussed, with a focus on technology as well as the "ecosystem" required to nurture and sustain these business enterprises. The chapter specifically focuses on applications of sorghum and millets in ready-to-eat (RTE) foods and other modern convenience-type foods and beverages, plus some feed products and the various technologies used for their manufacture, for example, extrusion cooking. To highlight the global nature of sorghum and millet food, beverage, and feed product development, the chapter brings perspectives and provides product examples from the United States, India, and Africa. Products covered include breakfast cereals and snacks, precooked pasta, unleavened flatbreads, health-promoting products, fortified blended foods (FBFs) used in government-sponsored aid programs, beers and nonalcoholic malt drinks, other nonalcoholic fermented or powder-based beverages, plus pet food and aquatic feed. These innovative applications point toward a gradual mainstreaming of sorghum and millets against the background of increasing demand for alternative grains as discussed previously.

Sorghum and Millets, Second Edition
https://doi.org/10.1016/B978-0-12-811527-5.00010-1

2. HUMAN FOOD, PET FOOD, AND ANIMAL FEED APPLICATIONS—WITH A FOCUS ON THE UNITED STATES

2.1 Snacks and Breakfast Cereals

RTE savory snacks and breakfast cereals constitute a multi-billion dollar market in the United States. Sorghum has seldom been used as the main ingredient in the production of crispy/crunchy expanded snack and breakfast cereal products, many of which are produced by the high-temperature short-time extrusion cooking process. Other cereal grains such as maize, wheat, oats, and rice have traditionally been used exclusively for these products. However, today the use of sorghum in this food product category is slowly increasing. One well-publicized example is a range of breakfast cereals which includes products like puffed oat rings, shredded wheat, and flakes and contains whole grain sorghum flour and sorghum bran from an antioxidant-rich, high-polyphenol variety. Scientific literature is also relatively scarce but growing as sorghum gains popularity in these applications. A limited number of studies have focused on expanded snacks using extrusion and sorghum alone (Gomez et al., 1988; Almeida-Dominguez et al., 1994; Devi et al., 2014; Mkandawire et al., 2015) or a combination of sorghum with maize, rice, wheat, groundnut (peanut), and cowpea-based ingredients (Falcone and Phillips, 1988; Youssef et al., 1990; Siwawej and Trangwacharakul, 1995; Licata et al., 2014). Results indicated that addition of maize, rice, or wheat flours to sorghum improved the radial expansion and sensory properties of snacks, while incorporation of the high-protein legume flours like groundnut and cowpea had variable effects.

In one research study, for example, the effect of a range of ingredient and extrusion process variables on the physical properties of directly expanded extruded sorghum snacks was investigated (Puppala, 2003). The parameters that were studied included extrusion in-barrel moisture, screw speed, sorghum variety, decortication level of sorghum flour, decorticate (bran) addition, and level of maize flour. The results are shown in Figs. 10.1 and 10.2 and explained in the following. It was clear that radial or sectional expansion reduced with increased level of sorghum flour (Fig. 10.1A), irrespective of the sorghum variety or decortication level. The breaking strength of the snacks showed an inverse relationship with expansion, which is a standard result, indicating that extrudates became harder

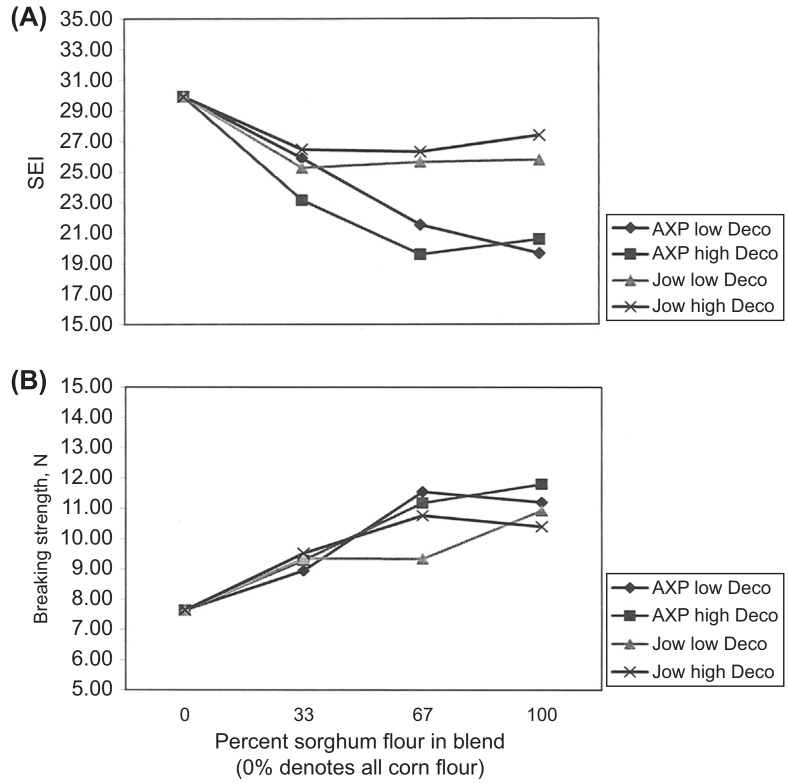

FIGURE 10.1 Effect of flour composition on (A) sectional expansion index (SEI) and (B) breaking strength of sorghum-based directly expanded snacks produced by extrusion (Puppala, 2003). AXP = variety Asgrow XP6126, Jow = variety Jowar 1, Low Deco = low decortication level, High Deco = high decortication level.

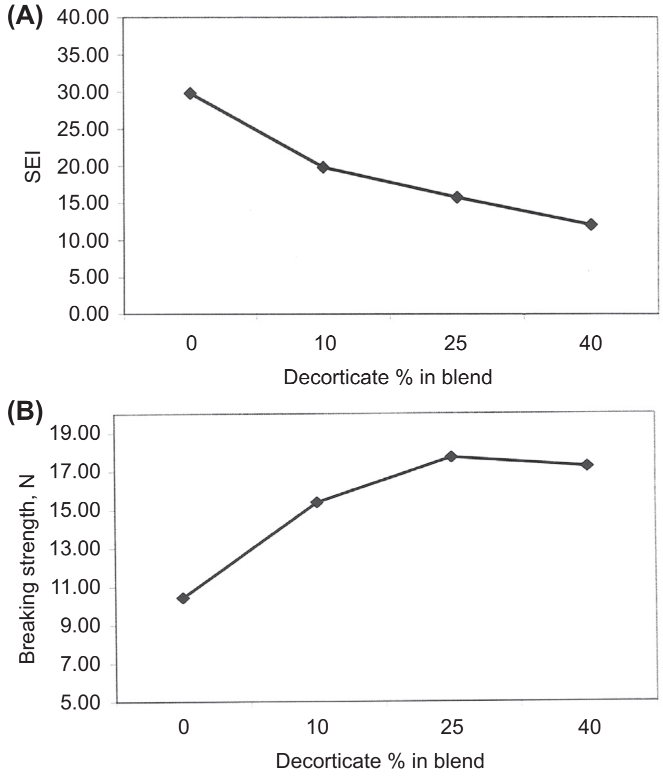

FIGURE 10.2 Effect of flour decorticate (bran) addition on (A) sectional expansion index (SEI) and (B) breaking strength of sorghum-based directly expanded snacks produced by extrusion (Puppala, 2003).

with increased level of sorghum (Fig. 10.1B). Starch forms the continuous gas-holding matrix in the expanded extrudates, while protein and fiber usually have a disrupting effect. Sorghum flours had higher protein (10.7%–12.3%) and less starch (72.0%–77.0%) compared with maize flour (6.7% and 81.0%, respectively), which was the reason for the poor expansion of extrudates with increasing level of sorghum. Extrudates from sorghum variety Jowar I had higher sectional expansion than those from variety Asgrow XP6126 (Fig. 10.1A) and was also due to the relatively higher starch and lower protein contents (PCs) in the former. Effects of sorghum variety on breaking strength and decortication level on both expansion and breaking strength did not show any clear trends. The breaking strength of comparable commercial products (puffed snacks) made with maize was in the same range (9.78–12.56 N) as the experimental products made from 100% sorghum flour, which was an encouraging finding. A decrease in in-barrel moisture (range 15.5%–17.7%) and increase in screw speed (range 300–400 rpm) led to an increase in expansion, which is also a standard result for expanded extrudates from any cereal ingredient including sorghum (Gomez et al., 1988; Almeida-Dominguez et al., 1994). Addition of the decorticate to Jowar I sorghum flour led to a more nutritious product but clearly reduced the expansion and increased the breaking strength of the extrudates (Fig. 10.2). The decorticate had higher fiber (5.5%), protein (13.6%), and lipid (8.1%) and lower starch (41.8%) contents compared with sorghum flour (fiber, protein, lipid, and starch contents of 0.1%, 10.6%, 1.6%, and 79.4%, respectively), which was the reason for the poor expansion on addition of the former, and the corresponding higher breaking strength.

2.2 Gluten-Free Precooked Pasta

Pasta products such as spaghetti and macaroni are popular foods in many countries because they are versatile, natural, and wholesome, and they are made using a relatively simple manufacturing process (Kruger et al., 1996). Durum wheat semolina is the best and most common ingredient used in pasta as it contains high-quality gluten in high concentration and has the right particle size, attributes important for optimum processing, storage, and cooking of pasta. Durum wheat or common wheat flours or a mixture can also be used in pasta production. However, the use of sorghum or millets in place of wheat to produce gluten-free pasta presents significant challenges. This is because gluten proteins of wheat have the unique property of forming an extensible, viscoelastic, and cohesive mass when mixed with water. Pasta relies on this property of gluten to strengthen and retain its structure, maintain the integrity of cooked product, and reduce cooking losses.

For individuals with celiac disease, a chronic enteropathy caused by consumption of prolamins present in wheat (gliadins), rye (secalins), barley (hordeins), and possibly oats (avidins) (Murray, 1999; Thompson, 2001), a diet free of gluten is advised. Sorghum is a recommended gluten-free food ingredient (Mestres et al., 1993), but due to it being devoid of gluten-like proteins, sorghum lacks the properties of wheat that make the latter ideal for pasta. In principle, a good quality pasta product cannot be produced with sorghum and other grains besides wheat when used alone (FAO, 1995). In the study described in the following on development of sorghum-based pasta, various additives were investigated to overcome these shortcomings. In addition, cooking the flour (starch gelatinization) was used as a binding mechanism to compensate for the absence of gluten proteins. Starch gelatinization also imparts precooked or rapid cooking properties to the pasta.

Optimum processing conditions were obtained for producing sorghum-based, precooked pasta using both lab- and pilot-scale extrusion-based cooking and forming processes (Cheng et al., 2007). A relatively high-moisture (>30% wet basis) extrusion cooking process led to gelatinization of starch for achieving binding of the product matrix, while at the same time keeping the specific mechanical energy (SME) in the moderate range (<100 kJ/kg) in order to form a dense, blister-free, unexpanded product. At lab-scale, the effects of adding corn starch, monoglycerides, eggs, gums, and natural color on the quality characteristics of the finished product were evaluated. Drying of the pasta with humidity adjustment improved its appearance, and addition of 0.5% monoglycerides to the sorghum flour prior to extrusion significantly improved pasta cooking quality (higher weight gain or water absorption and lower cooking loss during boiling in water based on standard methods; Fig. 10.3). Monoglycerides act as lubricating agents and reduce the mechanical-induced shear and degradation of starch granules, leading to better cooking quality. However, addition of eggs and gums to the sorghum flour did not improve pasta cooking quality.

Results from the pilot-scale study showed that the combination of low screw speed (185 rpm) and high in-barrel moisture (37%) gave better pasta appearance and cooking quality. The cooking loss ranged from 4.32% to 5.91% and was at the same level as the commercial durum semolina-based product (Fig. 10.4). Cooking time of pasta made with sorghum flour and 0.5% monoglycerides ranged from 5.5 to 7 min and was significantly lower compared with the semolina-based commercial product, indicating that the former was precooked. Differential scanning calorimetry data confirmed this result. No endothermic peak for starch gelatinization was identified for the sorghum pasta, implying that the products were fully cooked under the test conditions for extrusion and drying. Weight gain of pasta on cooking ranged from 120% to 129%, which was acceptable. Pasta brightness was also acceptable compared with the durum wheat commercial product. However, yellowness was not improved by adding whole eggs.

Results from consumer sensory evaluation of the sorghum pastas using a 9-point hedonic scale are shown in Table 10.1. The control precooked pasta, made from durum wheat semolina flour, had the highest scores for all attributes (but the lowest score for intensity of bitterness), which were significantly higher ($P \leq .05$) than the sorghum

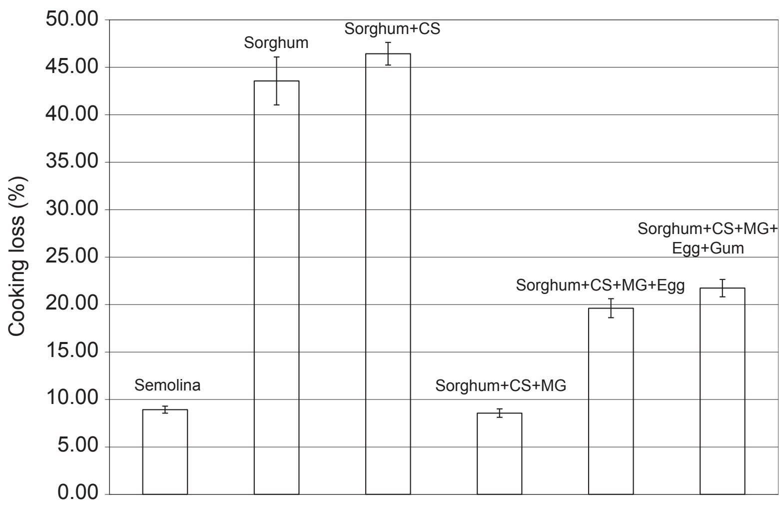

FIGURE 10.3 Cooking loss of sorghum-based pasta produced using lab-scale extrusion, compared with semolina-based pasta (Cheng et al., 2007). Additives: CS = 10% corn starch, MG = 0.5% monoglycerides, Egg = 10% whole eggs + egg whites, Gum = 2.0% guar + xanthan gums.

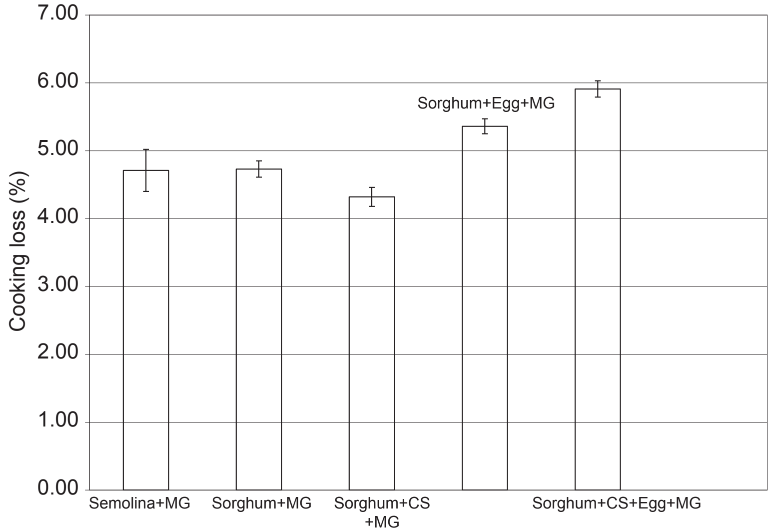

FIGURE 10.4 Cooking loss of sorghum-based pasta produced using pilot-scale extrusion, compared with semolina-based pasta (Cheng et al., 2007). Additives: CS = 10% corn starch, MG = 0.5% monoglycerides, Egg = 6% whole eggs.

