OVERVIEW: IMPORTANCE OF SORGHUM IN AFRICA

J R N Taylor

Department of Food Science, University of Pretoria, Pretoria 0002, South Africa,
E-mail: jtaylor@postino.up.ac.za

In terms of tonnage, sorghum is Africa's second most important cereal. The continent produces about 20 million tonnes of sorghum per annum, about one-third of the world crop. However, these figures do not do justice to the importance of sorghum in Africa. It is the only viable food grain for many of the world's most food insecure people. Much of the African continent is characterized by semi-arid and sub-tropical climatic conditions. Africa is the only continent that straddles both tropics. Sorghum originated in Africa. It is uniquely adapted to Africa's climate, being both drought resistant and able to withstand periods of water-logging.

Sorghum in Africa is processed into a very wide variety of attractive and nutritious traditional foods, such as semi-leavened bread, couscous, dumplings and fermented and non-fermented porridges. It is the grain of choice for brewing traditional African beers. Sorghum is also the grain of 21st century Africa. New products such as instant soft porridge and malt extracts are great successes. In the competitive environment of multinational enterprises, sorghum has been proven to be the best alternative to barley for lager beer brewing.

The potential for sorghum to be the driver of economic development in Africa is enormous. Continuing focussed fundamental and applied research is essential to unleash sorghum's capacity to be the cornerstone of food security in Africa.

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is a cultivated tropical cereal grass. It is generally, although not universally, considered to have first been domesticated in North Africa, possibly in the Nile or Ethiopian regions as recently as 1000 BC[1]. The cultivation of sorghum played a crucial role in the spread of the Bantu (black) group of people across sub-Saharan Africa[2]. Today, sorghum is cultivated across the world in the warmer climatic areas. It is quantitatively the world's fifth largest most important cereal grain, after wheat, maize, rice and barley. In Africa, sorghum is still largely a subsistence food crop, but as this paper will show it is increasingly forming the foundation of successful food and beverage industries.

PRODUCTION AND AGRONOMIC ASPECTS

World annual sorghum production is over 60 million tonnes, of which Africa produces about 20 million tonnes[3]. This makes sorghum, quantitatively the second most important cereal grain in Africa after maize. Table I shows the major sorghum producing countries of Africa. It can be seen that sorghum production takes places across the continent, with the northern African countries of Nigeria, Sudan, Ethiopia and Burkina Faso accounting for nearly 70% of Africa's production.

Country	**Production (tonnes x 10^3)**
Nigeria	7 081 (33.8)[a]
Sudan	4 470 (21.4)
Ethiopia	1 538 (7.3)
Burkina Faso	1 372 (6.6)
Egypt	862 (4.1)
Tanzania	736 (3.5)
Niger	656 (3.1)
Mali	517 (2.5)
Chad	497 (2.4)
Cameroon	450 (2.1)
Uganda	423 (2.0)
Mozambique	314 (1.5)
Ghana	280 (1.3)
South Africa	211 (1.0)
Rwanda	175 (0.8)
Benin	165 (0.8)
Togo	141 (0.7)
Senegal	140 (0.7)
Kenya	133 (0.6)
Zimbabwe	103 (0.5)
Somalia	100 (0.5)

a Percentage of Africa's sorghum production

Table I Countries in Africa with an annual production of at least one hundred thousand tonnes of sorghum (2001 data)[3]

However, these figures do not do justice to the importance of sorghum in Africa. It is the only viable food grain crop for many of the world's most food insecure people, who live in sub-Saharan Africa. In the mid 1990s, it was estimated that in 20 of the 29 countries in the region per capita daily food intake averaged less than 2,000 calories[4]; according to the FAO a daily intake of less than 2,400 calories is indicative of widespread hunger. The problem of food shortage in sub-Saharan Africa is to a large extent due to the fact that much of the region is characterised by semi-arid and sub-tropical climatic conditions. Africa is the only continent that straddles both tropics.

Sorghum is crucially important to food security in Africa as it is uniquely drought resistant among cereals and can withstand periods of high temperature. A yield trial of 30 entries in Zimbabwe (28 sorghum genotypes and 2 maize hybrids) showed that under irrigation the maize hybrids ranked 11 and 22, whereas under drought conditions they ranked 28 and 30[5]. Sorghum comes into its own in areas where the