TABLE 10.1 Consumer Evaluation Results for Pasta Produced by Pilot-Scale Extrusion

Pasta Sample	Appearance	Chewiness	Texture/Mouthfeel	Flavor	Intensity of Bitterness	Overall Acceptability
Semolina (control)	7.55a	6.80a	7.03a	6.81a	1.84a	7.24a
Sorghum	4.88b	5.61b	5.55b	4.71b	4.09b	5.24b
Sorghum + color	5.13b	5.41b	5.15bc	4.61b	4.28b	5.25b
Sorghum + corn starch	4.79b	5.24b	5.07c	5.46b	3.95b	5.09b

Mean values ($n = 78$) in the same column with the same letter are not significantly different ($P \leq .05$).
Data from Cheng, E.M., Alavi, S., Bean, S., 2007. Sorghum-based pre-cooked pasta utilizing extrusion processing. In: 25th Biennial Sorghum Research and Utilization Conference, January 14–16, 2007, Santa Ana Pueblo, NM.

pastas. The scores of all liking attributes of sorghum pastas were near the neutral region (neither like nor dislike) of the hedonic scale, and they were not significantly different. The bitter flavor and darker color associated with the sorghum flour contributed to the poorer sensory quality. The inferior viscoelastic properties of sorghum proteins were possibly the cause of poor ratings related to inferior texture and mouthfeel. Overall, results from this study indicated that sorghum-based pasta with good cooking quality and shorter cooking times, compared with commercial pasta, can be produced by extrusion processing after optimization of process variables (in-barrel moisture, screw speed, and drying humidity) and formulation, especially the inclusion of monoglycerides as lubricating agents during extrusion. However, the sensory attributes of the sorghum pasta were poorer compared with the semolina-based product especially, and this should be the focus of future research. A potential solution could be use of other gluten-free grains, such as rice, in combination with sorghum.

2.3 Nutritional and Food Assistance Applications

A concerted global effort over the last several years has helped to reduce the population of undernourished people. However, there are still close to a billion people around the world who are considered to suffer from chronic hunger and malnutrition. To help alleviate this tragedy, international agencies such as the United Nations World Food Programme and national programs like the United States Agency for International Development provide nutritious basic food products. Micronutrient fortified blended foods constitute a significant portion of these. Mostly, they are essentially high-protein porridge mixes fortified with vitamins and minerals, typically made from combinations of cereal (primarily maize) and legume (soybean) flours (USAID, Undated). Sorghum can be an alternate useful cereal ingredient for FBFs. Its advantages include the fact that is an environmentally sustainable crop (low water input and tolerant to heat stress and drought-like conditions) and not genetically modified and thus aligned with often restrictive regulations in recipient countries. Also, importantly, it is also traditionally part of the diet in many parts of Africa and Asia and acceptable to the people in these regions.

A project at Kansas State University in the United States focused on development and field testing of sorghum-based FBFs that are precooked and easy to prepare into porridges by end-users and also have superior nutrient density and acceptability compared with the currently used corn (maize)—soy blend product (CSB Plus); (Joseph, 2016; Delimont et al., 2017; Chanadang, 2017). Composite flours of sorghum—cowpea (SC), sorghum—soy (SS) and as a control corn-soy (CS) were extruded on a pilot-scale single screw extruder. Both whole and decorticated sorghum and maize were used to prepare these composites in order to understand the impact of fiber on processing and product characteristics. SC had the highest SME range (286—362 kJ/kg), followed by CS (139—371 kJ/kg), and the lowest SME was with SS (66—333 kJ/kg). SME was found to be positively correlated to starch content in the blends. SC composites had the most stable extrusion process followed by SS and then CS. Significant differences in extrudate physicochemical characteristics were observed between whole and decorticated binary composites on account of their different starch and fiber contents. Differences were also observed between the composites from the different grains. Water absorption index for SC was between 4.17 and 5.97 g/g and that for SS ranged from 2.85 to 5.91 g/g and CS from 2.63 to 5.40 g/g. Percentage starch gelatinization ranged from 85.4% to 98.8% for SC, 90.7% to 96.3% for SS, and 72.6% to 75.5% for CS.

The extrudates were milled into powders for further processing and fortification with nutrients. Milling characteristics were found to be dependent on extrudate bulk density, with low-density extrudates resulting in bigger particle size and vice-versa. Milled extrudates were evaluated for in-vitro starch and protein digestibility and also presence of antinutritional factors. Starch digestibility increased after extrusion. There was a significant reduction in antinutritional factors after extrusion. The phytic acid decreased by 27%—44%, and trypsin inhibitors decreased by 16.6%—28.1% (Table 10.2). The milled extrudates were fortified by blending with whey protein concentrate, sugar, oil, and micronutrient premixes of vitamins and minerals.

The final fortified blended porridge foods (SC blends, SS blends, and CSBs were evaluated for physical performance using the Bostwick consistency test for viscosity and were found to be within the acceptable range of 9—21 cm/min. These FBFs were also field tested for nutritional efficacy in a controlled randomized trial with 2000 children (aged 6—59 month) in Tanzania over a period of 20 weeks. The results indicated that the sorghum-based extruded FBFs were equally or more effective in reducing the risk of anemia and vitamin A deficiency compared with extruded CSB, and the currently being used nonextruded CSB Plus. These studies have shown that sorghum-based FBFs can be effectively used to expand the basket of products available for food aid applications.

2.4 Specialty Products—Sorghum Protein Concentrates

As mentioned, sorghum grain is safe for consumption by individuals afflicted with celiac disease. However, utilization of sorghum in human foods is limited partially due to the poor digestibility and lack of functionality of its proteins, which result from their location in the grain endosperm protein bodies, tight association with starch, and high degree of cross-linking induced by wet cooking (Duodu et al., 2003). If an economical and scalable process can be developed for release and/or concentration of sorghum proteins from the endosperm matrix, there is a potential

TABLE 10.2 Changes in Phytic Acid and Trypsin Inhibitor Before and After Extrusion for Production of Fortified Blended Foods

	Phytic Acid (mg/100 g)		Trypsin Inhibitor—TIA (mg/g)	
Formulation	**RM**	**ME**	**RM**	**ME**
SCB-V1	1138.50 ± 5.60a	832.07 ± 5.68b	228.54 ± 8.27a	177.55 ± 1.04b
SCB-V2	804.22 ± 1.74a	560.72 ± 3.24b	229.79 ± 4.23a	191.75 ± 1.13b
SCB-V3	942.05 ± 4.40a	689.21 ± 8.06b	233.73 ± 2.00a	186.59 ± 9.48b
SS'B—V1	0.75 ± 0.02a	0.56 ± 0.03b	210.60 ± 14.60a	169.53 ±0 .93b
CSB	567.54 ± 8.52a	317.64 ± 2.85b	190.21 ± 4.44a	136.67 ± 8.33b

CSB, corn soy blend; *ME*, milled extrudate; *RM*, raw material; *SCB*, sorghum cowpea blend; *SS'B*, sorghum soy blend; *TIA*, trypsin inhibitor activity, V1, V2, V3, different varieties of sorghum. Values in the same row not sharing the same subscript are significantly different at $P < .05$.

Data from Joseph, M.V., 2016. Extrusion, Physico-chemical Characterization and Nutritional Evaluation of Sorghum-based High Protein, Micronutrient Fortified Blended Foods (Ph.D. thesis). Kansas State University, Manhattan, KS.

for increase in their digestibility and even functionality and use as a nutritional supplement in gluten-free foods. An extensive review of current methods for concentration and isolation of sorghum proteins revealed that all of them are laboratory-scale techniques used for protein characterization and have no potential for commercial scale-up (De Mesa-Stonestreet et al., 2010). Furthermore, these methods typically use nonfood-grade reagents and do not improve protein digestibility and functionality.

To overcome the aforementioned limitations, a novel extrusion-enzyme liquefaction (EEL) process was developed to produce sorghum protein concentrates (De Mesa-Stonestreet et al., 2012). EEL involves extrusion pretreatment of sorghum flour and starch liquefaction with a thermostable α-amylase, followed by enzyme inactivation, protein separation, and drying (Fig. 10.5). To demonstrate the concept, a laboratory-scale EEL process was used to produce concentrates with higher PC (80% db) and digestibility (D; 74%) than those made by batch liquefaction. The optimum conditions for producing concentrates with both high PC and D were 32% (wb) in-barrel moisture content, and 2.5% α-amylase added after extrusion. Using these conditions, EEL was scaled-up to a pilot-scale process to produce sorghum protein concentrates with 72%–80% (db) PC and 62%–74% D, while the batch liquefied control had only 70% (db) PC and 57% D.

Dynamic oscillatory measurements of dough (55% moisture) and batter (65% moisture) containing sorghum protein concentrates (5% and 10%), and potato starch were performed to evaluate protein functionality. At lower moisture, pure potato starch and dough containing 10% sorghum protein concentrate had similar elastic and viscous moduli. At higher moisture, potato starch was more stable and exhibited significantly higher moduli than the batters with protein concentrates. Sorghum protein concentrates can potentially improve the quality of some gluten-free foods. EEL shows promise for commercial production of sorghum protein concentrates because of its high throughput and ability to deliver high PC and digestibility. Demand for sorghum in ethanol production has grown several fold in the last few decades in the United States (Sorghum Grower, 2018). The by-product stream from the EEL process, rich in starch and sugars, could be used for ethanol and also high-fructose syrup applications. This will benefit the economics of the process and its commercialization potential.

2.5 Pet Food and Aquatic Feed

Pet food is a huge market in the United States with annual sales of more than $25 billion. The population of dogs and cats alone in the United States is close to 165 million, and over two-thirds of households have a pet. Common pet foods contain between 30% and 60% carbohydrates, primarily from grains (Murray et al., 1999). Sorghum is rarely used for pet foods due to the lack of scientific data on the nutritional quality and acceptability of sorghum-based products. In fact, very few pet food brands utilize sorghum as the primary source of starch. Recent human nutrition studies have shown that sorghum could provide nutritional benefits related to slower digestibility of starch or lower

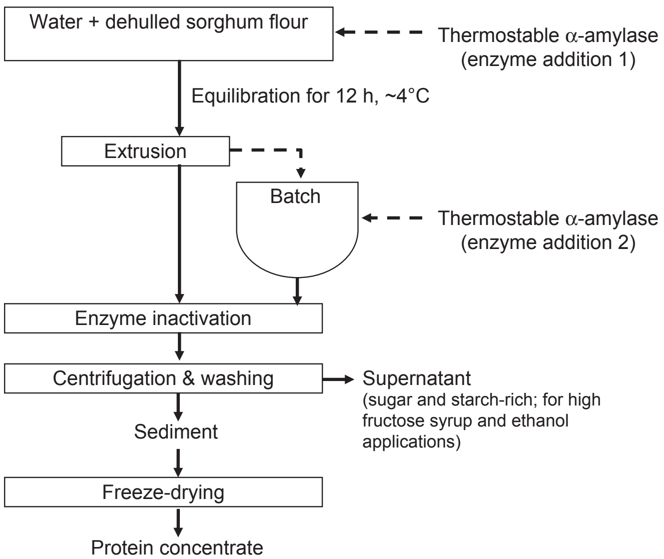

FIGURE 10.5 Extrusion-enzyme liquefaction (EEL) process for production of sorghum protein concentrate.

glycemic response (Simnadis et al., 2016; Anunciação et al., 2018), which could be advantageous in premium pet food products targeted toward obese, diabetic, and geriatric pets.

Work at Kansas State University evaluated the effect of particle size on the extrusion of sorghum-based dog food diets. Two types of nontannin sorghum (white and red) milled to three maximum particle sizes (0.5, 0.8, and 1.0 mm) were incorporated in a premium dog food formulation and compared with a rice-based dog food formulation. Formulas were extruded to achieve processing at two specific thermal energy:SME ratios (STE:SME), using different combinations of screw speed and preconditioning temperature (high STE:SME at 300 rpm/85−90°C and low STE:SME at 400 rpm/75−80°C). Water and steam flow in the preconditioner were varied to achieve the desired preconditioner temperature. The mean in-barrel moisture was 26% (wb).

Sorghum variety and milled grain particle size had no effect on SME. However, bulk density increased with particle size. The diets extruded at 400 rpm/75−80°C had higher bulk density. Percentage starch gelatinization increased as the particle size decreased (93%, 85%, and 82% of starch gelatinization for 0.5, 0.8, and 1.0 mm particle size, respectively; Table 10.3). Processing conditions did not influence the starch gelatinization (85% and 87% for 300 rpm/85−90°C and 400 rpm/75−80°C, respectively). The white sorghum had a higher percentage of starch gelatinization compared with red sorghum and rice (89%, 85%, and 80%, respectively). In feeding trials (in vivo) with dogs the sorghum-based pet food products were found to be more palatable than the maize-based control and also demonstrated lower glycemic response and a prebiotic effect with increase in colonic fermentation byproducts. These results indicated that sorghum can be an effective alternative to traditional grains such as maize and rice as a carbohydrate source in extruded pet foods.

The increasing cost of fish meal, which is the most expensive macroingredient in aquatic feed, has necessitated the search for alternative sources of protein. Adedeji et al. (2017) examined the use of distillers dried grain with solubles from sorghum (sDDGS) in the production of shrimp feed and subsequent growth trials with *Litopenaeus vannamei* (Pacific white shrimp/king prawn). High-density shrimp feed pellets can be produced using compression pelleting or pellet milling, which is a low energy forming process with limited amount of cooking involved or by extrusion processing that leads to much higher energy input and starch gelatinization. In this study shrimp diets with various levels of sDDGS inclusion (0%, 10%, 20%, 30%, and 40%), as a replacement for soybean meal, were produced using extrusion cooking and also by pelleting. SME during extrusion generally increased with sDDGS level. Bulk density of the extruded feed (0.53−0.58 g/cm^3) was lower than that of pelleted feed (0.61−0.65 g/cm^3), although sDDGS

TABLE 10.3 Degree of Starch Gelatinization (Using DSC) of Extruded Dog Food Based on Grain Sorghum

Extruded Treatments	Starch Gelatinization (%)
Red 1.0/400/low T[a]	77.28
Red 1.0/300/high T	83.56
Red 0.8/400/low T	85.05
Red 0.8/300/high T	79.56
Red 0.5/400/low T	92.2
Red 0.5/300/high T	90.8
White 1.0/400/low T	85.31
White 1.0/300/high T	83.5
White 0.8/400/low T	85.85
White 0.8/300/high T	89.45
White 0.5/300/high T	93.55
White 0.5/400/low T	95.46

[a]*Red, red sorghum; White, white sorghum; 0.5, 0.8, and 1.0, particle size in mm; 300 or 400, extruder screw speed in rpm; low T or high T, low versus high thermal energy input via preconditioning.*

level did not have an impact on porosity. The finished diets were 100% sinking in water, with some exceptions in the case of the extruded feed. Pellet durability index (89.4%–96.3%) had an increasing trend up to 20% and 30% sDDGS for the extruded and pelleted diets, respectively. Extruded feed had a higher degree of gelatinization than pelleted feed, although the proportion of gelatinized starch generally decreased with sDDGS level. Water stability (76.2%–91.6%) of the extruded feed was higher than for the pelleted feed and was also significantly influenced by sDDGS level.

The extruded and pelleted diets were evaluated in two growth trials with Pacific white shrimp for a duration of 9 and 6 weeks in 40 and 60 growth tanks, respectively. In both trials juvenile shrimps (initial weight 0.36–0.38 g) were stocked at a density of 10 shrimps per tank. Both growth trials resulted in no significant differences in final mean weight and survival of the shrimp with respect to sDDGS level. Feed conversion ratio (FCR) is defined as the weight of the input divided by the output (thus weight of feed per weight of shrimp). Based on pooled data, extruded feeds produced significantly larger shrimps with a lower FCR in trial 1 (Table 10.4). However, pelleted feeds produced significantly larger shrimps and lower FCR in trial 2 (Table 10.5). Overall results indicated that up to 40% sorghum DDGS can be used in feed formulations without affecting the growth performance or weight gain of Pacific white shrimp. Sorghum DDGS is a by-product of the fuel ethanol production process which is discussed extensively in Chapter 13: Industrial and Nonfood Applications. Such value-added uses of sorghum DDGS have the potential of increasing the commercial viability of the ethanol industry and the market value and utilization of sorghum.

TABLE 10.4 Response of Juvenile Pacific White Shrimp/King Prawn (*L. vannamei*) (Initial Weight Mean + Standard Deviation; 0.35 + 0.032 g) to Sorghum Distilled Dry Grains With Solubles (sDDGS)-Based Extruded and Pelleted Diets After a 63-Day Growth Trial (Trial 1)

sDDGS Level (%)	Mean Weight (g)	Final Biomass per Tank (g)	Feed Conversion Ratio	Survival (%)	Weight Gain (%)
EXTRUDED					
0	4.59	37.40	2.99	82.50	1226.08
10	4.48	36.90	3.02	82.50	1175.50
20	4.99	43.60	2.72	87.50	1190.63
30	4.69	43.40	2.87	92.50	1260.90
40	4.82	42.00	2.83	87.50	1153.29
P value	.6011	.0350	.6296	.2959	.5258
PELLETED					
0	4.50	36.40	3.10	82.50	1196.70
10	4.28	33.60	3.22	80.00	1171.10
20	4.22	35.60	3.24	85.00	1062.60
30	4.43	34.70	3.10	80.00	1163.80
40	4.18	31.30	3.26	75.00	1060.10
P value	.9045	.5410	.9668	.8938	.7167
POOLED DATA					
Extruded	4.71	40.67	2.89	86.50	1201.28
Pelleted	4.32	34.35	3.18	80.50	1130.90
P value	.0135	.0001	.0106	.0842	1.8226

Based on Student–Newman–Keuls test, no significant differences ($P > .05$) were found among treatment means ($n = 4$). *FCR*, feed conversion ratio = feed offered per shrimp/weight gain per shrimp.