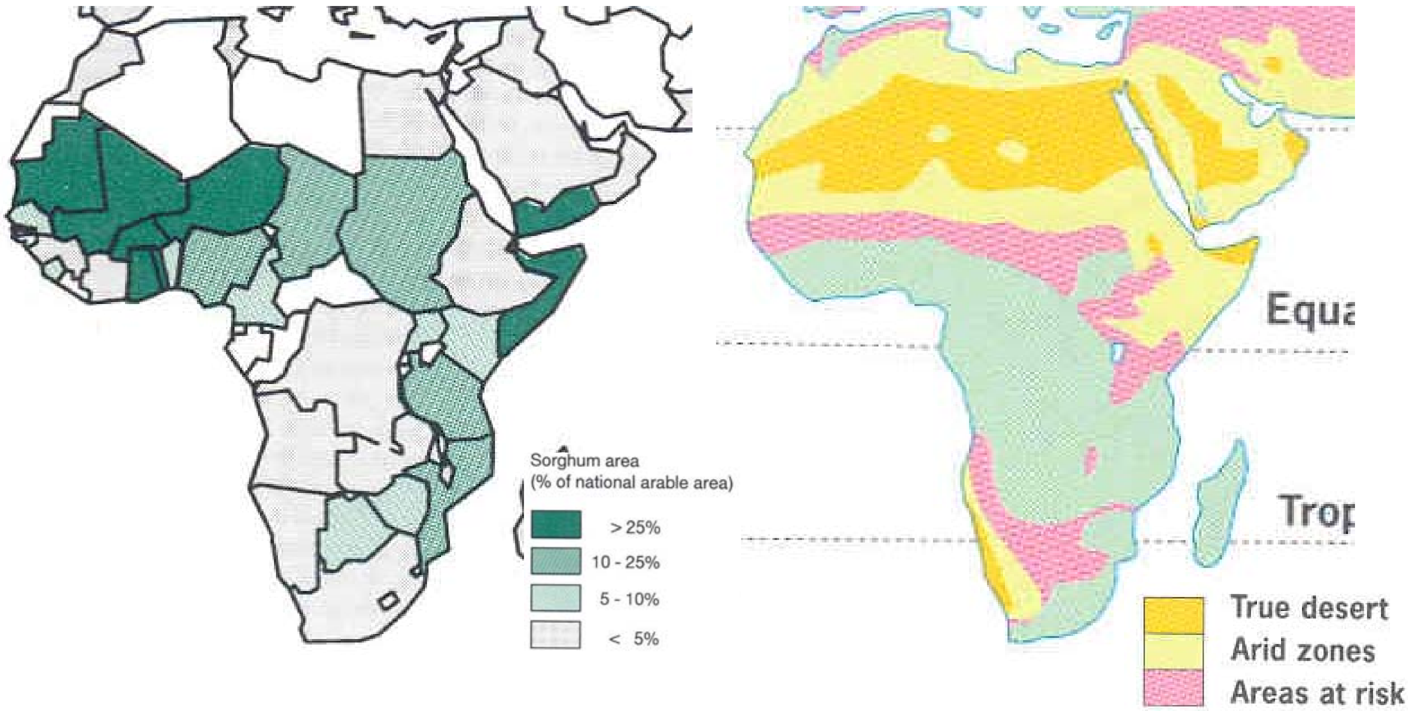

Figure 1 Relative importance of sorghum in African countries[10] and the continent's arid zones

annual rainfall is in the range 500-700 mm per year. Hence, most of the countries in Africa where sorghum is a significant arable crop are arid and areas at risk of desertification (Fig. 1). It also be seen that sorghum is also an important crop in east Africa where overall there is good rainfall. This is related to the fact that the rain in sub-tropical Africa is intermittent and characterised by brief periods of very high rainfall. In fact sorghum is not only drought-resistant, it can also withstand periods of water-logging[6]. In Kenya, trials during the short rainy season showed that an improved sorghum variety KAT 369 yielded 4.1 tonnes/ha in comparison to the 3.2 tonnes/ha for maize[4]. The precise reasons for sorghum's environmental tolerance are not fully understood, and are undoubtedly multifactorial. Sorghum often has very deep penetrating and extensive roots[7]. Apparently it conserves moisture by reducing transpiration when stressed by leaf rolling and closing stomata; higher than normal levels of epicuticular wax appear to be of importance in this respect[8]. Sorghum also appears to have a high capacity for osmotic adjustment to stress to maintain turgor pressure in cells[9]. Certain sorghum varieties also posses "stay green" genes that enable them to continue to photosynthesise, post-flowering during drought. Further research into the mechanisms of sorghum's environmental tolerance will clearly be highly beneficial.

Over the past 25 years sorghum production has increased steadily in Africa, from 11.6 million tonnes in 1976 to 20.9 million tonnes in 2001 (Fig. 2). However, as can be seen the increase in production has been as a result of increasing the land area under cultivation and there has been no overall improvement in yield. Average yields remain below 1 tonne/ha. This is because sorghum cultivation in Africa is still mainly characterised by traditional farming practices; with low inputs (no inorganic fertiliser or pesticides) and traditional varieties or landraces[10]. Such low yields mean that there is often no surplus sorghum, without which processing industries cannot be created.

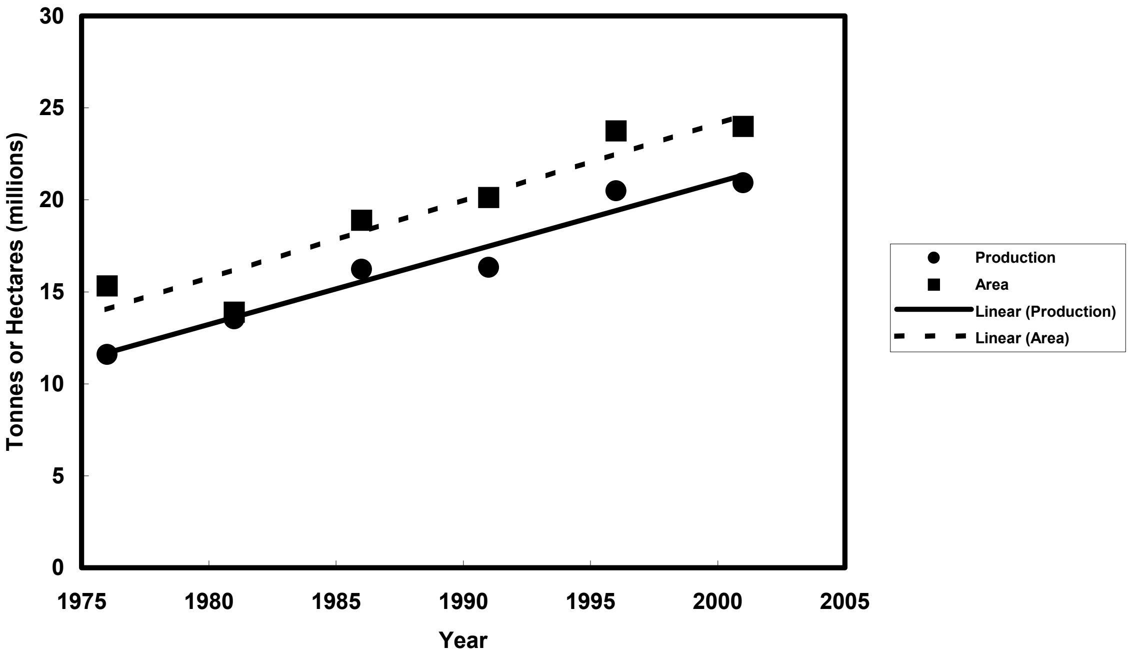

Figure 2 Sorghum production and yield trends in Africa, 1976 to 2001

However, where intensive agriculture is practised with improved varieties or hybrids, yields are much higher and comparable with other major cereals, for example in South Africa the average commercial yield in 2001 was 2.34 tonnes/ha compared to 2.49 tonnes/ha for maize[3].

Obviously continually increasing cultivation area is environmentally highly damaging and in the long-term unsustainable, and efforts must be intensified to improve sorghum agriculture in Africa. Higher yields are essential, not only for rural food security but also for increasing commercialisation.