Data from Adedeji, A.A., Zhou, Y., Fang, X., Davis, D.A., Fahrenholz, A., Alavi, S., 2017. Utilization of sorghum distillers dried grains (sDDGS) in extruded and steam pelleted shrimp diets. Aquacult. Res. 48, 883–898.

TABLE 10.5 Response of Juvenile Pacific White Shrimp/King Prawn (*L. vannamei*) (Initial Weight Mean + Standard Deviation; 0.38 + 0.02 g) to Sorghum Distilled Dried Grain With Solubles (sDDGS)-Based Extruded and Pelleted Diets After a 42-day Growth Trial (Trial 2)

sDDGS Level(%)	Mean Weight(g)	Final Biomassper Tank (g)	Feed Conversion Ratio	Survival (%)	Weight Gain (%)
EXTRUDED					
0	4.14	37.10	2.12	90.00	971.80
10	4.02	36.42	2.19	90.00	974.40
20	4.66	42.78	1.84	91.67	1171.80
30	4.69	43.62	1.82	93.33	1174.80
40	4.33	40.98	1.99	93.33	1077.10
P value	.0802	.0822	.0592	.9549	.0971
PELLETED					
0	4.86	37.56	1.78 (ab)	78.00	1177.30
10	4.99	39.00	1.71 (ab)	78.00	1247.20
20	5.15	43.83	1.66 (b)	85.00	1280.80
30	4.68	35.82	1.84 (ab)	76.67	1130.40
40	4.19	37.62	2.07 (a)	90.00	1002.80
P value	.0587	.3391	.0469	.1699	.0579
POOLED DATA					
Extruded	4.37	40.18	1.99	91.67	1073.98
Pelleted	4.77	38.76	1.81	81.53	1167.69
P value	.0169	.2629	.02	.0005	.0881

Based on Student–Newman–Keuls test, no significant differences ($P > .05$) were found among treatment means ($n = 6$). FCR, feed conversion ratio = feed offered per shrimp/weight gain per shrimp.
Data from Adedeji, A.A., Zhou, Y., Fang, X., Davis, D.A., Fahrenholz, A., Alavi, S.S, 2017. Utilization of sorghum distillers dried grains (sDDGS) in extruded and steam pelleted shrimp diets. Aquacult. Res. 48, 883–898.

3. CONVENIENCE FOODS AND BEVERAGE APPLICATIONS—WITH A FOCUS ON INDIA

3.1 Sorghum- and Millet-Based Commercial Products

The growth in demand for sorghum- and millet-based convenience foods and beverages in India is evidenced by the introduction of a number of innovative products in the market. The products are targeted at addressing lifestyle diseases based on the health benefits of sorghum and millets. This section describes the development of and technologies used in the manufacture of the various types of millet- and sorghum-based products that are now popular in the Indian market. Additionally, selected examples of millet/sorghum-based commercial value-added food products available in India are presented in Table 10.6.

3.1.1 Flaked Products

Flaking of millet and sorghum is achieved by first moisture conditioning of the grains, usually up to a moisture content above 17%. This is followed by flaking, which is carried out either using an edge runner (Fig. 10.6A) or a suitably designed roller flaker (Fig. 10.6B). The flaked product is finally roasted, where the moisture content is reduced to 6%–8%. The efficiency of flaking is dependent on the critical step of moisture conditioning of the grains before undertaking the flaking and roasting processes. For each grain type, several process optimization steps need to be undertaken with respect to moisture conditioning, flaking machine operating parameters, and roasting time and temperature.

The millet and sorghum flakes are packed in air-tight containers or flexible pouches and sold directly as such in the market (Fig. 10.6C) or used in the production of millet-based breakfast cereals together with other ingredients

TABLE 10.6 Select Millet−Sorghum-Based Commercial Value-Added Food Products in the Indian Market

Food Product	Consumed as	Ingredients (Sorghum or Millet Ingredients Are in Bold)
Toasted millet muesli	Breakfast Cereal	Rolled whole grain oats, **finger millet, pearl millet flakes**, toasted with palm Jaggery, dried fruits, and nuts. Variants: dark chocolate/cranberry, almond/roasted cacao bean, raisin/fig, and honey with salted pistachios
Multigrain high-protein millet-based flour	High-protein millet-based flour for Indian flatbreads (roti) as nutritious food for children and adults (pre−post workout food)	Whole wheat flour, defatted soya flour, amaranth flour, and **foxtail millet**. Gluten-free variant: **foxtail millet**, amaranth flour, defatted soya flour, bengal gram flour, potato starch, tapioca flour, and edible gum Unrefined multigrain flour variant to control blood sugar: whole wheat flour, **foxtail and pearl millets**, bengal gram flour, whole green gram flour, semolina, defatted soya flour, wheat bran, psyllium husk, fenugreek powder, flax seeds powder.
Multi millet dosa mix	Breakfast/snack	**Kodo millet, little millet, foxtail millet,** rice**, pearl millet, finger millet, sorghum,** black gram, fenugreek, cumin, salt
Multigrain choco malt	Health drink	Wheat, **finger millet**, **pearl Millet**, red rice, white rice, green gram, black gram, barley, maize, peanut, horse gram, bengal gram, soya, kidney beans, peas, red beans, green beans, cocoa powder, cashew, almond, pistachios, cardamom, jaggery, dry ginger, *Senna auriculata*.
Millet porridge mix	Weaning food	**Barnyard millet, kodo millet, little millet, foxtail millet**, green gram, cumin seeds, cashew, and almond.
Bisibelebath with millets and oats	Breakfast food	**Little millet, kodo millet**, oats, green gram, black gram, bengal gram, tamarind powder, red chilly, coriander seeds, cinnamon, asafoetida cake, turmeric powder, cloves, mustard seeds, desiccated coconut, salt
Millet rawa	Breakfast mix	Coarse semolina of roasted **sorghum, pearl millet,** and **finger millet**
Millet chikkis (bars)	Snack	Roasted **sorghum**, **pearl millet**, wheat, sugar, liquid glucose and jaggery
Millet pappad	Snack	Black gram flour, **yellow sorghum**, red chilly, asafoetida, edible vegetable oil
Ragi flakes	Breakfast food	**Finger millet**, sugar/jaggery
Millet bites (cookies)	Snack	**Multi millets** Variants: multi millet-caraway/, multi millets-flaxseeds/Multi-multi millet-almond, -multi millet-chocolate, -multi millet-coconut
Millet sathumaavu mix	Organic baby food	**7 different millets (barnyard millet, finger millet, foxtail millet, kodo millet, little millet, pearl millet, sorghum)**, sesame seeds, rice, black gram, green gram, roasted gram, lentil, wheat dalia, sago, horse gram, maize, almonds, cashew, cardamom.

Data compiled based on market survey/information sourced from different manufacturers of sorghum and millet products.

such as honey, nuts, seeds, dehydrated fruits, and vegetables (Fig. 10.6D). Speciality flake-based products such as "organic" mixed millet flakes prepared from finger millet, foxtail millet, little millet, kodo millet, and blended with "organic" amaranth, fruit powders, salt, sugar, minerals, and vitamins, in packaged and branded forms are also popular in India. It is important to note that these products need to be packed under dehumidified conditions and using packaging material having appropriate moisture and oxygen barrier properties, thus enhancing shelf-life and delaying the onset of rancidity, which is often associated with millet-based products. To overcome the problem of rancidity in millet flakes and other millet-based products (especially those based on pearl millet), research was undertaken to understand the diversity in rancidity profile of commercial pearl millet lines available in India

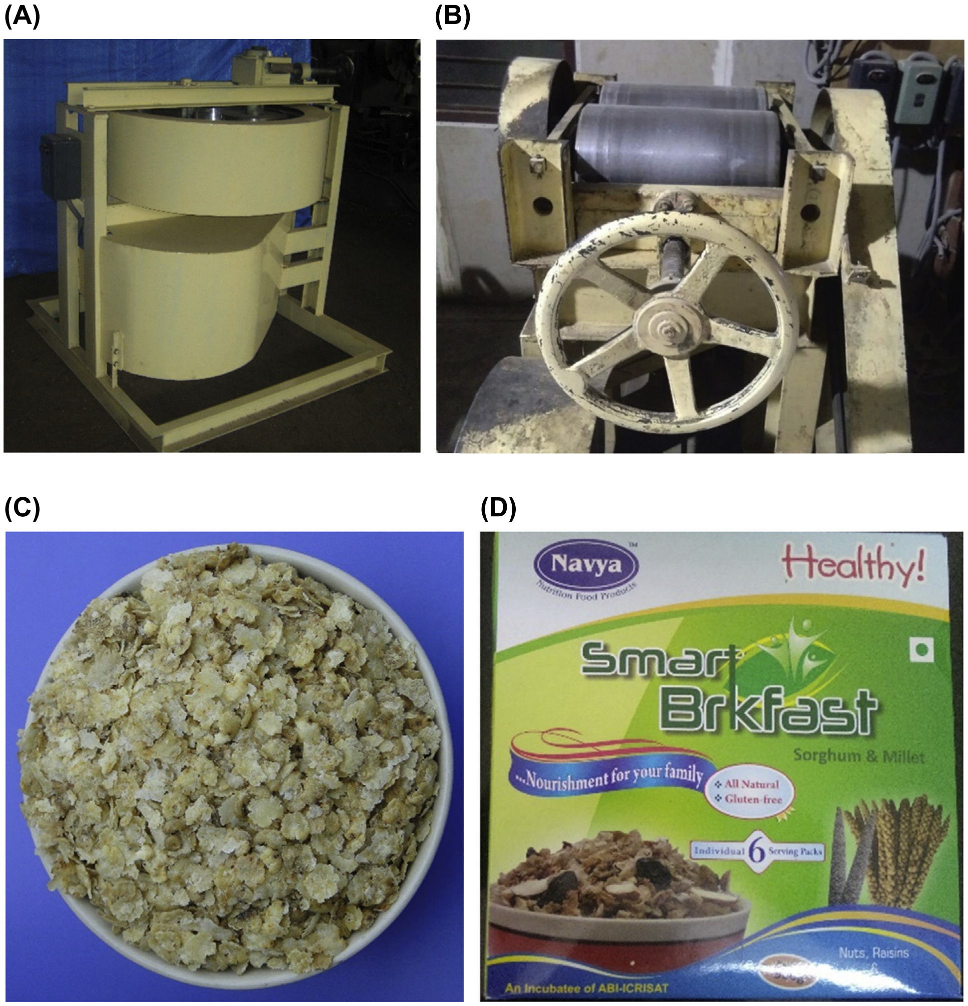

FIGURE 10.6 Some equipment used for flaking of sorghum and millet, and sorghum flakes and breakfast food made from flaked sorghum and millet in India. (A) Edge runner, (B) roller flaker, (C) Sorghum flakes, (D) Breakfast food. *Pictures (A) and (B) courtesy of Mathesis Engineers Pvt. Ltd, Hyderabad, India, Pictures (C) and (D) courtesy of Priyanka Durgalla, ICRISAT, Hyderabad, India.*

(Datta Mazumdar et al., 2016). The study revealed the existence of a diversity in rancidity profile among the various pearl millet lines studied. The study was based on monitoring and comparing the progression in development of oxidative rancidity and hydrolytic rancidity by measuring peroxide value (PV) and acid value (AV) in fat extracted from flours of the pearl millet lines, which had been stored under accelerated storage conditions. PV and AV are indicators of the extent of oxidative rancidity and hydrolytic rancidity, respectively. Thus varieties which develop low PV and AV values are less susceptible to rancidity compared with varieties which develop high values, under similar conditions of accelerated storage. The data obtained from this study are presented in Fig. 10.7 and show the potential for developing shelf-stable millet-based products using pearl millet varieties with low tendency to become rancid, in association with the right processing (thermal processing and addition of antioxidants) and packaging interventions.

3.1.2 Puffed and Extruded Products

Popping of millets and sorghum results in delicious puffed (popped) products, which are consumed as snacks. The popping quality of the millet and sorghum grains varies with variety, grain hardness, and the moisture content of the grains. A number of studies have contributed toward understanding the popping process in millets and sorghum (Shukla et al., 1986; Thorat et al., 1988; Murty et al., 1982; Malleshi and Desikachar, 1981). Kernels with medium to thick pericarp, hard endosperm, and conditioned to a typical grain moisture content of 15%–18% (Sailaja, 1992) are critical for obtaining maximum popping yield. Grain popping in India has traditionally been done using roasting. However, with the growing demand for millet- and sorghum-based “pops,” a number of

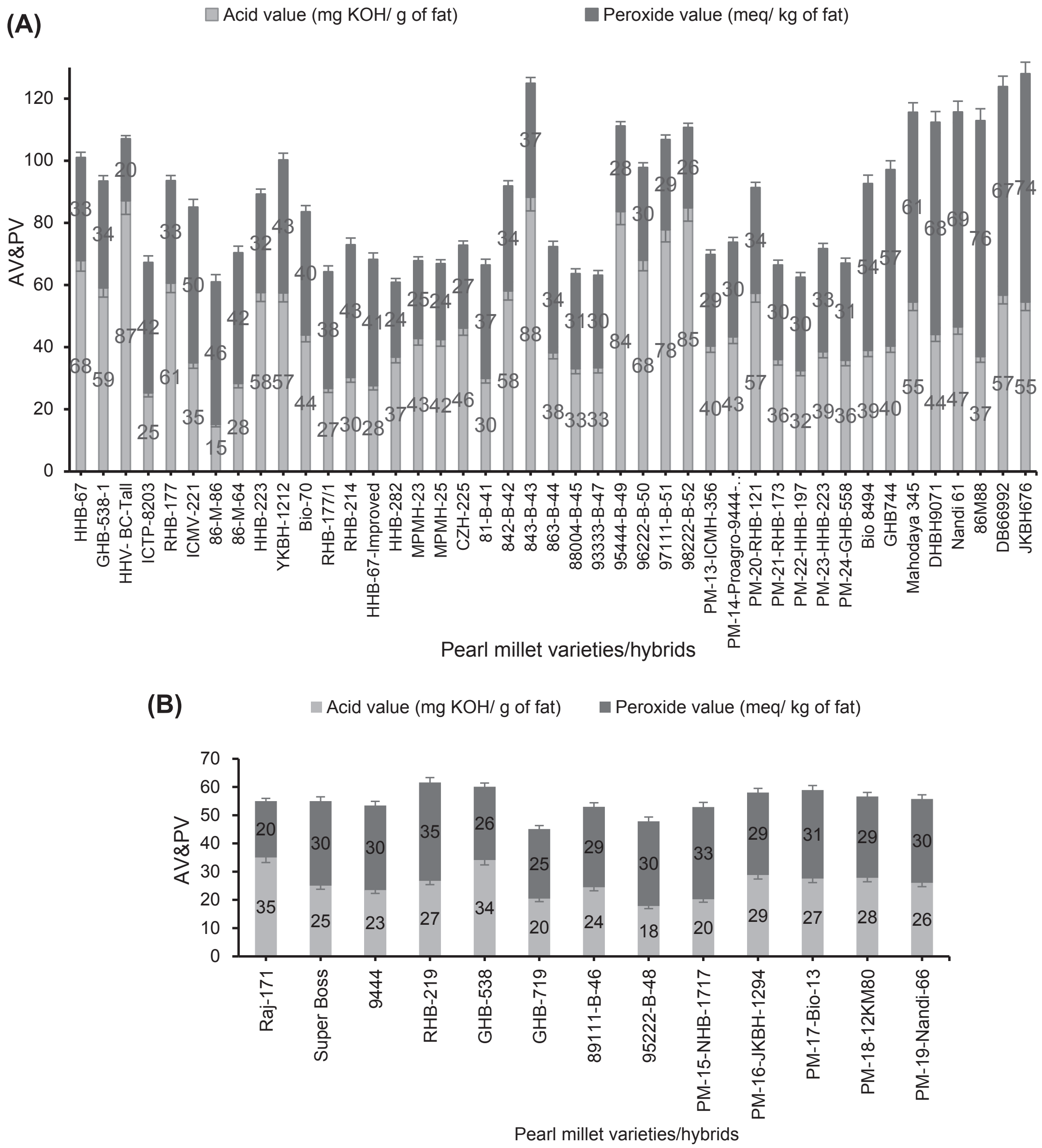

FIGURE 10.7 (A) Peroxide value (PV) and acid values (AV) (10-day storage) of pearl millet varieties/hybrids showing high susceptibility toward rancidity (either PV or AV > 36). (B) PV and AV (10-day storage) of pearl millet varieties/hybrids showing low susceptibility toward rancidity (either PV or AV < 36). *(A and B) Adapted from Datta Mazumdar et al., 2016. Determination of Variability in Rancidity Profile of Select Commercial Pearl Millet Varieties/hybrids. DC 24. Poster presented in CGIAR Research Program on Dryland Cereals Review Meeting held at Hyderabad, India, 5-6 October 2016. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Telengana, India. http://oar.icrisat.org/10422/.*

mechanical popping machines have been developed. The use of microwave oven for popping sorghum has also been explored (Mishra et al., 2015). Grain having higher bulk density, true density, and hardness was found to positively affect the popping volume and yield when using microwave oven popping. In addition, grains with high amylose content were found to exhibit better popping yield, volume, and resulted in "pops" with a higher sensory score. The study also reported better popping with kernels having a medium-to-thick pericarp.

A number of extruded products made using sorghum and millets as the main ingredients in the formulations are also popular in India. Datta Mazumdar (2012) showed that extruded products with acceptable sensory and textural quality suited to the Indian palate can be prepared using an appropriate combination of sorghum/millets and pulses (Fig. 10.8). Dehulling (decortication) of sorghum and pearl millet grains was found to reduce product hardness and resulted in crunchier extrudates with both sorghum and pearl millet. Composite flours were prepared using whole

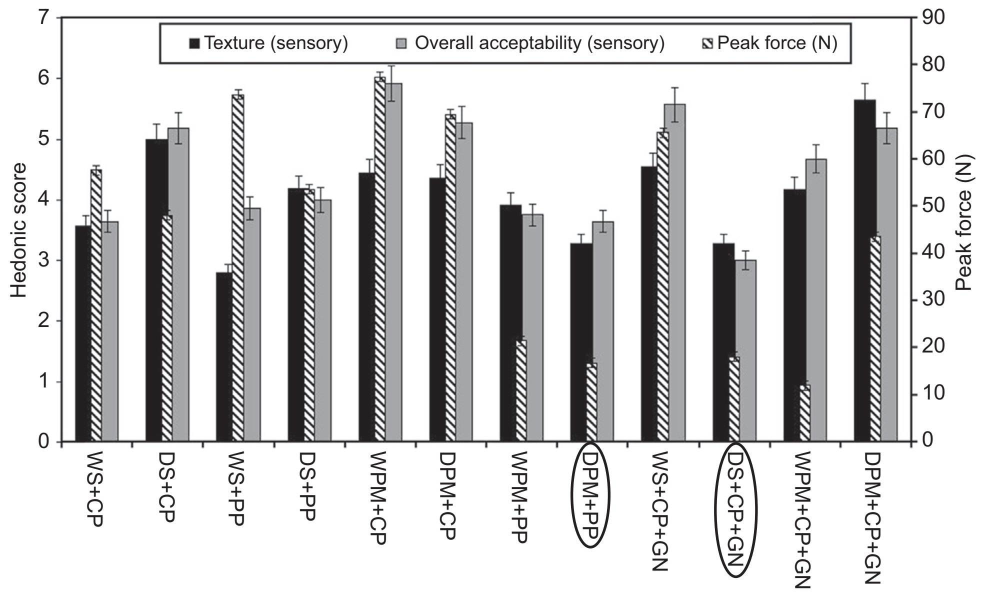

FIGURE 10.8 Mean sensory scores (9-point hedonic scale: 1 = like extremely, 9 = dislike extremely) for texture and overall acceptability obtained during sensory evaluation of extrudates obtained from different composite flours, based on sorghum and pearl millet (data shown in primary Y-axis). The corresponding peak force values obtained during textural analysis are also plotted (data shown in secondary Y-axis). The best blends DPM + PP and DS + CP + GN are *circled*. *CP*, Chickpea; *DPM*, dehulled pearl millet; *DS*, dehulled Sorghum; *GN*, ground nut; *PP*, Pigeon Pea; *WPM*, whole pearl millet; *WS*, whole Sorghum.

sorghum and whole pearl millet as well as dehulled sorghum and dehulled pearl millet along with the other crops cultivated in the semi-arid tropics, namely chickpea, pigeon pea, and groundnuts. The controls were 100% whole/dehulled sorghum flour and 100% whole/dehulled pearl millet flour, and the composite flours comprised chickpea flour (30%), pigeon pea flour (30%), or a blend (30%) of equal combination of chickpea−groundnut flour or pigeon pea−groundnut flour. Extrusion cooking was carried out using a twin screw extruder (temperature: 115 and 90°C for two different heating zones, screw speed: 400 rpm, and die diameter: 3 mm), and texture and sensory analysis of the extrudates was conducted.

Sensory analysis, involving an informal consumer panel, indicated that in the case of the sorghum blends, extrudates prepared from the blend of dehulled sorghum, chickpea, and groundnut (70:15:15) was most acceptable. This correlated well with its high expansion ratio (2.80 ± 0.11) and low bulk density (0.16 ± 0.01 g/cm^3) as well as with the texture analysis data (peak force = 18.12 N and slope = 0.09 N/mm). In the case of the pearl millet blends extrudate prepared from dehulled pearl millet and pigeon pea (70:30) was found to be most acceptable by the sensory panel. The sensory data were further supported by the low values obtained for peak force (16.81 N) and slope (0.01 N/mm). The expansion ratio was 2.81 ± 0.09 and the bulk density 0.22 ± 0.01 g/cm^3. The nutritional profiles of the blends were also superior when compared with the 100% pearl millet control. A number of healthy extruded snacks have been developed based on this study and commercialized through entrepreneurs in India (Sharma et al., 2016).

3.1.3 RTE Sorghum/Millet Roti (Unleavened Flatbread)

Sorghum *roti* (unleavened Indian flatbread) is known by various names in different languages of India, for example, *chapati* (Hindi), *bhakri* (Marathi), *rotla* (Gujarati), and *rotte* (Telugu). *Roti* is consumed by children from the age of 2 years as well as adults (Subramanian and Jambunathan, 1980), either at breakfast, lunch, or supper. Occasionally, they are sun-dried and stored for more than a week. *Roti* is consumed with several side dishes depending upon the socioeconomic status of the consumer, for example, cooked vegetables, dhal (various soups/curries prepared from pulses), meat, milk, curd, buttermilk, pickles, chutneys, sauce, and so on. They are often softened with milk or buttermilk when used to feed old people and children.

Traditionally, sorghum *roti* is prepared manually by women in India, using approximately 50 g flour mixed with 50 mL of warm water in increments and is kneaded by hand (Fig. 10.9) on a smooth wooden board (5−7 cm high) into a dough (Subramanian and Jambunathan, 1980). As the dough attains a proper consistency, it is made into a 6-cm diameter ball and pressed by hand into the form of a circular disk. The disk is placed on the wooden board

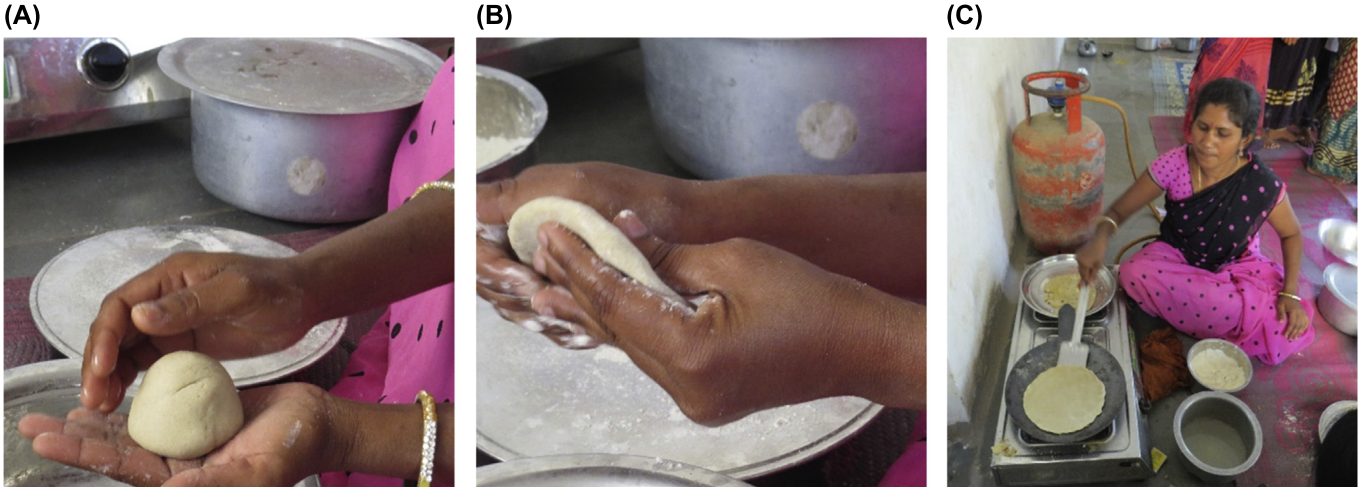

FIGURE 10.9 Traditional method of preparation of sorghum roti. (A) Preparation of Sorghum dough. (B) Roti dough shaping with hands. (C) Pan baking of shaped dough to obtain roti. *Pictures courtesy of Harshavardhan Mane, ICRISAT, Hyderabad, India.*

and flattened by fast and deft hand strokes into a thin circle or formed into a disk by hand. Small quantities of dry flour are used as dusting flour to eliminate stickiness during handling. *Roti* size varies from 12 to 25 cm in diameter and 1.3–3.0 mm in thickness, depending upon the region. Today, with the growing demand for ready-to-cook (RTC) and ready-to-heat (RTH) sorghum and millet *rotis*, especially targeting the diabetic population, a number of *roti*-making machines have been developed and are available commercially. These machines work on the principle of mechanical bread dough rolling and sheeting and are available in semiautomatic as well as automatic formats (Fig. 10.10).

The demand for healthy, low glycemic index (GI) and gluten-free alternatives and also for convenience in preparation due to lack of cooking time from the growing middle class, double income, and nuclear families in India has resulted in the development and commercialization of a number of RTE/RTH (ready-to-heat) sorghum/millet *roti*–type products. These RTE/RTH *rotis* are prepared using sorghum/millet flour, and shelf-stability is obtained mainly through the use of the permitted preservative sorbic acid (added as potassium or sodium sorbate). The Food Safety and Standards Authority of India, under the Food Safety and Standards Regulations (FSSAI, 2011), permits the use of sorbic acid in *roti* up to a maximum of 1000 ppm. The use of sorbic acid along with salt, sugar, and citric acid in dough for wheat-based *roti* followed by in-pack pasteurization at 90°C has been reported to result in a product with shelf-life of up to 6 months (Arya, 1984). Similar approaches for extending the shelf-life of RTE sorghum/millet *roti* have been adopted along with innovations in packaging. With the aim of reducing the GI of the product, multigrain *roti* using varying combinations of sorghum, millets, and pulse flours to replace a certain percentage of the traditionally used wheat flour is also another popular type of RTE/RTH *roti* in the Indian market.

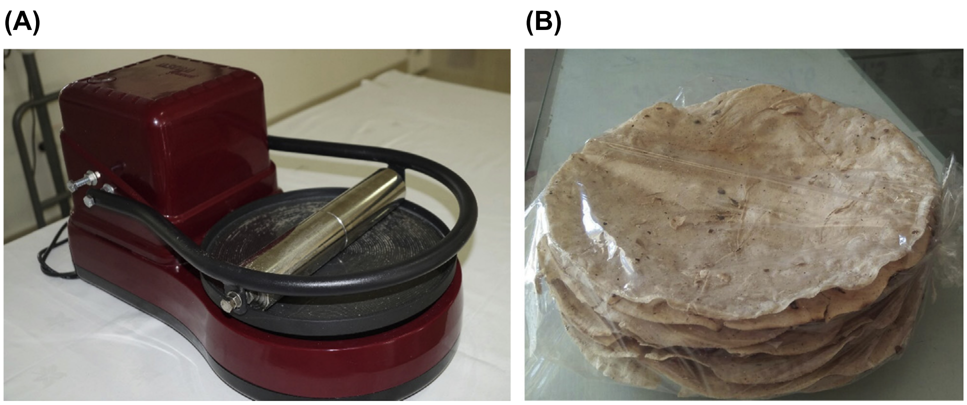

FIGURE 10.10 Commercial roti-making machine and RTE sorghum roti. (A) Roti making machine. (B) RTE sorghum roti. *Pictures courtesy of T. Sai Manideep, ICRISAT, Hyderabad, India.*

3.2 Sorghum- and Millet-Based Health Foods

Sorghum- and millet-based health foods, especially fermented foods, are popular in India. These fermented foods are being explored as sources of probiotics due to growing consumer demand. Research on understanding the probiotic potential of sorghum and millets has led to isolation of bacteria from sorghum and pearl millet flour and batter samples and characterization of their probiotic properties (Kunchala et al., 2016). The bacteria isolated were characterized for various traits including gram staining, morphology, biochemistry, IMViC tests, probiotic potentials (acid [pH 2 and 3], bile [0.5%], and NaCl [6% and 9%] tolerance), phenol tolerance (0.4%), antibiotic tolerance, and antimicrobial activity against human pathogens. A total of nine probiotic bacterial isolates were shortlisted based on these traits (Table 10.7). The sequences of 16s rDNA gene of the nine isolates were found to match *Bacillus subtilis* (two isolates), *Bacillus cereus* (three isolates), *Bacillus pumilus* (one isolate), *Bacillus amyloliquefaciens* (one isolate), *Sphingobacterium thalpophilum* (one isolate), and *Brevibacterium* sp. (one isolate) in Basic Local Alignment Search Tool analysis. This study indicated that the selected bacteria isolated from sorghum and pearl millet could be exploited to develop new probiotic foods. In addition, there are a number of traditionally fermented sorghum- and millet-based foods in India that have the potential to be explored and developed into probiotic foods such as *ambali* and *rabadi.* They are balanced composite foods, rich in B vitamins, and are well suited to hot climates owing to their content of lactic acid, which acts as a preservative. Lactic acid bacteria fermentation contributes toward their safety, nutritional value, shelf-life, and acceptability. Furthermore, it is reported that fermented products involving lactic acid bacteria fermentation can also have viricidal and antitumor effects (Blandino et al., 2003). The methods of preparation and properties of *ambali* and *rabadi* are briefly described in the following.

3.2.1 Ambali (Fermented Nonalcoholic Drink Using Finger Millet)

Ambali is a finger millet—based semiliquid fermented product popular in the South Indian states of Telangana, Tamil Nadu, and Karnataka (Sarkar et al., 2015). The preparation process involves mixing finger millet flour with rice starch (flour:starch ratio of 1:4) followed by soaking and fermentation overnight in earthen pots. *Leuconostoc mesenteroides*, *Lactobacillus fermentum*, and *Streptococcus faecalis* are reported to be responsible for the fermentation process (Ramakrishnan, 1980). The fermented product is then diluted in water to the desired consistency for consumption. Salt is added to taste, and the *ambali* is simmered over low heat, cooled, and consumed. The fermentation process enhances the nutritional quality of the product by increasing the digestibility of carbohydrates and proteins. The bacterial metabolism during fermentation results in an improved indispensable (essential) amino acid profile, including tryptophan (Singh and Raguvanshi, 2012), and increased levels of vitamins such as riboflavin and thiamine. The fermentation process also reduces the levels of antinutritional factors such as phytic acid and thus enhances the bioavailability of minerals. Being a rich source of calcium as well as potential probiotic bacteria, *ambali* is considered beneficial both as a weaning (complimentary) food as well as geriatric food.

TABLE 10.7 Probiotic Properties, Identity, and National Center for Biotechnology Information (NCBI) Accession Numbers of the Nine Probiotic Potential Bacteria Isolated from Flour and Batter Samples of Sorghum and Millets

Isolate	Acid Tolerance (pH)	Bile Tolerance (%)	Phenol Tolerance	NaCl Tolerance (%)	Identified Isolate	Accession Number
PHFB-22	2	0.3	0.2%	9	*Bacillus subtilis*	—
PHFF-11	3	0.5	0.2%	6	*Bacillus cereus*	KM624626
S6SF-44	2	0.3	Nil	3	*Bacillus amyloliquefaciens*	KM624628
S8CF-32	2	0.5	Nil	9	*Bacillus subtilis*	KM624629
S8SF-4	2	0.5	Nil	3	*Sphingobacterium thalpophilum*	KP326566
SKSB-14	3	0.3	Nil	3	*Brevibacterium* sp	KM817772
SKSB-55	3	0.3	Nil	6	*Bacillus cereus*	KM658265
SKSF-7	2	0.3	Nil	6	*Bacillus cereus*	KM658262
SKSF-8	3	0.3	Nil	9	*Bacillus pumilus*	KM658263

Data from Kunchala et al., 2016. Characterization of potential probiotic bacteria isolated from sorghum and pearl millet of the semi-arid tropics. Afr. J. Biotechnol. 15, 613—621.