SORGHUM GRAIN STRUCTURE AND CHEMISTRY

Structure

Except for its much smaller size and generally oval shape the structure of the sorghum grain (Fig. 3) is remarkably similar to that of maize. For example, both grains have both a horny and a floury endosperm and a large fat-rich germ. Neither grain has a true hull (husk), unlike for example barley or rice. This means that processing technologies such as methods of dry and wet milling applied to maize can and are applied to sorghum. One important aspect of sorghum grain structure is that the pericarp (outer bran layer) appears to be more friable than that of most other cereals. This is disadvantageous in dry milling as the flour can be become contaminated with bran. The friable nature of the sorghum pericarp is probably related to the fact that it, almost uniquely among cereals, contains starch granules (Fig. 3). Grain shape, the large germ, pericarp friability and the very variable proportion of horny to floury endosperm in grain are issues that need to be addressed in the selection of suitable sorghum types for dry milling. These factors also impact on sorghum dry milling technology (see under dry milling).

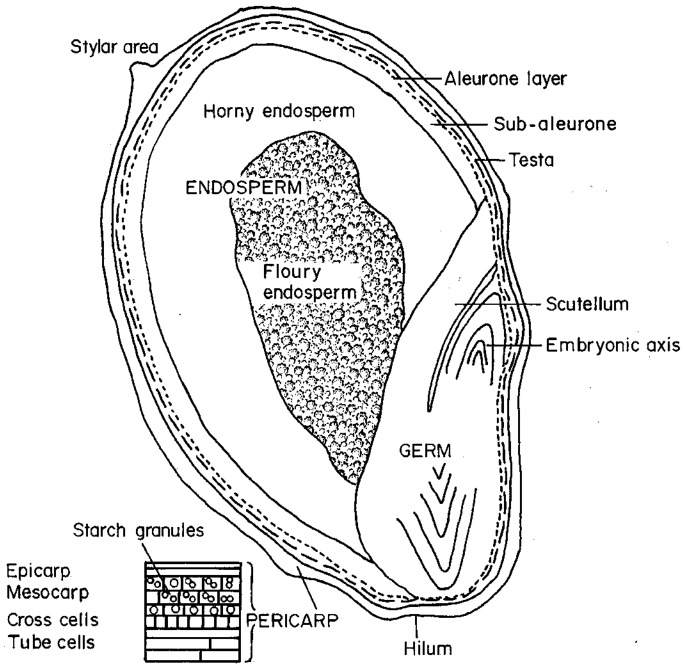

Figure 3 Diagrammatic section through the sorghum grain

The absence of a hull in sorghum grain was up until recently considered as a major problem with regard to using sorghum to brew lager and stout (clear) beers. This is because when brewing with barley malt, the hulls act a filter bed in lautering, the technology traditionally used to separate the wort (unfermented beer) from the spent grain. In the 1990s, this problem was solved with the development of tangential-flow mash filters with automatic discharge of spent grain[11]. Since then the commercial use of sorghum for clear beer brewing in Africa has become firmly established (see under lager beer).

Chemistry

Table II compares the significant chemical characteristics of sorghum grain with that of the other major cereals. Sorghum is essentially unique among the major cereals in that some (a minority of) varieties, the so-called "tannin", "bitter", "bird-proof", "bird-resistant" or "brown" types contain condensed tannins (reviewed by Serna-Saldivar and Rooney[12]). The condensed tannins, otherwise known as proanthocyanidins, are located in the testa (seed coat) and pericarp of the grain (Fig. 3). Tannins confer considerable agronomic advantages to these tannin sorghums. Bird-predation, a major problem in the bushveld areas of southern Africa, is reduced as the tannins are bitter. Further, the tannins protect these sorghums from insect and fungal attack. However, the drawback of the tannin sorghums is that the tannins can bind with the both the grain proteins[13] and with enzymes of the digestive tract[14], reducing the nutritional value of the grain. The tannins can also adversely affect the quality of malt made from high-tannin sorghum by reducing its enzymic activity[15].

All varieties of sorghum, like all other cereals, contain greater or lesser amounts of polyphenolic compounds. Many sorghums are pigmented by certain of these compounds: the anthocyanins, anthocyanidins and other flavonoids, which colour or stain the grains red, brown or purple (reviewed by Serna-Saldivar and Rooney[12]). The pigments are concentrated in the pericarp and/or in the glumes (modified leaves partially enclosing the grain), but may extend into the endosperm. These pigments can colour sorghum food products. However, recently attention has been drawn to the possibility that such polyphenolic compounds have beneficial "functional" anti-oxidant properties[16].

The endosperm cell wall, non-starch polysaccharides of sorghum are rich in the water-unextractable "water-insoluble" glucuronoarabinoxylans[17]; in contrast to the cell walls of barley, which are mainly of the "water-soluble" β-glucan type and those of wheat, which are "water-soluble and insoluble" arabinoxylans. These differences may have importance consequences when sorghum is used in brewing[17] and in bread making[18]. Sorghum proteins, like those of all cereals except wheat, do not have the ability to form a gas-holding, visco-elastic dough. However, leavened bread-type products have traditionally been produced in Africa using sorghum and newer developments enable the production of conventional bread with sorghum (see under injera).

Sorghum	Other cereals
Some varieties contain condensed tannins	Not present in wheat, rice and maize, perhaps very low levels in barley
All varieties contain greater or lesser amounts of polyphenols	Present in wheat, rice, maize and barley, but generally in lower amounts
Many varieties highly pigmented	Some varieties of wheat, rice, maize and barley also highly pigmented
High starch gelatinization temperature	Rice starch the same temp Maize starch slightly lower, wheat and barley starch considerably lower
Endosperm non-starch polysaccharides predominantly insoluble	Rice and maize the same Barley rich in soluble non-starch polysaccharides Wheat contains both insoluble and soluble types
Endosperm protein rather inert	Maize protein similar Rice and barley protein somewhat less inert Wheat protein will form visco-elastic dough
Protein quality poor, deficient in lysine	Maize, barley and wheat similar Rice protein quality is better
Protein digestibility reduced after wet cooking	Rice similar? Wheat, maize and barley protein digestibility reduced to a lesser extent
Fat content quite high	Maize even higher Wheat and barley low Rice very low
Malt contains low levels of ß-amylase	Maize similar Rice higher Wheat and barley high levels

Table II Sorghum grain chemistry compared to wheat, rice maize and barley.

The protein of sorghum, like most other cereals, is deficient in the essential amino acid lysine. A further protein quality problem, in this case apparently unique to sorghum (and possibly rice), is that the digestibility (and hence nutritional value) of sorghum protein is significantly reduced when the grain is wet cooked during food processing[19], as in the making of the African staple food, porridge. As a consequence, the mechanisms responsible have been the subject of considerable research (reviewed by Duodu *et al.*[20]) and improvement in the protein quality of sorghum food products is discussed in many of the Afripro workshop papers and posters.

Sorghum malt, unlike barley malt, contains low levels of ß-amylase[21], the enzyme that sequentially cleaves maltose units from the non-reducing end of starch molecules. Since the production of maltose, a fermentable sugar, is an important aspect of the brewing process, modifications to the mashing process can be required for sorghum malt (see under malt extract).

Bearing in mind the particular characteristics of sorghum grain, the processing of sorghum into foods and beverages will now be examined.

DRY MILLING

The production of virtually all sorghum foods involves first milling the grain. Sorghum milling generally involves two operations: 1) Debranning - removal of the unpalatable, sometimes tannin-rich and highly pigmented bran and the rancidity causing fat-rich germ, 2) Reducing the endosperm into a meal or flour. Traditionally, in Africa sorghum milling has been done using a pestle and mortar. Today, mechanised milling is becoming the norm, creating a milling industry and the opportunity for manufacture of more sophisticated sorghum food products.

Debranning

Probably the most common method of mechanised sorghum milling in Africa is by abrasive debranning (also known as decortication or dehulling), followed by hammer milling of the endosperm material. A very popular type of dehulling machine is the PRL (Prairie Research Laboratory) dehuller (Fig. 4). This dehuller was first developed in Canada, hence the name. The PRL dehuller comprises a horizontal barrel containing some 13 evenly spaced carborundum disks (25 cm diam., 2.1 cm wide) that rotate clockwise against the grains at approx. 2,000 rpm[22]. Power is provided by an electric motor, diesel or petrol engine. Sorghum grain (5-25 kg) is fed into the barrel by means of a hopper fitted with a flow regulator. The bran and germ are progressively abraded off and removed by means of a fan.

PRL-type dehullers are now manufactured commercially in Botswana, South Africa and Zimbabwe, with more than 200 in use in southern Africa. Their manufacture has created a significant industry. But more importantly, in for example Botswana, rural sorghum mills have contributed greatly to improving food security by eliminating the drudgery of hand-pounding, growing the market for farmers to sell their sorghum and by creating milling enterprises[22].

Drawbacks of the PRL dehuller for industrial milling are that the batch size is rather small and milling losses can be very high, up to 30%. A recent major innovation that addresses these problems is the development in South Africa of small roller mills for milling coarse grains such as sorghum. These small roller mills consist of 2 or 3 pairs of rollers, plus a vibrating screen sieving device to remove the bran from the flour. Typically such mills have a capacity of 500 kg/hour. The top pair of rollers are coarse fluted “break” rolls, the second pair are finer break rolls and the third pair (if present) are smooth “reduction” rolls. Research has shown that with moderate pre-conditioning (to 16% moisture), milling with such a roller mill can consistently produce sorghum meal of higher extraction, and slightly lower ash and fat content compared to debranning and hammer milling[23]. This type of roller mill is being widely adopted across Africa. Notwithstanding this, there is still scope for improving the efficiency of sorghum milling, especially large-scale commercial milling.

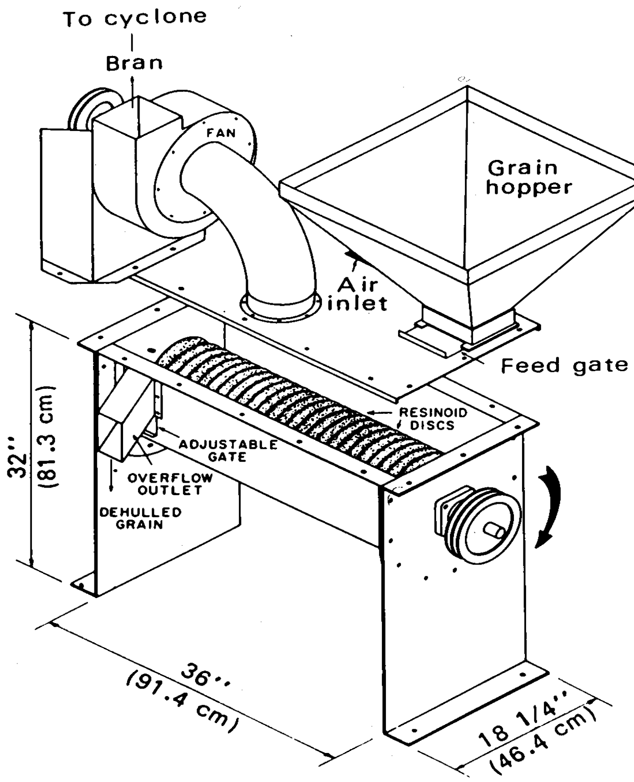

Figure 4 Exploded view of a PRL dehuller

Roller milling

Drawbacks of the PRL dehuller for industrial milling are that the batch size is rather small and milling losses can be very high, up to 30%. A recent major innovation that addresses these problems is the development in South Africa of small roller mills for milling coarse grains such as sorghum. These small roller mills consist of 2 or 3 pairs of rollers, plus a vibrating screen sieving device to remove the bran from the flour. Typically such mills have a capacity of 500 kg/hour. The top pair of rollers are coarse fluted "break" rolls, the second pair are finer break rolls and the third pair (if present) are smooth "reduction" rolls. Research has shown that with moderate pre-conditioning (to 16% moisture), milling with such a roller mill can consistently produce sorghum meal of higher extraction, and slightly lower ash and fat content compared to debranning and hammer milling[23]. This type of roller mill is being widely adopted across Africa. Notwithstanding this, there is still scope for improving the efficiency of sorghum milling, especially large-scale commercial milling.

TRADITIONAL SORGHUM FOODS AND BEVERAGES

The importance of sorghum in Africa can be adjudged from the fact that there is an almost bewildering variety of African traditional sorghum foods and beverages. These include: whole grain rice-type products, breads and pancakes, dumplings and couscous, porridges, gruels, opaque and cloudy beers, and non-alcoholic fermented beverages (reviewed by Murty and Kumar[24], Rooney and Waniska[25] and Taylor and Dewar[26]).