3.2.2 *Rabadi (Fermented Nonalcoholic Drink Using Pearl Millet)*

Rabadi is a popular drink in the north-western part of India. It is a traditional lactic acid bacteria-fermented product prepared with pearl millet and wheat (Sathe and Mandal, 2016). Improvement in the protein quality of *rabadi* is achieved by addition of dairy protein in the form of curd. Blandino et al. (2003) reported that non-lactic acid bacteria such as *Bacillus* and *Micrococcus* are also associated with *rabadi*. The type of bacterial flora developed in such fermented foods depends on the water activity, pH, salt concentration, temperature, and the composition of the food matrix. Preparation of *rabadi* involves mixing of pearl millet and wheat flours in equal proportions with curd added (flour to curd ratio 1:2.5) to provide the starter culture. This is followed by preparation of a slurry by addition of water (flour to water ratio 1:6) and allowing overnight fermentation in earthen pots. Salt is added to this fermented batter to taste, and the mixture simmered over a low flame. The product is then cooled, spiced, and consumed (Gupta and Nagar, 2010).

3.2.3 *Healthy Dry Premixes*

Today, "*Rag*i Malt" is one of the most popular healthy dry premix products in India. Traditionally, especially in the southern part of India, "*ragi* malt" is the most common and popular homemade millet-based weaning food and is prepared using finger millet, which is called *ragi* in India. Finger millet is notably, rich in calcium (364 ± 50 mg/100 g), along with its other nutritional attributes (Longvah et al., 2017) and is a very suitable cereal for preparing weaning foods. However, in order to enhance carbohydrate digestibility, improve the essential amino acid profile and vitamin content, and enhance micronutrient bioavailability by reducing antinutritional factors, malting (sprouting) of finger millet is undertaken as an important unit operation for preparing *ragi* malt. The finger millet grains are washed to remove stones and dirt, the water drained off, and the moist grains are then allowed to sprout in a vessel covered with a moist cloth. Depending upon the temperature, sprouting takes between 1 and 2 days. The grains are washed with fresh water every day, and the water drained off to maintain optimum moisture content required for sprouting and to avoid any microbial growth. The sprouted grains are then dried in the shade, toasted, ground into flour, sieved, and blended with sugar and/or with spices such as cardamom and stored in air-tight containers. *Ragi* malt powder is traditionally mixed in warm milk and served to children. In India *ragi* malt is available as a commercially packaged product, both in its traditional form as well as in different variants/flavors such as chocolate (blended with cocoa powder) or fruit (blended with fruit powders). The concept of *ragi* malt has now been further adapted in the Indian market using other millets and sorghum and mixed millet/sorghum malt premixes and also different variants such as weaning and health drinks are available.

In the Indian market, a number of other innovative beverage premixes have been developed and commercialized which leverage the low GI (Vahini and Bhaskarachary, 2013), high-dietary fiber, and high polyphenol characteristics of millets and sorghum. Mixed millet drink premixes and other similar products are prepared by adding ingredients such as foxtail millet, proso millet, barnyard millet, little millet, kodo millet, green gram (mung bean), and spices such as cardamom, cashew, and almond in various proportions, after appropriate pretreatment (malting, roasting) of the grains. These beverage premixes are marketed in India as gluten-free, slowly digestible (low GI), and rich in bioactives, vitamins, and micronutrients.

Another product concept that has been adapted in the Indian market is the use of the antioxidant-rich bran fraction of different millets as a "fiber enhancer" for food products. The fiber enhancers are sold as powdered mixes and are added as an ingredient in formulations of different food products in amounts as per the fiber content desired. The mixed millet fiber enhancers can be used to enhance the fiber contents as well as the flavor profile of products such as flatbreads (*roti*), breads, cookies, beverage premixes, and ice cream.

3.3 Supplementary Foods for Addressing Malnutrition

The health benefits associated with millets and sorghum can also be leveraged for the development of healthy supplementary food products for dietary diversity and alleviating malnutrition among vulnerable populations in India, especially women and children. These products are targeted at the Indian government's supplementary nutrition programs (Kapil and Pradhan, 1999; Kapil et al., 1992), such as the Integrated Child Development Services scheme, mid-day meal program, and other similar programs. Typically, millet or sorghum is incorporated into the food product as a primary ingredient and provides the source of carbohydrate, dietary fiber, and micronutrients. The most important aspect that needs to be taken into consideration in using millets and sorghum in supplementary food products is to ensure that their digestibility is enhanced, antinutrients are reduced, and bioavailability of micronutrients increased. Given that these products are to be affordable and produced locally through involvement of small and medium enterprises, there are very limited options for exploring high-end processing technologies.

Millets and sorghum are typically malted to make them suitable for use in these supplementary food products. The advantages of malting in enhancing nutritional quality, for example, enhanced protein digestibility and nitrogen solubility index and increased lysine content (the first limiting indispensable amino acid) by transamination in sorghum (Dewar, 2003; Taylor, 1983) and pearl millet (Pelembe et al., 2002, 2003), have been well documented. Using the right malting conditions to obtain optimum nutritional quality enhancement is critical to ensure maximum benefit of the malted grains in supplementary nutritional products. A few key points that need to be considered in this regard are grain variety, diastatic power (amylase activity) of the grains, steeping time and temperature, and moisture content of the grain at the end of the steeping or soaking period (steep-out moisture). As steep-out moisture depends on the rate of water uptake into the grain during steeping (Taylor et al., 2006), appropriate treatments during steeping by addition of cell wall disrupting agents, for example, alkali or commercial hydrolytic enzymes, should be considered as part of the process optimization step.

The malted grains are then incorporated in supplementary food formulations, either in whole, dehulled, powdered, or flaked form. Malted millet and sorghum in RTE and RTC (ready-to-cook) format have been used for providing supplementary nutrition in the tribal areas of India (ICRISAT, 2017). Three different products formulated with malted sorghum or millet as one of the key ingredients have been developed by ICRISAT to address malnutrition (Fig. 10.11). These are RTC Multigrain Meal (an RTC version of a popular recipe called *kichidi* that is traditionally based on a cooked blend of rice and lentils), RTC *Jowar* Meal (an RTC version of another popular recipe called *upma* that is traditionally prepared as a thick porridge made from dry roasted semolina or coarse rice flour), and an energy and nutrient-dense RTE spread consisting of groundnut, malted sorghum, and malted legumes. The RTC Multigrain Meal comprises approximately 37% malted sorghum grits and 19% malted foxtail millet grits, the other ingredients being mung bean, curry tree (*Murraya koenigii*) leaves, salt, sugar, and spices. The RTC *Jowar* Meal comprises approximately 69% malted sorghum grits, and the other ingredients are chickpea, groundnut, curry leaves, salt, and spices. The RTE spread comprises approximately 23% malted sorghum with groundnut, and malted chickpea, sugar, and vegetable oil as the other ingredients. The malted sorghum and millet are used in the supplementary food formulations primarily as a source of digestible carbohydrates. The carbohydrate contribution from the malted sorghum/millet components is approximately 77%, 83%, and 32% in the Multigrain Meal, *Jowar* Meal, and the RTE spread, respectively.

In India, the push toward promoting the use of millets and sorghum in supplementary foods for addressing malnutrition has been prioritized by both the central government (The Pioneer, 2017) and by various state governments. For example, "*bisi bele bath*" and "*pulao*" (traditional rice and pulse-based dishes) where rice is replaced with millets are provided as part of the mid-day meal program in the State of Karnataka (The Hindu, 2018). Other states in the country such as Tamil Nadu and Odisha have also taken similar initiatives toward introducing millets in different supplementary nutrition programs.

(A) (B) (C)

FIGURE 10.11 Malted millet and sorghum ready-to-cook (RTC) and ready-to-eat (RTE) food products for addressing malnutrition. (A) Ready to cook upma mix. (B) Ready to cook kichidi mix. (C) RTE spread. *Pictures courtesy of P.S. Rao, ICRISAT, Hyderabad, India. Adapted from ICRISAT, 2017. Tackling Malnutrition through Nutri-food Basket. An Infographic. http://www.icrisat.org/wp-content/uploads/2017/11/ Tackling-Malnutrition-Through-Affordable-Nutri.pdf.*

3.4 Affordable Processing Technologies for Sorghum and Millet

An important initiative in India is the development and promotion of the availability of low-cost and efficient primary processing machinery especially for farming and rural communities in order to encourage entrepreneurship around sorghum- and millet-based value addition. This is being done to enable compression of the value chain by eliminating intermediaries and transfer of the profit margins from the end consumer price to the farmers. The key equipment needed to promote community-level rural millet processing enterprises is explained in the following:

3.4.1 Destoner—Aspirator—Grader

The destoner—aspirator—grader is required to enable farmers to sort and grade, as per the market demand, their produce at the farm gate or community level. This provides the farmers with bargaining power and linkage to the markets. A destoner—aspirator—grader (Fig. 10.12A) is used to remove impurities like stones and foreign materials and also to separate different sizes of grains. The machine has three important components: destoner, which removes

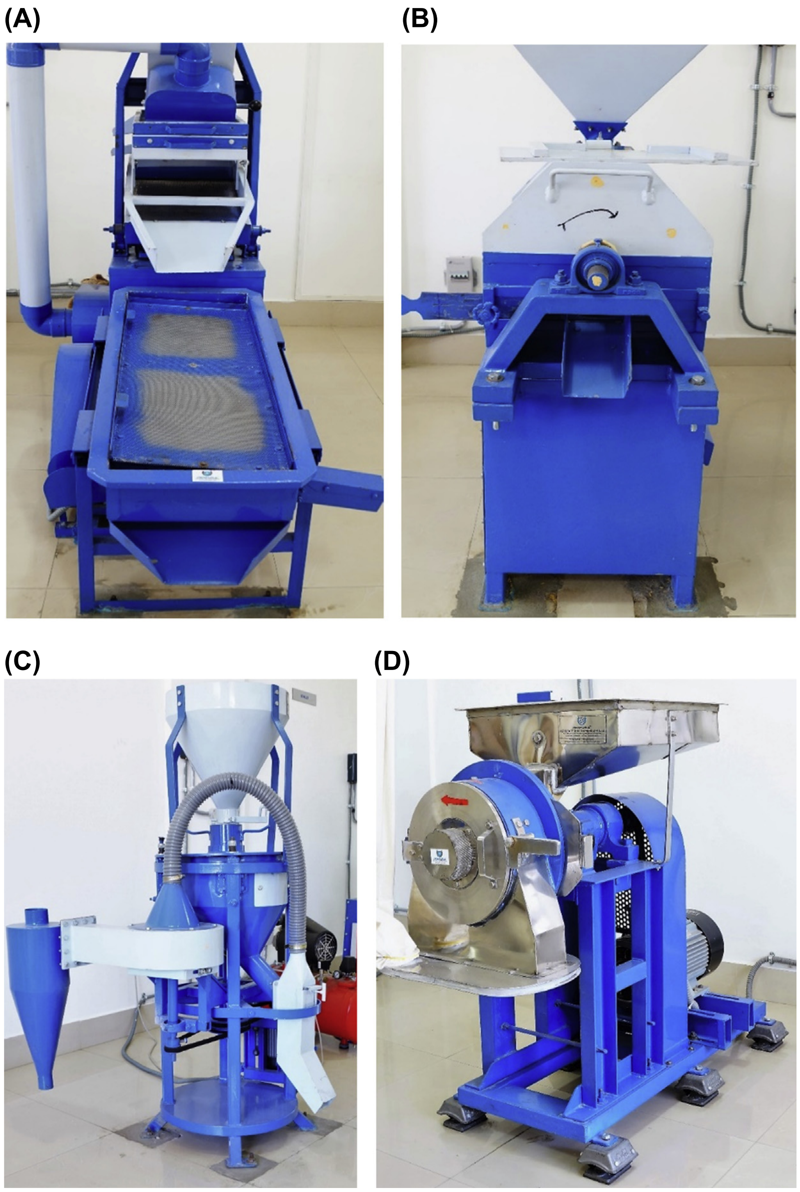

FIGURE 10.12 Some key equipment used for promoting rural, community-level sorghum and millet processing enterprises. (A) Destoner cum Aspirator cum Grader. (B) Sorghum Dehuller. (C) Millet mill. (D) Double stage pulveriser. (E) Flour sifter. (F) Roaster. (G) Blender. (H) Polybag sealing machine. *Pictures courtesy of Priyanka Durgalla, ICRISAT, Hyderabad, India.*

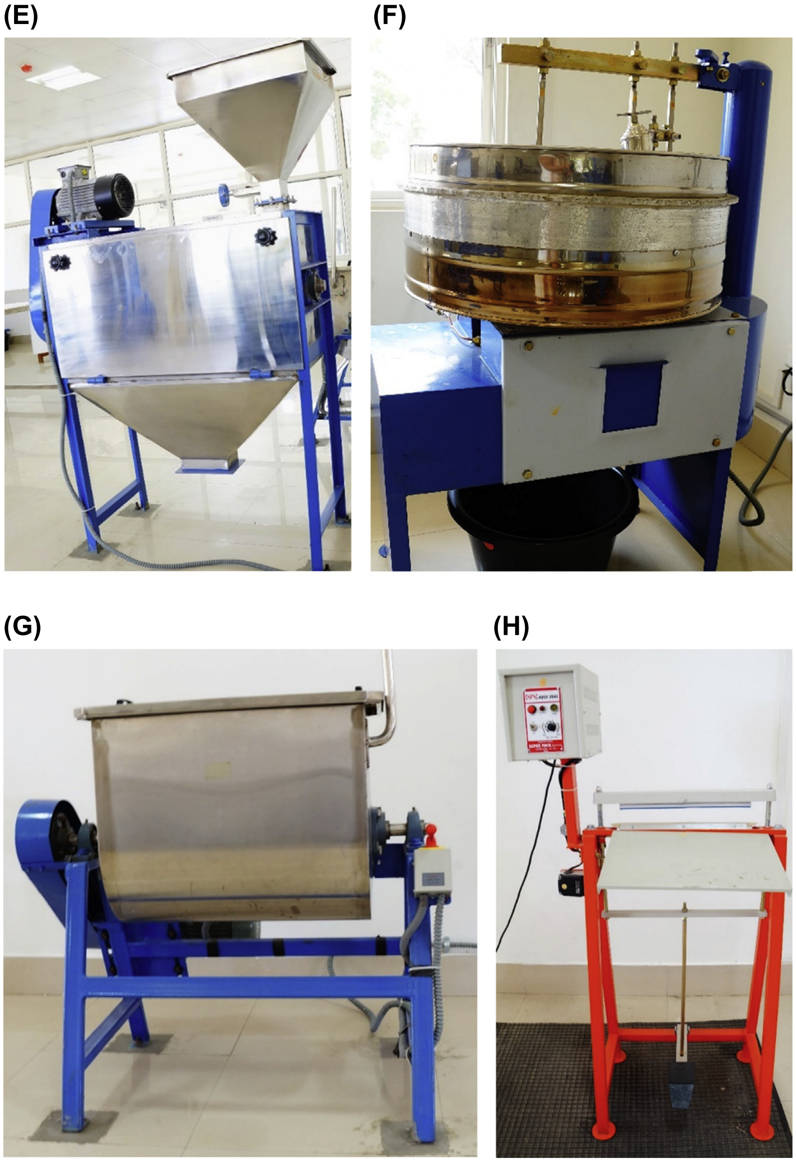

FIGURE 10.12 Con’t

stones, mud balls, sand, and other heavier materials from the millet grains; aspirator, which removes high- and low-density impurities like husk, dust and sand; and grader, which sorts large grains from smaller grains in a batch.

3.4.2 Dehuller

Dehulling (also known as decorticating) is the process of removing the outer hull/husk from the grains. In case of sorghum and pearl millet which are “naked” caryopses and do not have a hull “dehulling” actually involves removal of the pericarp layers. Traditionally, sorghum and millets have been dehulled manually by women in India, using a pestle and mortar and/or wooden/stone grinders, which involve considerable drudgery and are time-consuming. As a consequence, the consumption of small millets has drastically declined in its production regions and across India. However, with the growing demand for processed and packed sorghum and millet grains, there is an increasing demand for mechanical dehulling machines to cater to the needs of the small and medium enterprise sector. A mechanical dehulling machine based on abrasive action of an emery-coated rotating cylinder (Fig. 10.12B) has been promoted in India to efficiently dehull sorghum, pearl millet, and finger millet. However, this dehuller was found to be unsuitable for the small millets such as foxtail, little, kodo, proso, and barnyard millets, for which a specially designed millet mill is used.

3.4.3 Millet Mill

The millet mill (Fig. 10.12C), based on the principle of rubbing the outer covering of the grains between two abrasive stones, is used to remove the husk layer of small millets. The machine is suitable for dehulling small millets and has a processing capacity of 100 kg/h with grain of 10%–12% moisture content.

3.4.4 Roaster

Roasting of sorghum and millet grains and other ingredients to prepare various RTC products is an important unit operation that needs to be undertaken by the community-level rural millet enterprises. To enable them to carry out this operation, each of these processing units is provided with a simple gas-fired roaster (Fig. 10.12F), which is capable of roasting approximately 20–25 kg of grains per batch. The roaster consists of a rotating pan into which the grains to be roasted are loaded. The pan is heated by a gas burner from the bottom. Baffles are provided to continuously mix and stir the grains as the roasting takes place through heat transfer from the surface of the hot pan to the grains. Once the roasting is completed, the grains are discharged by opening a discharge outlet at the center of the pan. The roasted grains are collected at the bottom into a suitable container.

3.4.5 Pulveriser

A pulveriser (Fig. 10.12D), which is basically a hammer-type mill, is designed to convert the sorghum and millet grains into flour. The grains pass through two different chambers and are subjected to a hammering action, resulting in the conversion of the grain to flour. The pulveriser is designed in such a manner that when coarse flour is required, the second chamber is opened up, thus resulting in a single chamber. This reduces the residence time of the grains in the chamber, yielding a more coarse flour. The outlet of the pulveriser is provided with interchangeable screens, which further aids in controlling the desired meal/flour particle size as per requirement from the market. The pulveriser is suitable for making both coarse flour (*rava*) and fine flour, both of which are in high demand in the Indian market. The mixture of the fine and coarse flour is then passed through a flour sifter for further separation into fine and coarse flour fractions.

3.4.6 Flour Sifter

A flour sifter (Fig. 10.12E) is designed to grade the flour obtained from the pulveriser into the desired particle size. The sifter comprises a cylindrical mesh screen placed around a central rotating arm having paddles, which enables the flour of the desired particle size to be sifted through the mesh screen. The mesh screen is removable, and the equipment can be fitted with the size of mesh as per the particle size of the flour desired. The flour to be sifted is loaded inside the cylindrical mesh, through a hopper provided on the top. The fine flour which passes through the mesh is collected at the bottom, and the coarse flour is collected through an outlet provided at one end of the rotating cylindrical mesh.

3.4.7 Blender

As the purpose of the community-level processing facilities is to add value to local crops, especially millets and sorghum, a ribbon blender (Fig. 10.12G) is provided in each of these facilities to enable blending of different ingredients, enabling production of different supplementary food formulation blends. Malted/unmalted roasted sorghum and millet flours/grits of different particle size can be blended with processed pulses, fruit powders, spice powders, and so on as per the product formulation using the blender. The products can also be fortified with vitamin and micronutrient premixes using the blender.

3.4.8 Polybag Sealing Machine

To enable the packaging of the supplementary food formulations into heat sealable pouches by the community-level processing facilities, paddle-operated polybag sealing machines (Fig. 10.12H) are provided. This enables the employment of rural women and youth in the packaging operation. Each pack is hand filled with a weighed quantity of the product and sealed using the paddle-operated polybag sealing machine.

4. BEERS AND NONALCOHOLIC BEVERAGES—WITH A FOCUS ON AFRICA

The modern sorghum- and millet-based beverages produced in Africa can be classified into three major product groups: liquid beers and nonfermented, nonalcoholic malt beverages; liquid-soured starchy gruel-type nonalcoholic beverages; and dry instant powder-based beverages, both starchy and malted milk-type products.

4.1 Lager and Stout Beers and Nonalcoholic Malt Beverages (Including Gluten-Free Versions)

In Western countries, barley, which is a major cereal crop in these largely temperate countries, is by far the major grain used in brewing. However, in sub-Saharan Africa, with its tropical and arid-subtropical climates, sorghum and millets are major cereal crops and the basis of the region's traditional cloudy and opaque beers. Table 10.8 compares the grain structure and chemistry of sorghum and the major millets with that of barley, in respect of their malting and brewing quality. Sorghum is a much better option for commercial brewing than the millets primarily because its kernel is similar in size to that of barley, whereas the kernels of the millets are all very much smaller. Sorghum is also far more commercially available.

The idea of using sorghum as a barley substitute for malt and in the brewing of "Western-type" beers (ales, bitter, lager, and stout beers) has a long history. In 1917, during the First World War when trade was severely disrupted, locally produced sorghum malt beverages were demonstrated at the Madras Exhibition in India (Viswanath et al., 1918). However, worldwide, ongoing, and large-scale lager and stout brewing using sorghum malt first commenced in Nigeria only in the late 1980s. This was in response to a government ban on the importation of barley (Akinyoade et al., 2016). Brewing lager and stout beers with sorghum (often as an unmalted whole grain adjunct) have subsequently spread across West Africa, largely through the efforts of the West African Sorghum Value Chain project (European Cooperative for Rural Development, 2008). A similar development using whole grain sorghum adjunct took place in East and Central-Southern Africa during the early 2000s, commencing in Uganda (Mackintosh and Higgins, 2004). The brewing of gluten-free beers based on sorghum also commenced in several Western countries in the early 2000s. Perhaps, the best known of these is Redbridge beer, produced in the United States by Anheuser-Busch, now part of the AB-InBev group.

4.1.1 Lager and Stout Beers

4.1.1.1 Malting Brewing Technology

When discussing brewing technologies in respect of the still rapidly developing technology of sorghum lager and stout beer brewing, there is often something of a disconnect between what is actually happening in commercial practice and what is published in the public domain. For example, even as recently as 2011, one publication concluded with reference to research into the brewing behavior of a range of malted cereals and pseudocereals, including sorghum, that these grains "could potentially be used for brewing purposes" (De Meo et al., 2011). This is notwithstanding the fact that, as mentioned, sorghum malt has been routinely used in Nigeria for lager and stout brewing since the 1980s. Because of this disconnect and to avoid revealing proprietary information, this discussion of technologies will inevitably be somewhat generic in nature.

The processes used to brew lager and stout beers with sorghum are very diverse, especially with respect to the type of grain material used. Concerning grain materials, there is a continuum from one extreme where sorghum malt is used on its own, through sorghum malt plus barley malt with or without added commercial enzymes plus unmalted sorghum grain (whole or decorticated) adjunct, to barley malt plus unmalted sorghum grain adjunct (whole or decorticated), to the other extreme of just unmalted (raw) whole grain sorghum grain plus commercial enzymes (Taylor et al., 2006). The choice of materials and brewing process is dictated by factors such as the availability of particular raw materials, available brewing equipment, process cost, and consumer preference.

4.1.1.2 Sorghum Grain Type

With regard to suitable sorghum grain types, in Nigeria, white tan-plant (nontannin), white Type II tannin, and yellow endosperm (nontannin) sorghum types have or are currently being used for malting (Ogbonna, 2011; Akinyoade et al., 2016). In East and Central-Southern Africa white tan-plant sorghum is preferred for use as unmalted grain adjunct (Mackintosh and Higgins, 2004). Concerning other sorghum types, there is clear evidence that with red Type III tannin sorghums, the tannins present can substantially inhibit malt amylase activity (Beta et al., 2000) and give reduced extract, fermentable sugars, and free amino nitrogen (FAN) when brewing with unmalted grain and commercial enzymes (Adetunji et al., 2013). As a consequence, red tannin and red nontannin

TABLE 10.8 Comparison of the Grain Structure and Chemistry of Sorghum and the Major Millets With That of Barley, With Reference to Malting and Brewing

Attribute	Sorghum	Millets	Barley
Kernel size and weight	Slighter smaller than barley (1000 kernel weight [approx. 28 g])[a]	Much smaller than barley Pearl millet: approx. 1/4th the size; proso millet: approx. 1/5th, foxtail millet: approx. 1/8th, teff tiny	Thousand kernel weight (approx. 35 g)[a]
Kernel structure	Naked grain	Variable Finger millet—loose utricle, Teff—naked, foxtail millet—Hulled, pearl millet—naked, proso millet—Hulled	Grain surrounded by fibrous husk Acts as a filter bed during wort separation
Condensed tannins	None in most types High in Type III tannin sorghums Moderate in Type II tannin sorghums	None in most species Moderate in some varieties of finger millet	Very low
Starch gelatinization temperature	Average 63.1–73.5°C[b]	High Finger millet—average 66.4–74.4°C[b] Teff—average 65.1–84.6°C[b] Foxtail millet—78.8°C[c] Pearl millet—average 60.3–72.3°C[b] Proso millet—73.4°C[d]	51–60°C[e]
Malt α-amylase activity	Slightly lower than barley malt[f]	Very little comparative data Pros millet—lower than barley malt[c]	High
Malt β-amylase activity	Very much lower than barley malt[e]	Little comparative data—but generally much lower than barley malt Pearl millet—somewhat higher than sorghum malt[g] Proso millet—much lower than barley malt[d]	High
Malt modification	Glucurono arabinoxylan–rich endosperm cell walls not substantially degraded[h,i]	No firm information	Beta-glucan rich endosperm cell walls fully degraded[j]

[a] *Kent and Evers (1994)*.
[b] *Emmambux and Taylor (2013)*.
[c] *Kumari and Thayumanavan (1998)*.
[d] *Zarnkow et al. (2007)*.
[e] *Lineback (1984)*.
[f] *Taylor et al. (2013)*.
[g] *Pelembe et al. (2004)*.
[h] *Glennie (1984)*.
[i] *Palmer (1991)*.
[j] *Morrall and Briggs (1978)*.

sorghums (i.e., types which do not contain condensed tannins but are rich in flavonoid-type polyphenols) are generally not used in lager and stout beer brewing. Interestingly, however, research by Adetunji et al. (2013) revealed that worts from unmalted red, nontannin sorghum were similar to those from white, nontannin sorghums in terms of both physicochemical and sensory quality. In view of the better agronomic quality of red, nontannin sorghums this work indicates that this type of sorghum could be used to a greater extent in sorghum lager and stout brewing.

The effects of brewing with unmalted waxy type sorghum, where the starch is essentially only amylopectin, as an adjunct on brewing efficiency and beer quality have been studied quite extensively. Figueroa et al. (1995) found that there was more rapid starch hydrolysis with waxy sorghum adjunct than with normal sorghum resulting in higher hot water extract (essentially a measure of the yield of fermentable sugars and dextrins). This was attributed to the lower gelatinization temperature (probably actually pasting temperature) of the waxy sorghum, 69.6°C, compared with approximately 72°C for normal sorghum. Beers brewed with waxy sorghum adjunct have also been found to filter more rapidly (Osorio-Morales et al., 2000) and their worts to have higher levels of FAN (the nitrogen source for yeast growth during fermentation; Ortega Villicaña and Serna Saldivar, 2004). Recently, it has been shown that sorghum malts made from waxy sorghum lines exhibited greater endosperm modification and generally gave higher extract than malts from similar normal starch lines when mashed under standard barley malt brewing conditions (Mezgebe et al., 2018). The results indicated that waxy sorghum malt had considerable potential as a partial barley malt substitute.

High-protein digestibility (HPD) sorghum types have been developed that have modified protein body and endosperm structure that facilitates access to the endosperm protein by protease enzymes (Oria et al., 2000; Da Silva et al., 2011). Research has shown that when malted, these HPD sorghums have approximately 50% higher FAN than normal sorghums (Mugode et al., 2011). However, when mashed either in the form of malt or raw whole grain adjunct together with exogenous protease enzymes, wort FAN was not substantially increased. Notwithstanding this, novel sorghum lines with the HPD trait and reduced phytate (myoinositol hexaphosphate) expression were found to yield substantially higher wort FAN (23% increase) and hot water extract (a measure of starch hydrolysis; a 2.8%-point increase) and increased levels of Mg, P, Fe, and Ca minerals in a whole grain mashing process together with a commercial sorghum brewing enzyme cocktail (Kruger et al., 2012). These minerals are essential micronutrients for yeast fermentation performance (Walker, 2004).

4.1.1.3 Malting

As explained, the tannins in tannin-type sorghum can inhibit amylase activity during brewing. In response to this problem chemical treatments have been developed to inactivate the tannins and are applied in the sorghum malting process. For industrial opaque beer brewing in Southern Africa, red Type III tannin sorghum is often used, and grain is generally chemically treated by steeping (soaking) it in a very dilute formalin solution to inactivate the tannins. This treatment prevents the tannins from inhibiting the malt amylases during brewing (Beta et al., 2000). An alternative process of steeping sorghum in dilute sodium hydroxide solution, which also inactivates the tannins (Ezeogu and Okolo, 1996; Dewar et al., 1997a), is widely used in Nigeria for producing sorghum malt for lager and stout brewing. However, recent research indicates that the tannins in white Type II tannin sorghums, the only type of tannin sorghum malted in Nigeria, have little inhibitory effect on amylase activity during the mashing process (Adetunji et al., 2015) nor on consequent levels of malt hot water extract obtained and wort fermentable sugars (Adetunji et al., 2013). It is more likely that the dilute alkali steeping serves primarily as a method to reduce microbial load on the sorghum malt (Leyfedi and Taylor, 2006).

The technology of malting sorghum is in principle identical to that of barley, except that the temperature of the steeping and of germination steps is up to 10°C higher (than that commonly used for barley malting, 24−30°C (Dewar et al., 1997a,b,c; Morrall et al., 1986), as opposed to around 18°C or lower for barley (Hough et al., 1971). This low temperature is suboptimal for sorghum malting (Dewar et al., 1997c), as are temperatures of 32°C and higher (Morrall et al., 1986). Another difference between sorghum and barley malting is that during the germination step of sorghum malting, seedling growth is very extensive. As a consequence, the germinating sorghum needs to be watered to at least maintain the same moisture content in order to attain malt optimum quality in terms of parameters like amylase activity and FAN (Morrall et al., 1986).

With regard to malt quality for brewing, generally sorghum malt is very deficient in β-amylase activity in comparison with barley malt (Dufour et al., 1992; Taylor and Robbins., 1993). Furthermore, the β-amylase activity has been shown to be limiting in brewing with sorghum malt (Del Pozo-Insfran et al., 2004). β-Amylase is the enzyme that hydrolyzes dextrins into maltose, which in turn is fermented by yeast into ethanol and carbon dioxide. Although manipulation of germination moisture levels can increase the level of sorghum malt β-amylase somewhat (Taylor and Robbins, 1993), the low β-amylase activity of malted sorghum appears to be due to it containing only one form of the enzyme, unlike the multiple forms in barley (Ziegler, 1999).

Sorghum malt is often just dried at a relatively low temperature (50−60°C), rather than “kilned” at the higher temperatures employed with barley malt. This is done to conserve amylase activity, which can be significantly reduced at higher temperature (80°C; Aisen and Muts, 1987) but limits the development of the characteristic malt color and flavor resulting from caramelization and Maillard browning reactions. However, there is some evidence that a two-stage sorghum malt drying regime, where the malt is initially dried at a low temperate then latterly at higher temperature can both conserve amylase activity and develop malt character (Owuama, 1997). Also, by roasting sorghum malt at 200°C, a dark, nonenzymic malt with a range of volatile flavor and color compounds, including pyrazines, furans, aldehydes, ketones, esters, and alcohols, can be produced (Lasekan et al., 1997). This sort of malt is ideal as an ingredient to color and flavor dark beers. However, in practice, it seems that African commercial sorghum-based stout beers are produced either with a proprietary barley-based ingredient or simply with caramel coloring.

4.1.1.4 Mashing

Another important difference between sorghum and barley that impacts on the brewing process used is that the gelatinization temperature of sorghum starch is considerably higher than that of barley starch, approximately 63.1−73.5°C as opposed to 51−60°C, respectively (Table 10.8). Since starch must be fully gelatinized in order for it be rapidly hydrolyzed by α-amylase, the high gelatinization temperature of sorghum starch can result in incomplete starch hydrolysis and saccharification (fermentable sugar production) when brewing with sorghum if the mashing process is not optimized (Goode and Arendt, 2003).