Fermented foods and beverages

A characteristic of many African sorghum foods and beverages is that as part of their production they undergo a lactic acid fermentation by lactic acid bacteria, generally of the genus *Lactobacilli*. These so-called "fermented foods" are appetisingly sour in taste. The fermentation is also of critical importance with regard to the shelf-life and safety of food in Africa. The production of lactic acid lowers the pH of the food, which slows down or prevents its spoilage by other microorganisms and renders the food safe from the growth of pathogens[27]. Still today in Africa most people do not have access to modern food preservation methods, such as refrigeration, and sadly many do not even have a ready source of safe drinking water. In fact, the World Health Organization estimates that annually there are some 1,500 million episodes of diarrhoea worldwide in children under five and over 3 million children die as a direct result[27].

Apart from the food safety issue, many other nutritional advantages of lactic acid fermentation have been found, or claimed. Fermentation has been found to increase *in vitro* carbohydrate availability[28] and starch digestibility[29]. Similarly sorghum protein *in vitro* digestibility is improved by fermentation[19,28,30]. Concerning micronutrients, there is some evidence that B vitamins, particularly thiamine, are increased when sorghum is fermented[28]. Although fermentation does not change the quantity of minerals, there is probably some improvement in their availability since the quantity of phytate (myoinositol hexaphosphate), a powerful chelator of divalent metal ions present in sorghum and other cereals, is substantially reduced by fermentation[31].

Two fermented food and beverage products, injera and sorghum beer, will be used to illustrate the importance and potential of traditional sorghum foods in Africa.

Injera

Injera, a large circular, fermented pancake-like bread, is the staple food of Ethiopia. Injera is produced from an number of cereal flours, but primarily tef and sorghum, either singly or in combination. What is interesting is that despite the fact that neither

of these grains contain gluten, injera is a leavened bread with a attractive spongy texture. To make sorghum injera (Fig. 5) the grain is first debranned then ground into a fine flour using a disk mill. The flour is mixed with water in an approx. 50:50 ratio and kneaded to form a dough. Starter culture from a previous fermentation is added to initiate fermentation. The dough is covered and allowed to stand for 2-3 days. A portion of the dough, about 5%, is mixed with water. This slurry is added and cooked to make a gruel. This is the key to the injera process. The gruel, which contains gelatinised starch, acts as a binder providing viscosity and thus allowing some gas holding during fermentation. The warm gruel is then added back to the dough and thoroughly mixed. Water is then added to make a batter, which is allowed to stand for 2-3 hours. The batter foams greatly. Lactic acid bacteria appear to be primarily responsible for the fermentation[32]. When the foam collapses the batter is spread on a hot griddle and baked covered. Good injera is so flexible that it can be folded or rolled.
In 21st century Africa there is a rapid growth in many “modern-type”fast foods, including flatbreads and “wraps”, containing fillings. Injera has huge potential for commercialisation in this market. In addition, the technology of gelatinising part of the flour to make a viscous batter, the so-called “custard” process has also successfully been applied to make conventional leavened pan bread from sorghum[33]. This technology also has considerable potential where the use of wheat is uneconomic.

Sorghum beer

Throughout sub-Saharan Africa, sorghum is the grain of choice to produce traditional cloudy and opaque (sorghum) beers. The key ingredient of these beers is sorghum malt, which provides hydrolytic enzymes (especially amylases to ferment sugars into ethanol and carbon dioxide), starch (the source of fermentable sugars), yeast nutrients and beer flavour and colour substances.

Sorghum malting

In southern Africa, malting sorghum for opaque beer brewing has developed into a large scale commercial industry with some 150,000 tonnes of sorghum being commercially malted annually. This figure includes a small amount of sorghum malted for the production of a sorghum malt breakfast cereal “Maltabela”. Sorghum is also malted commercially on a large scale in Nigeria for the production of lager beer and stout and for non-alcoholic malt-based beverages (see under malt beverages).

In the countries of Africa where sorghum is malted commercially, the respective agricultural departments and commercial breeders breed sorghum cultivars with good malting quality for brewing. The primary quality criterion is their potential to produce malt with high diastatic power (amylase activity).