When brewing with sorghum malt alone, it is possible to obtain complete starch hydrolysis and good saccharification despite its low β-amylase activity and high starch gelatinization temperature. This can be achieved by separating the clear enzyme-containing supernatant portion of the mash from the denser starch-containing portion and then cooking the latter to fully gelatinize the starch, and then combining the two fractions together again to enzymically hydrolyze the starch (Palmer et al., 1989; Taylor, 1992). In fact, such a decantation-type mashing process is used in the brewing of the West African traditional cloudy sorghum beer, variously called dolo, pito, or burukutu.

No doubt, decantation mashing has or is still used in the brewing of specialized premium and gluten-free type sorghum lager beers. However, in large-scale sorghum lager and stout brewing, both with sorghum malt and sorghum grain adjunct, the sorghum is cooked first to gelatinize the starch, prior to hydrolysis using barley malt and/or commercial amylase enzymes during mashing. Thus, in effect where sorghum malt is used, it is acting primarily as a cereal adjunct, rather than being the source of both hydrolytic enzymes (amylases, nonstarch polysaccharide degrading enzymes, proteases, lipases, phytase etc.) and yeast nutrients (carbohydrates, FAN, lipids, vitamins, and minerals) as is the case with barley malt.

Fig. 10.13 shows the general large-scale industrial sorghum brewing cooking and mashing processes used for brewing lager beer/stout in Africa. It can be seen that, in principle, the process is the same irrespective of whether brewing is with sorghum malt or raw sorghum grain. One feature of note, with both the sorghum malt brewing and the raw sorghum grain plus commercial enzyme process is at "mash in," there is a short incubation period at relatively low temperature (approximately 55°C) before the malt or grain is cooked to gelatinize the starch. This period of incubation, referred to in brewing as a "protein rest," is carried out primarily to modify (degrade) the sorghum

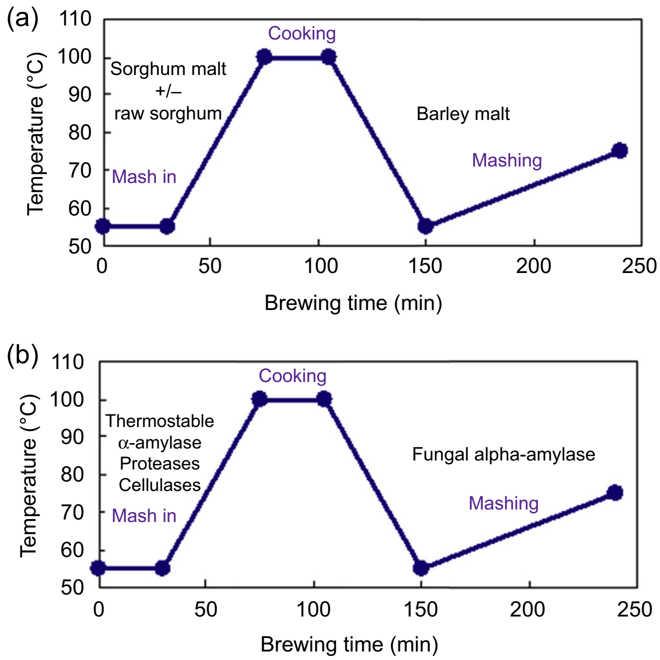

FIGURE 10.13 Generalized sorghum beer lager beer/stout processes. (A) Using sorghum malt, raw sorghum grain, and barley malt; (B) Using just raw sorghum grain and commercial enzymes.

endosperm structure (the endosperm protein matrix (Ng'andwe et al., 2008) and the cell walls). This enables more complete "gelatinization" of the starch granules so that the starch is better available for hydrolysis by α-amylase (Ezeogu et al., 2005). When brewing with sorghum malt, its endogenous cellulases and protease are utilized (Fig. 10.13), but with raw sorghum grain, commercial cellulose-type enzymes and proteases need to be added. The action of the proteases also produces FAN for yeast nutrition (Taylor and Boyd, 1986; Goode and Arendt, 2003; Ng'andwe et al., 2008). The low temperature of up to 55°C is necessary as the protease enzymes, in particular, are heat-labile. When brewing with barley malt, its endogenous β-amylase is responsible for fermentable sugar production during mashing (Fig. 10.13A), whereas the maltose-producing fungal α-amylase enzyme is generally used for saccharification when brewing with commercial enzymes (Fig. 10.13B). In fact, it is notable that the raw sorghum grain-commercial enzymes brewing process is remarkably similar in principle to the dry grind grain bioethanol process (Kwiatkowski et al., 2006). Undoubtedly, proprietary process efficiency improvements in the dry grind grain bioethanol process are being incorporated into the sorghum grain-commercial enzymes brewing process to improve its efficiency.

Obviously, the question arises that if the sorghum malt is simply used as an adjunct, why bother brewing with sorghum malt, since malting the grain is an expensive process? The primary reason that the sorghum is malted is for the provision of yeast nutrients. During malting, substantial levels of FAN are produced as a result of hydrolysis of the cereal proteins by the malt protease enzymes (Dewar et al., 1997c). This FAN acts as a source of nutrition for yeast growth and rapid and complete fermentation (Pickerell, 1986). Malting, through the action of the endogenous malt hydrolytic enzymes on the malt substrate, also makes other yeast nutrients available such as minerals and B vitamins (Briggs et al., 2004). Malting may also contribute some malt flavor to the beer, but it is doubtful that this is significant in view of the fact that the sorghum malt is dried at relatively low temperature. The use of malted sorghum, as opposed to raw sorghum grain, is probably also dictated by brewing tradition and by consumer perception as to how beer should be brewed.

The form of the raw (unmalted) sorghum used can also influence mashing performance and quality. Perez-Carillo et al. (2012) found that decorticated sorghum (approximately 10% decortication) gave higher wort FAN levels than whole grain sorghum, notwithstanding the fact that the level of protein was higher in the whole grain. They attributed this to inhibition of proteolysis by fiber and phenolics in the whole grain. Furthermore, they found that FAN levels were enhanced by inclusion of protease in the mash to the extent that the decorticated and protease-treated sorghum mash had double the FAN level of the mash with whole grain sorghum with added protease.

4.1.1.5 Wort Separation

The sorghum kernel is naked, that is, the outermost layer is the pericarp (bran), whereas the barley kernel is enclosed in a fibrous husk (also known as a hull). For this reason, theoretically, sorghum should be a more efficient brewing material than barley, as the barley husk comprises some 4% by weight of the grain (Bhatty, 1999). However, the husk is very useful when brewing with malted barley because after mashing, the wort (the liquid) is most commonly separated from the spent grain (insoluble malt components) using a lauter tun. The basic principle of the lauter tun is that the barley malt husks act as the filtration bed. As sorghum grain does not have a husk, this presented a significant challenge when sorghum grain or malt was first used for lager and stout brewing. In breweries equipped with lauter tuns for mash filtration various solutions were developed, including brewing with a proportion of barley malt which is now common practice or when brewing with a 100% sorghum grist, using barley malt husks collected from barley malt brews as the filter bed. The latter is not very satisfactory as the husks can rapidly become microbiologically contaminated. A far better solution is to use alternative wort separation equipment, most commonly a mash filter. A mash filter (Fig. 10.14) is a plate and frame filter press comprising a series of filter "cloths." The filter cloths are generally of stiff, fine, nylon-type mesh. Modern mash filters are completely automated in operation, whereby the filter plates are separated from each mechanically or hydraulically, and the spent grain removed from the filter cloths. Basically, because the grain or malt is more finely milled when mash separation is by mash filtration, there can be 3%−4% improvement in extract (soluble solids) yield compared with brewing with a lauter tun, although maintenance costs are higher (Buttrick, 2006).

4.1.1.6 Fermentation

As indicated, in most commercial brewing with sorghum, the cereal grist comprises either a high ratio of unmalted sorghum adjunct to malt or the grist is 100% unmalted sorghum grain. This can potentially result in a shortage of yeast nutrients, most notably, FAN, as the unmalted sorghum grain has only approximately 15% of the FAN in sorghum malt (Mugode et al., 2011). The effect of low FAN levels on sorghum fermentation efficiency has been a concern for several decades. Pickerell (1986) found that there was a direct relationship between the

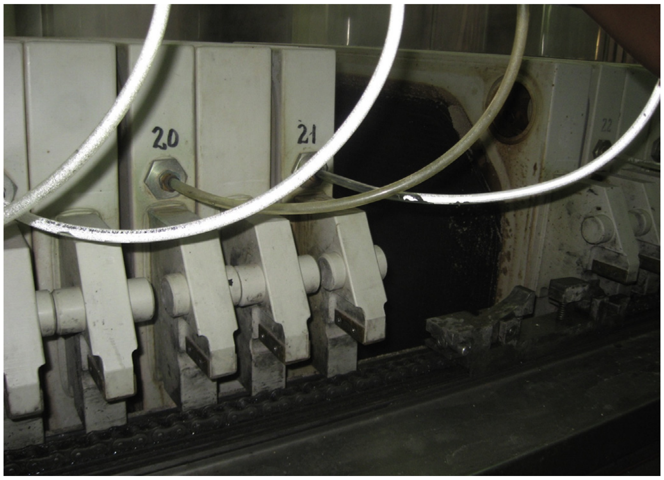

FIGURE 10.14 Close up of a mash filter in a sorghum lager brewery showing the open plates.

fermentable sugar level in 100% sorghum malt worts and the level of wort FAN required to guarantee a normal and rapid fermentation in order to obtain an ethanol yield of 99% of the theoretical potential. Goode and Arendt (2003) investigated the brewing and fermentation efficiency of a 50:50 whole unmalted sorghum grain:barley malt grist plus commercial enzymes brew versus a 100% barley malt brew. They found that fermentation efficiencies were similar; 6 days to attain 95% of total ethanol for the sorghum grain:barley malt brew, and 5 days for the barley malt brew. However, this was probably as a result of the fact that the wort FAN level in the sorghum:barley malt wort was 195 mg/L, a level classified by Pickerell (1986) as being very high. Dlamini (2015) investigated the effects of wort FAN levels on the fermentation efficiency in whole grain unmalted sorghum plus commercial enzyme worts. The worts had FAN levels of only approximately 70 mg/L, and fermentation efficiency was very suboptimal. Supplementation with exogenous nitrogen sources was required in order to attain normal and complete fermentation.

4.1.1.7 Beer Flavor

With regard to the influence of brewing with sorghum on beer flavor, Barredo Moguel et al. (2001) found that there was no effect of sorghum adjunct type, waxy versus regular sorghum, on the production of fusel alcohols (the higher alcohols—propanol, isobutanol, and amylisoamyl alcohols) during fermentation. Furthermore, the levels of fusel alcohols in the beers were within the expected range for commercial beers. Higher alcohols contribute a "warming" character to beer flavor, intensify ethanol flavor, and act as precursors to the production of the more highly flavored esters (Briggs et al., 2004). However, the desirable levels of higher alcohols and esters in beer are dependent on the type of beer being brewed. Mass market lager beers have much lower levels than ales, for example. The level of fusel alcohols in sorghum brewing fermentations can be influenced by FAN level. Perez-Carrillo et al. (2012) found higher levels of propanol, isobutanol, and amyl alcohols in beers where commercial protease had been added during mashing to boost FAN levels. Using GC-MS, 31 flavor compounds were identified in an experimental beer brewed with barley malt and decorticated white sorghum (Ma et al., 2016). The predominant compounds in descending order were butanol, isoamyl-alcohols, ethyl acetate, and acetaldehyde. All the flavor compounds present were typical of lager beers and ales, indicating that white sorghum adjunct does not impart any unique flavors to the beer. This is almost certainly not the case when red or tannin-type sorghums are used in beer brewing.

4.1.2 Millet Beers

The small size of millet grains, their limited availability, generally high cost, and poor brewing attributes militates against their common use in brewing lager and stout beers. However, they can be used as an exotic ingredient of specialty premium or gluten-free beers.

Pelembe et al. (2002, 2004) found that the malting conditions for pearl millet were similar to those for sorghum, with an optimum germination temperature of 25—30°C and time of 3—5 days with malt quality being directly related to germination moisture. However, the steeping time required was much shorter, only 8 h (Pelembe et al., 2002) compared with around 24 h for sorghum steeping, presumably due to the far smaller size of the pearl millet kernel. Pearl millet malt had much higher levels of β-amylase activity (approaching that of barley malt) and of FAN compared with sorghum malt, but a similar level of hot water extract (60%–69%, c.f. >80% expected for barley malt; Pelembe et al., 2004).

Zarnkow et al. (2007) investigated optimum malting conditions for proso millet. They found that like other tropical cereals, its starch had a high gelatinization temperature (73.4°C). The optimum malting conditions were 22°C for 5 days of germination producing a malt with low and very low levels of α- and β-amylase activity, respectively compared with barley malt. Notwithstanding, these poor-quality parameters, when mashed, the proso millet malt gave a fair level of extract (64.8%) and fair apparent attenuation (76%, cf. 81%–86% for barley malt), a measure of wort potential fermentability. Furthermore, by optimizing the mashing conditions for the α- and β-amylase enzymes and splitting the mash to fully gelatinize the starch, Zarnkow et al. (2010) were able to produce a wort from proso millet malt with similar extract, apparent attenuation, and FAN to barley malt. However, there was evidence that the level of lipid peroxidation products was rather high, which could adversely affect beer stability.

4.1.3 Gluten-Free Beers

There are many ingredients that can be used for brewing gluten-free beers and several processes that can be applied. The ways of brewing gluten-free beers can be divided into three general categories (Hager et al., 2014):

- Brewing with barley and removing the toxic hordein proteins by adsorption, precipitation, or enzyme hydrolysis or alternatively using the newly developed ultralow gluten barley varieties (Tanner et al., 2016),
- Brewing with starchy grains that are only distantly related to barley, such as rice, maize, sorghum, the millets, and pseudocereals such as amaranth, quinoa, and buckwheat (De Meo et al., 2011),
- Brewing with sugar syrups, either sucrose- or starch-derived plus yeast nutrients.

Thus, the use of sorghum and millets in gluten-free beer brewing is only one of many options. This is despite the fact that they are traditional brewing cereals and that today sorghum is widely used in Africa in brewing lager and stout beers. What is often not recognized is that just because a beer is brewed with, for example, 100% sorghum does not guarantee that it is gluten-free. There are very stringent regulations as to what constitutes gluten-free. The European Union limit for gluten in food and beverage products is 20 mg/kg (European Commission, 2009). Hence, what is probably as important as the type of grain used is the avoidance of contamination with barley and other gluten-containing cereals, particularly wheat, during cultivation, storage, transport, and manufacture. In fact, strict controls must be in place through the entire supply chain, starting with seed certification right to the point of sealing the beer bottle or can. Furthermore, complete traceability documentation is normally required.

4.1.4 Nonalcoholic Malt Beverages

Nonalcoholic malt beverages are produced in many countries around the world. In West Africa these products are very popular and go under trade names such as “Malta” and “Maltina” and are generally produced with sorghum (malt and/or grain) as part of their ingredients. Typical ingredients are barley malt (or malt extract), sorghum malt, unmalted sorghum grain adjunct, and maize adjunct, plus sucrose and hops or hop flavoring. In principle, nonalcoholic malt beverages are unfermented wort, which is carbonated and pasteurized. Hence, their process of manufacture is the same as that used for beer brewing as shown in Fig. 10.13, but without the yeast alcoholic fermentation and maturations steps. However, it is likely that some of the products are not “brewed” but are simply concoctions of the ingredients, and hence their production process is essentially identical to that used to make sugar-sweetened carbonated soft drinks. In West Africa, the nonalcoholic malt beverages are characteristically dark in color as caramel color is added (Fig. 10.15A). They may also be enriched with B vitamins and minerals.