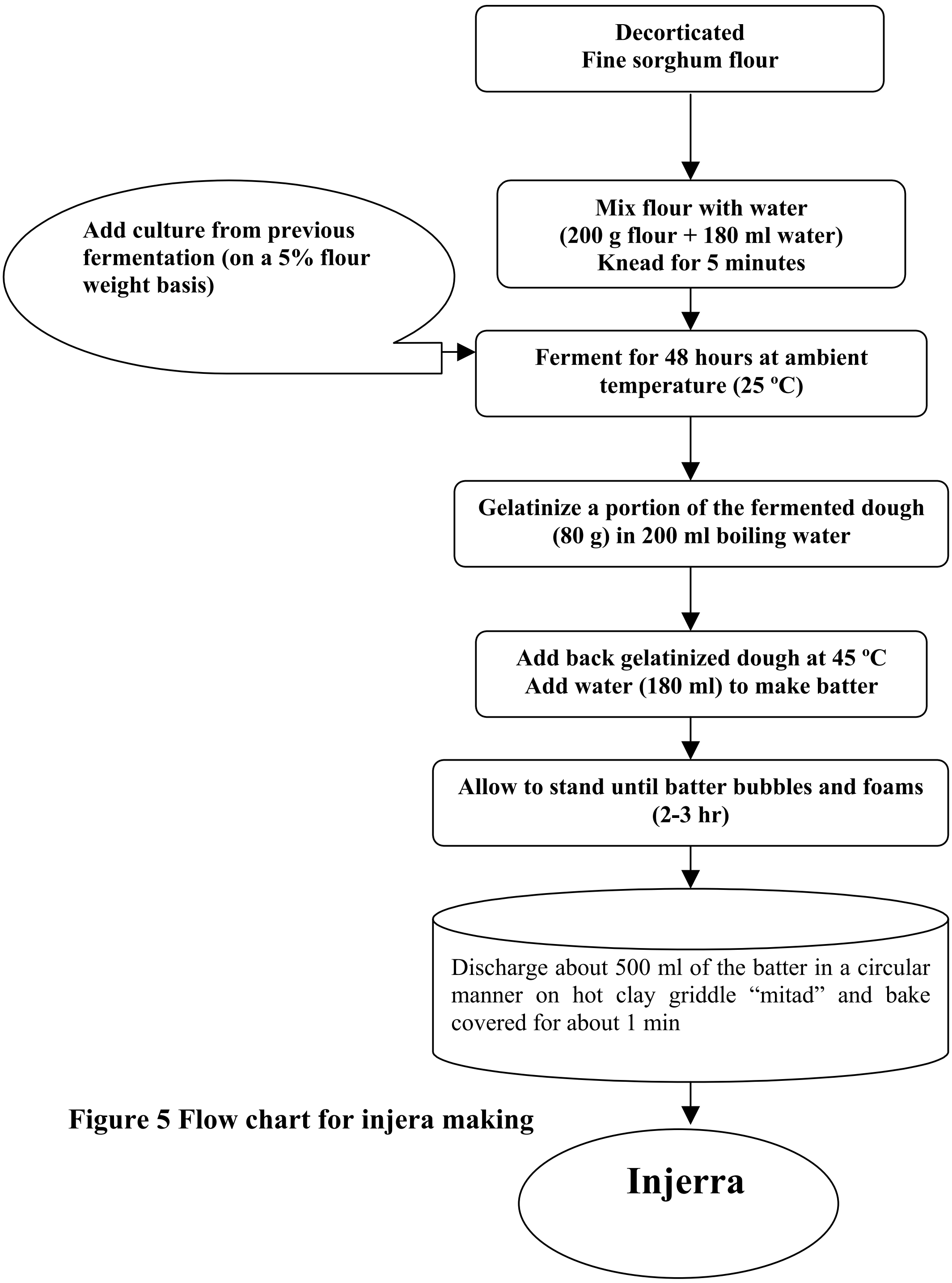

Figure 5 Flow chart for injera making

The sorghum malting process, both traditional and modern commercial, is split into three unit operations: steeping, germination, and drying (reviewed by Taylor and Dewar[26,34]).

Steeping involves immersing the grain in water until it has imbibed sufficient water to initiate the metabolic processes of germination. Steeping also serves two other functions: Dirt, chaff and broken kernels are removed from the grain by washing and flotation. The steeping step is often also used to inactivate the tannins in tannin sorghum varieties. If not inactivated the tannins bind with the malt amylase enzymes, resulting in reduced sugar production[15]. A process of inactivating the tannins by soaking sorghum grain for a 4-6 hour period at the beginning of steeping in a very dilute solution of formaldehyde is widely used. However, in recent years the use of formaldehyde has not been viewed favourably because of its potential health risk. Alternative methods of inactivating tannins are now being introduced. Steeping the grain in dilute alkali (sodium hydroxide) seems to be a safer and almost equally effective method[35,36] and is now used commercially in Nigeria.

Germination involves seedling growth in warm water-saturated air. The germination step in sorghum malting is carried out in two alternate ways: floor malting and pneumatic malting. Figure 6 shows commercial floor and pneumatic maltings in southern Africa. In floor malting the steeped grain is spread out on a concrete floor, normally outdoors, in a layer between 10-30 cm deep. The germinating grain may be covered with sacking or shade cloth to reduce moisture loss. The grain is watered at intervals with a hosepipe (or by the rain). In South Africa, nearly 100,000 tonnes of

A

B

Figure 6 Industrial sorghum maltings in southern Africa. A) Outdoor floor maltings, B) Pneumatic maltings

Pneumatic maltings are used to produce sorghum malt for industrial brewing. They comprise rectangular or circular chambers of 1-1.5 m deep by up to 100 m long. The germinating grain rests on a slotted, steel false floor, below which is a plenum (chamber). The grain is aerated by means of fans blowing air through the plenum and hence up through the bed of malt. At intervals during germination the grain is watered by spraying and turned by means of helical screws which transverse the chamber. Turning prevents matting of the grain and consequently facilitates an even flow of air through the malt bed. Pneumatic sorghum maltings are in operation in South Africa, Zimbabwe and Nigeria.

Drying involves reducing the moisture content of the green (moist) sorghum malt to around 10% to produce a shelf-stable product. Drying is generally carried out in box with a perforated floor, similar to the germination box only rather deeper. Warm dry air is blown through the green malt. The air temperature should not be more than 50°C, as higher temperatures significantly reduce the amylase activity of the malt. In some outdoor floor maltings the malt is sun-dried by spreading the grain out in thin layer and turning it periodically.

Sorghum beer brewing

Large-scale commercial "opaque beer" brewing now takes place in many countries in southern, central and eastern Africa. It is one of the few examples of industrialisation of a traditional African product. However, only in South Africa, Zimbabwe, Botswana, Namibia and Swaziland is brewing carried out in the traditional way using sorghum malt. In other countries food-grade industrial enzymes are used as the source of hydrolytic enzymes. The cereal used in these other countries is essentially maize grain only, with possibly a little sorghum or millet for flavour and colour, hence the generic name opaque beer. Total opaque beer production in southern and eastern Africa is around 1,700 million litres per year. It should be noted, however, that perhaps at least twice this volume of beer is home-brewed using commercially manufactured sorghum malt. In some countries, notably Botswana, industrial sorghum beer production has been growing rapidly at around 5% per year. However, in others, notably South Africa, there is strong evidence that as consumers become more affluent they drink lager beer in preference to sorghum beer.

A modern, efficient sorghum beer brewing process, the split sour, double-cook process (Fig. 7) will be described. It should be noted that there are considerable variations in processes accordingly regional beer tastes and the equipment available in a particular brewery (reviewed by Daiber and Taylor[37]).

The lactic acid fermentation known as souring is an integral part of this brewing process. Souring involves incubating an 8-10% slurry of sorghum malt at a strictly controlled temperature of 48-50°C for a period up to a two days. The lactic acid bacteria culture is maintained by back-slopping.

Adjunct cooking involves boiling a slurry of cereal for 1.5-3 hours at atmospheric pressure, or for a rather shorter time under pressure. These long periods both gelatinise and solubilise the starch. A portion of the sour is cooked together with the adjunct and a second portion is added during mashing; hence the name "split sour". The first portion of sour lowers the pH of the mash to around 4.5, close to the optimum for the sorghum malt amylases.

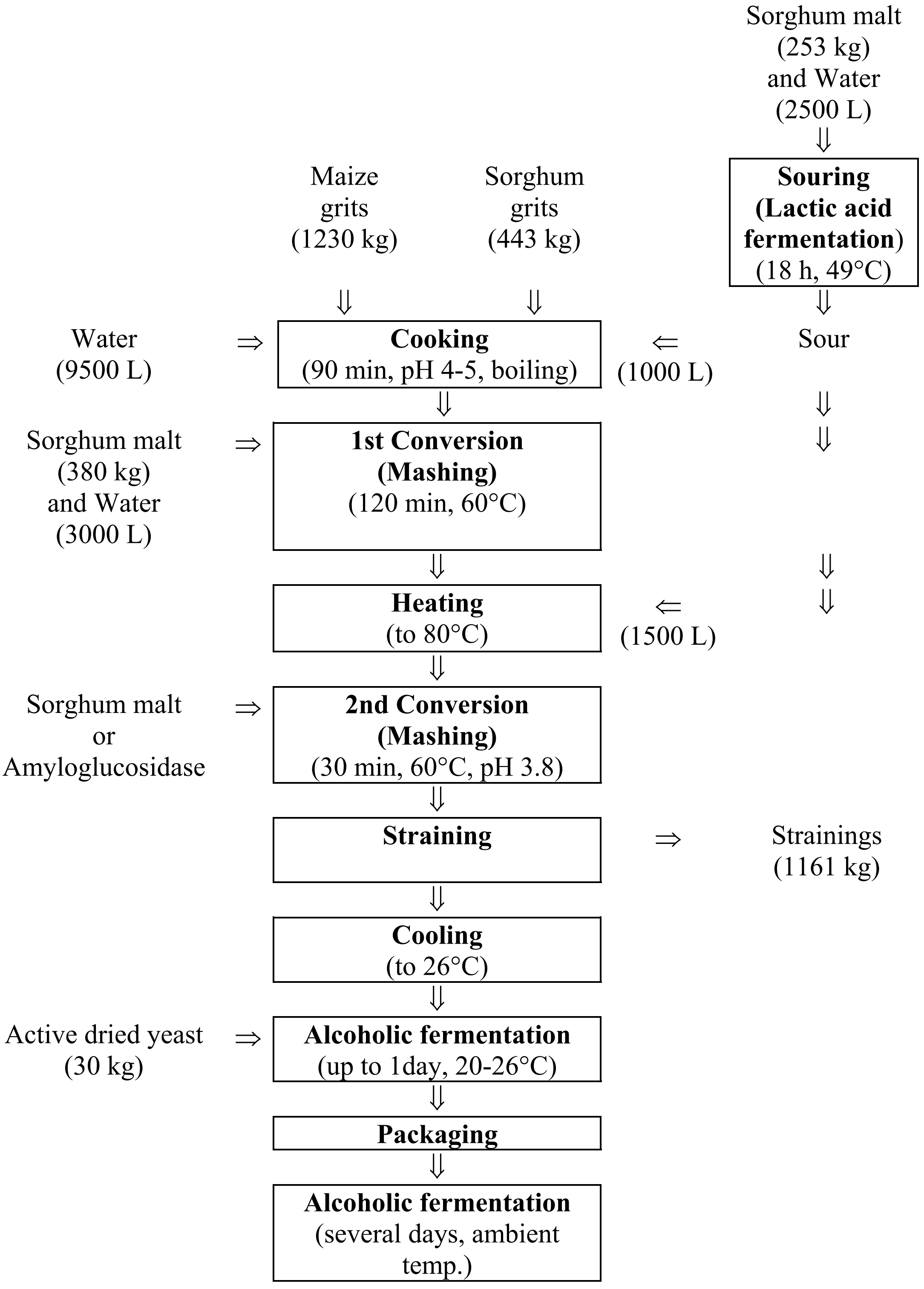

Figure 7 Split sour, double-cook industrial sorghum beer brewing process

The cereal mash is then cooled to 55-60°C using plate or tubular heat exchangers. Mashing or as it is known in opaque beer brewing, “conversion” is then carried out. A quantity of conversion malt (about 25% of the cereal adjunct) is added. Conversion is at constant temperature for approximately 1.5 hours. Mashing aims to solubilise and enzymatically hydrolyse the cereal to create a fermentable wort.

At the end of mashing period, the second portion of sour is added to bring the pH to the desired pH of the beer, around pH 3.8. The whole mash is then cooked again, hence the name “double cook”. The second cook gelatinises all the conversion malt and second sour starch. This step greatly improves the efficiency of the process. To obtain the desired viscosity a short mashing period of about 15 minutes at around 60°C is performed after cooking. A small quantity of malt or industrial amylase is added to thin the mash.

The spent grain is removed by a process known as straining. The mash is strained at elevated temperature using high-speed centrifugal decanters. Decanters separate primarily on the basis of gravity and remove insoluble material such as raw starch insoluble protein, and fibre. After decanting, the wort is invariably passed through fine vibrating screen to remove coarse material of low density such as malt pericarp.

The wort is then cooled to 30°C by heat exchange and pitched with active dried yeast. The pitched wort is then either fermented in bulk for draught sale or packaged into containers. A wide range of sizes of containers are used, from 1 to 20 L, and differing in type from non-returnable cardboard cartons and low-density polyethylene bottles, to returnable high-density polyethylene bottles and drums. What all the containers have in common is that they have small slits or vents in the top to allow the escape of carbon dioxide from the actively fermenting beer. Opaque beer is distributed and consumed while actively fermenting.

NOVEL AND NON-TRADITIONAL SORGHUM PRODUCTS

Sorghum is not just a grain of tradition in Africa, it is also increasingly the key ingredient in highly successful novel and non-traditional food and beverage products. Three examples will be described: instant soft porridge, malt beverages and lager beer with reference to the technologies involved and the economic significance of these developments.

Sorghum instant soft porridge

Morvite, a product of King Food in South Africa (part of the Tiger Foods group) is pre-cooked sorghum with added vitamins (hence the name), plus citric acid, sugar and other sweeteners. It is a dry powder to which one simply adds either hot or cold water or milk to make an instant breakfast porridge or beverage. One hundred grams of Morvite makes a substantial contribution to the recommended dietary allowance (RDA) for protein, vitamins A, B, C, D and E, and minerals such as calcium, phosphorus, iron and iodine.