4.2 Nonalcoholic Soured Starchy Beverages

In Southern Africa, lactic acid bacteria-fermented nonalcoholic starchy cereal beverages are a very popular traditional drink (Taylor, 2016), which today is commonly called mageu, also known as *magou*, *aHewu*, *amaRhewue*, *emaHewu*, or *amaHewu* in various local languages. For many years, mageu has been manufactured industrially from maize (Holzapfel and Taljaard, 2004). Recently, there has been an upsurge in small and relatively large-scale commercial manufacture of the sorghum version of the beverage generally called motoho, which is widely consumed by the Sotho-speaking people of Lesotho and South Africa (Gadaga et al., 2013). Fig. 10.16 compares the traditional and modern commercial processes for making motoho. Although, in principle, their processes are the same, involving cooking the sorghum meal to make a thin porridge and carrying out a lactic acid bacteria fermentation to sour the product, there are some important differences. In the traditional process the sorghum

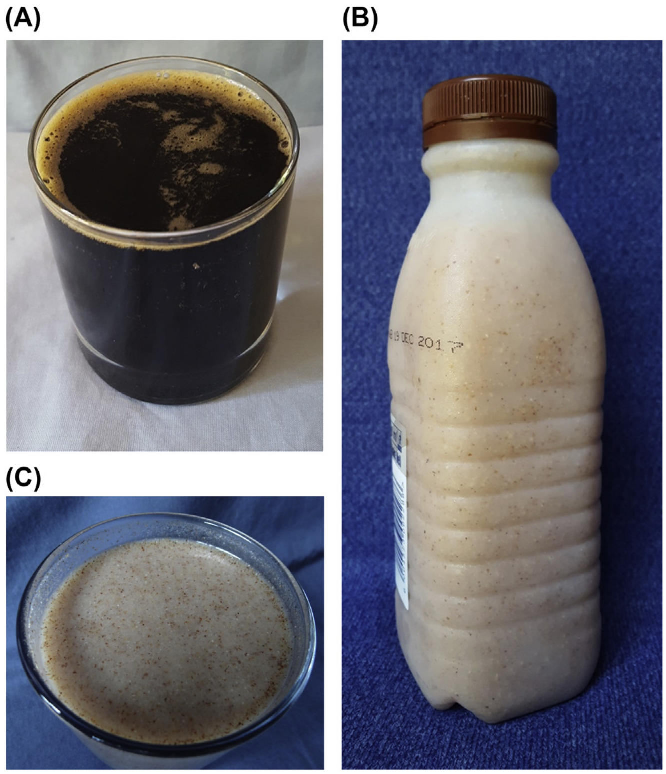

FIGURE 10.15 Sorghum beverages. (A) Nonalcoholic malt beverage. (B) Motoho—nonalcoholic soured starchy beverages. (C) starchy gruel-type nonalcoholic beverage.

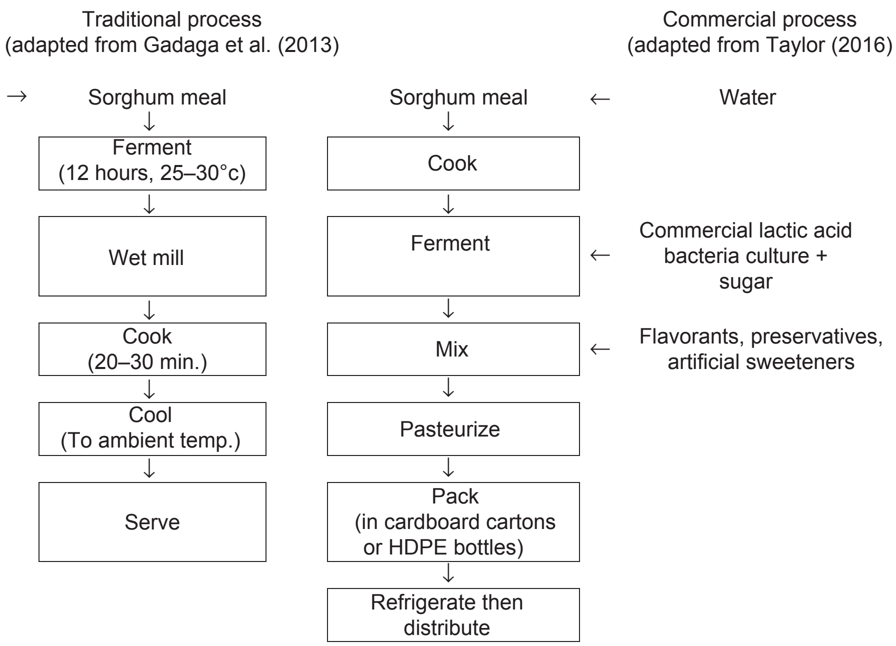

FIGURE 10.16 Comparison of the traditional and modern commercial motoho production processes.

meal is cooked first and then fermented with a traditional microbial culture. The traditional microbial culture is a mixture of different lactic acid bacteria and yeasts, and normally obtained by "back-slopping," that is, the use of a small portion of a previous successful fermentation. Cooking after fermentation means that the traditional motoho will only have a short life of 2–3 days at ambient temperature as it will be subject to further fermentation by spoilage bacteria. In contrast, in the modern commercial process the sorghum is cooked to sterilize it and then fermented with a specific commercial lactic acid bacteria strain. Chemical preservatives are invariably then added, plus other additives like artificial flavors and synthetic sweeteners. The motoho is then pasteurized and filled into plastic bottles (Fig. 10.15B). When stored under refrigeration, it will have a shelf-life of several weeks.

There are also many commercial product variations on the motoho theme. In Zimbabwe similar products are produced with sorghum malt and maize meal using a truncated version of the commercial opaque beer brewing process. Some of these products are nutritionally enriched with dairy ingredients such as milk powder or whey powder. This year (2018), in South Africa this concept has been taken further in a product that combines a traditional African cereal gruel with yoghurt.

4.3 Instant Powder-Based Beverages

For consumer convenience, there are also instant beverage powder products made from, or containing, sorghum. To prepare these beverages, the consumer simply stirs freshly boiled water or milk into the powder. These powder-type products can be classified into two types: starchy gruels and malted milk beverages.

4.3.1 Starchy Gruel Type

This type of product is loosely based on traditional African sorghum gruels like motoho. It is manufactured by pregelatinizing sorghum meal using technologies such as extrusion cooking, drum drying, or puffing. After which, the dried product is milled into a flour. Various ingredients are then incorporated, including sugar and artificial sweeteners, flavorants, and colorants (Fig. 10.15C). Commonly, fruit acid, for example, citric acid, is included to mimic the flavor imparted by the lactic acid fermentation in the traditional gruel. The products are generally also fortified with a range of vitamins and essential minerals.

4.3.2 Malted Milk Beverages

Malted milk beverages are popular products worldwide with trade names such as "Milo" and "Bournvita." In Nigeria malted milk powders are commonly produced with sorghum malt/malt extract in place of barley malt/malt extract (Ozuru et al., 2016). In addition to the malt, they contain a wide range of ingredients, normally including sugar, milk solids, and cocoa powder. They are also generally fortified with vitamins and minerals.

4.4 Nutritional Attributes

Table 10.9 shows the nutrient composition of various commercial African ready-to-consume nonalcoholic beverages made with sorghum. As can be seen, the beverages differ greatly in energy and macronutrient content. The differences in energy content are primarily due to the amount of water relative to solids in the products, which in the case of the powder-based products is solely a consequence of consumer preference when preparing the beverage. The differences in macronutrient content are also to some extent related to product water content and also to the ingredients used. For example, the nonalcoholic malt beverages are high in carbohydrates and sugars mainly as a consequence of them being made with malt and having a high level of sucrose added. In fact, the level of sugars in these nonalcoholic malt beverages is similar, if not higher, than in sugar-sweetened carbonated soft drinks.

Generally, as would be expected, the beverages are low in protein as they are cereal-based. However, compositing with milk solids or yoghurt improves their protein content (Table 10.9) and essential amino acid composition. The vitamin and mineral contents of the beverages are influenced very greatly by whether they are fortified. In fact, some micronutrients, notably, vitamins A and C, will be essentially absent in the beverages made from cereals only, such as the nonalcoholic malt beverages and the starchy gruels, unless they are fortified.

TABLE 10.9 Approximate Nutrient Composition of Nonalcoholic Sorghum-Containing Beverages (Values/100 mL)

Beverage Type	Energy (kJ)	Protein (g)	Total Carbs. (g)	Sugars (g)	Fat (g)	Dietary Fiber (g)	Vit A (IU)	Vit. B1 (mg)	Vit. B2 (mg)	Vit. B3 (mg)	Vit. B5 (mg)	Vit. B6 (mg)	Vit. C (mg)	Ca (mg)	Na (mg)
Malt beverage 1 (Nigeria)	243	0.3	14.0	11.0	0	–	–	0.18	0.18	2.4	0.62	0.25	0	–	0
Malt beverage 2 (Nigeria)	238	0.4	13.7	–	<0.1	–	247	0.15	0.15	2.0	0.52	0.21	2.52	34	–
Instant powder-based starchy gruel prepared with water (South Africa	217	1.1	10.8	3.5	0.4	0.9	20	0.03	0.03	0.4	0.12	–	4.50	30	47
Starchy gruel 1 (South Africa)	585	0.7	33.0	2.5	0.3	–	–	–	–	–	–	–	–	–	1
Starchy gruel 2 (South Africa	131	0.1	6.4	1.0	0.2	0.8	–	–	–	–	–	–	–	–	13
Maize–sorghum composite starchy gruel containing whey powder (Zimbabwe)	270	1.0	14.7	–	0.2	–	–	–	–	–	–	–	–	–	–
Cereal–yoghurt composite starchy gruel (South Africa)	193	1.4	8.0	4.0	1.1	<0.5	–	–	–	–	–	–	–	42	38
Malted milk beverage prepared with water (Nigeria)	150	0.9	8.3	4.5	0.4	0.8	63	0.02	0.02	2.5	0.15	–	4.50	90	–

IU, International Units; –, no data.

5. CONCLUSIONS AND FUTURE DIRECTIONS

Sorghum in particular and to a lesser extent, the millets and its processing coproducts are increasingly being used in value-added applications spanning food, beverages, pet food, and animal feed. This chapter has detailed innovative products ranging from snacks, breakfast cereal, food aid or nutritional intervention foods, gluten-free pasta, alcoholic and nonalcoholic beverages, dog and cat food, and aquatic feed. These applications span large-scale commercial production such as in the United States, medium-scale and small-scale food industry sectors as in Africa and India, and government or privately funded nonprofit initiatives as well. Cutting-edge research in these areas as well as the descriptions of processing technologies involved clearly underline the progress made in the last few years and the potential for the future. In the United States alone sorghum use in food and industrial applications has increased by 1.2 million metric tons in the 9-year period between 2008 and 2017, and the number of retail food products containing sorghum has been growing rapidly with the current total being more than 1000 (Sorghum Grower, 2018).

Sorghum and millets are increasingly important crops and ingredients for food companies as environmental sustainability aspects such as water usage, energy, and carbon footprint become a key focus (Fassl, 2018) and consumer demand for gluten-free and nutritious products continues to increase. Other key factors that will impact on the use of these crops in food applications in the coming years include novel process technologies, validated health claims, and value-chain development, keeping in mind that is smallholder farmers who grow the majority of sorghum and millets around the world. These aspects are discussed in more detail in the following.

5.1 Novel Technologies

A pressing need is for economical processing technologies which can improve the nutritional quality of sorghum and millet food products. Concerning improving protein quality, as described in Section 2.4, an interesting approach is to use extrusion cooking not just as a way of gelatinizing starch but at the same time to utilize it as an enzyme reaction vessel (De Mesa-Stonestreet et al., 2012).

With regard to starch itself, a novel technology that is being widely investigated to produce resistant starch (RS) is heat-moisture treatment. Heat-moisture treatment involves the heating of flours or starch under limiting moisture conditions with the aim of modifying the starch so that, for example, it will be resistant to hydrolysis by digestive amylases and hence have a low GI. With sorghum, Sun et al. (2014) found that heating sorghum starch or flour at 100°C at a 20%−25% moisture content in sealed vessels increased the temperature and enthalpy of gelatinization with a concomitant increase in starch crystallinity. Working with foxtail millet flour, Amadou et al. (2014) combined pre-fermentation by lactic acid bacteria with heat-moisture treatment. They observed a threefold increase in both slowly digestible starch (SDS) and RS in the flour, and an approx. 66% increase in PC. However, it should be noted that the flour dry matter loss as result of fermentation was not recorded.

In sorghum brewing, a seemingly intractable problem is that the starch gelatinization temperature of sorghum is too high to allow optimal simultaneous gelatinization and saccharification (hydrolysis of starch into fermentable sugars) by the malt amylases. At a temperature high enough to gelatinize the sorghum starch (around 75°C), the amylases are rapidly inactivated. The problem is compounded by the low β-amylase activity in sorghum malt (Table 10.8). A patented invention by Mulder (2014) apparently solves this problem through a process of continuous production of wort from mash. The process involves decoction-type mashing, whereby a portion of the mash containing the starch is separated and carefully heated to gelatinize the starch and then recombined with an aqueous malt enzyme suspension. The potential of this type of process in sorghum brewing has been explained previously in the Section 4.1.1.4. The invention, however, advances the technology much further as it also combines decoction into a complete continuous brewing process involving fermentation as well as mashing.

It has been noted that the processes of brewing and grain bioethanol production are remarkably similar, and that technological developments in the latter are being applied in brewing (Taylor and Taylor, 2018). One such development is simultaneous saccharification and fermentation (SSF). SSF comprises simultaneous enzymatic production of fermentable sugars and yeast alcoholic fermentation in the fermentation vessel. This obviates the need for a separate mashing step and its attendant vessels. Fermentable sugar production in SSF can be achieved either by simple addition of commercial amylase enzymes such as glucoamylase (amyloglucosidase), using immobilized enzymes (Dyartanti et al., 2015), or by the use of yeast strains that have high amylase activity (Ogata et al., 2017). An issue with the latter approach is that such yeast strains are currently invariably genetically modified. Using immobilized glucoamylase, Dyartanti et al. (2015) obtained an approximately 3% higher yield of ethanol in experimental sorghum grain bioethanol production using SSF than by simply adding the enzyme.

5.2 Validation of Health Claims

One of the reasons for the expanding demand by consumers for sorghum- and millet-based value-added products is increasing awareness of their health benefits. Researchers worldwide have generated a wealth of information on the nutritional and nutraceutical properties of millets and sorghum. Manufacturing companies are now aggressively marketing such value-added products, mostly based on the information available in the public domain, with health claims attributable to inclusion of sorghum and millets in their formulations. The health claims include gluten-free, high-fiber, prebiotic-rich, low-glycemic, antioxidant-rich cardiovascular disease and cancer-preventing, antiaging, and so on. However, each food product is prepared using different processing technology which may involve different ingredients, time—temperature combinations, steps such as malting or fermentation, different pressure and shear forces, and so on. The varying formulations and different processing conditions are known to alter both the nutritional and health-promoting attributes of the food products (for further detail, see Chapters 7 and 8). Hence, it is important that each sorghum- or millet-based food product be validated for their respective health claims and not to rely on health claims merely made based on the properties of the raw grains. The much-needed health claim validations for sorghum- and millet-based products can be achieved by fostering strategic collaborations between industry and academia. For small-scale entrepreneurs venturing into sorghum millet food—based business enterprises, appropriate support from business incubation centers having infrastructure and facilities for research, product development, and health claim validation is critical.

5.3 The Sorghum and Millet Value Chain in Emerging Countries

As stated, sorghum and millets are widely grown by smallholder farmers in the dryland areas of Africa and Asia. However, such farmers are least benefitted in the present crop production and utilization system as there is hardly any value addition to the produce provided by the farmer. This is attributable to the lack of access to basic primary food processing equipment and requisite scientific and technological expertise. The previously mentioned constraints deprive the smallholder farmers of the monetary benefits of value addition by food processing to meet the growing market demand for added-value sorghum and millet products. The inclusion of the smallholder farmers in the value chain can be achieved by compressing the "sorghum/millet value chain" by empowering farmers and rural communities with efficient food processing technologies and business skills. This will enable them to add value to their produce and thus gain additional income by shifting part of the profit component from the hands of the middlemen who currently purchase their grain to supply to large-scale processors. In order to ensure a sustainable value chain for sorghum and millets and to facilitate a revolution in the "sorghum and millet value chain," the smallholder farmers and the rural communities can be organized into cooperatives, and small- and medium-scale enterprises established in rural communities around sorghum- and millet-based products and technologies. To achieve this, an appropriate ecosystem needs to be established for incubation of sustainable business enterprises, coupled with promotion campaigns to increase awareness in consumers and policymakers of sorghum and millets as a healthy ingredient in food products. These steps will go a long way toward strengthening the sorghum and millet value chain in emerging countries.

Acknowledgments

The authors would like to acknowledge various funding sources that have supported the research described in this chapter. These include the United Sorghum Checkoff Program; Micronutrient Fortified Food Aid Products Pilot program funded by the Foreign Agricultural Service of the United States Department of Agriculture (contract number # FFE-621-2012/033-00); CGIAR Research Program on Dryland Cereals (2012—2016); and the Department of Science and Technology of the Government of India (grants INT/SL/12/P-001 and DST/INT/South Africa/P-14/2016).

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