Morvite was originally developed as an easy to prepare and consume mid-shift nutrient supplement for miners. Latterly it has been adopted by provincial governments in South Africa for school meals. Perhaps most interestingly, Morvite has found a place on the supermarket shelves. Since 2000 production has increased by 20% and is now running at about 12,000 tonnes a year, between 15 and 20% of South Africa's entire commercial sorghum milling production. Morvite is such a success that King Food is investing in additional manufacturing capacity and is bringing out flavoured varieties.

An instant sorghum porridge like Morvite is relatively simple to manufacture. In addition to the normal dehulling and milling machines, it requires equipment for dry cooking, such as an extrusion cooker or gun puffer and a ribbon blender to mix the dry ingredients. On account of its ease of manufacture Morvite sells in the supermarket at about half the price of oat porridge and a third that of cornflakes. Hence, this type of added value sorghum product is an attractive choice for both manufacturer and consumer.

Malt beverages

In Nigeria, a wide variety of non-alcoholic malt beverages are very popular. These include both bottled "brewed" non-alcoholic malt drinks such as "Malta" products of the Guinness and Heineken companies and hot, malt and cocoa, powder-based drinks such as "Milo", a Nestlé product. Traditionally these products are produced using barley malt extract. Malt extract is a sweet, sugar-rich wort (unfermented beer), which can be concentrated by evaporation to a dark-coloured, richly flavoured syrup or dry powder. In 1988 the Nigerian government banned the importation of barley and other cereals, to save foreign exchange. This forced food and beverage manufacturers to develop local cereal alternatives Suitable sorghum cultivars, such as the white Farafara for beer brewing and yellow Short Kowrie for malt beverages have been selected and now cultivated on large scale. Sorghum malting in Nigeria has now become a major industry both for both lager and stout beer brewing and for malt beverage manufacture, with approximately 15,000 tonnes of sorghum being malted annually.

To completely gelatinise and solubilise the starch and to conserve the ß-amylase activity of the sorghum malt, which as stated is rather low, special mashing processes have been developed[38,39]. These are based on the principle of decoction, whereby a portion of the mash containing the starch is removed, cooked to gelatinise the starch and then added back to the rest of the mash to be enzymatically hydrolysed into sugars. Decoction may be carried out in a single step, or in a number of steps of progressively increasing temperature. The latter method provides more optimum conditions for the different malt enzymes. Technologies have also been developed to roast sorghum malt for malt beverages to produce the required colour and a complex, nutty, sweet "chocolate" aroma, characteristic of barley malt[40].

Despite the fact that the ban on cereal importation has long since been rescinded local sorghum has become the grain of choice in Nigeria for both beer brewing and malt beverage manufacture. These developments have benefited local farmers and led to industrial development, as well as saving the cost of unnecessary imports.

Lager beer

As described, sorghum brewing in Nigeria started out of necessity. However, because of its cost-effectiveness and unique properties, sorghum is starting be used for lager brewing elsewhere in Africa. The South African Breweries-Miller group, which runs many breweries throughout Africa, has after much development work begun commercial brewing of sorghum lager beer in Uganda. The Uganda story will be described as it is anticipated that it will serve as a model for similar schemes in other African countries where barley is uneconomic. Development of local commercial sorghum farming is a major aim.

The project began in 2001 with selection of a suitable local variety for brewing[41]. Epuripur, a tannin-free, corneous endosperm, white-grained variety was selected. Epuripur was developed by the Serere Animal and Agricultural Research Institute in Uganda and first released in 1995. It has a yield potential of 2.5-3.0 tonnes/hectare. In January 2002 seed multiplication started. The sorghum is now being grown in the Soriti and Kumi districts, areas that previously grew cotton but have for many years been without a cash crop. Farmers growing this sorghum variety under contract for Nile Breweries can expect a good guaranteed price of US $150/tonne. It is anticipated that any surpluses will be readily sold to food aid organisations such the World Food Programme, as Epuripur is a high quality food grade sorghum. Interest from farmers has been almost overwhelming, with applications from every area in Uganda from nearly 1000 farmers or farmer groups.

Although the details of the brewing process are secret, it is known that sorghum grain (not malt) with conversion with industrial enzymes is used. What is particularly interesting is that sorghum was selected, rather than maize, because it was found that there was not a fat rancidity problem with sorghum. The beer, which is called Eagle Lager, was launched in January 2003 and so far sales are exceeding all predictions. It is anticipated that the annual requirement for sorghum will shortly be around 3,000 tonnes a year.

It is clear that brewing lager beer with sorghum in this way can result in a quality product, which is much more affordable than beer brewed with barley malt. Increased demand resulting from affordability will lead to greater requirement for sorghum bringing direct benefit to local farmers.

CONCLUDING REMARKS

Today, the imperative for sorghum to become Africa's primary food grain has never been greater. In 2002 there was drought in many countries of sub-Saharan Africa. Southern Africa is facing its worst food crisis since the early 1990s. There are widespread food shortages in the region with half a million households vulnerable to famine[3]. North of the Equator, in Ethiopia for example, 15 million people, about a quarter of the country's population, are food insecure[42]. As seen, the potential for sorghum to be the driver of economic development in Africa is enormous.

Continuing focussed fundamental and applied research is essential to unleash sorghum's capacity to be the cornerstone of food security in Africa. Proteins, as they are the primary expression of the genetic code and fundamental to the metabolic processes of the plant, and because they are of major functional and nutritional importance in foods, should be at the core of this research.

REFERENCES

1. Kimber, C.T. Origins of domesticated sorghum and its early diffusion into India and China. In 'Sorghum: Origin, History, Technology, and Production', (C. Wayne Smith and R.A. Frederiksen, eds), John Wiley & Sons, New York (2000) pp 3-98.
2. Diamond, J. Guns, Germs and Steel, Vintage', London (1998).
3. Food and Agriculture Organization of the United Nations. www.fao.org 20 February (2003).
4. International Crops Research Institute for the Semi-Arid Tropics. ICRISAT Now: Sowing for the Future, ICRISAT, Patancheru, India (1994).
5. Osmanzai, M. Sorghum response to water deficit. In: 'SADC/ICRISAT Southern Africa Programs: Annual Report 1992', ICRISAT, Bulawayo, Zimbabwe (1992) p 8.
6. Doggett, H. Sorghum, 2nd Ed, Longman Scientific & Technical, Harlow, UK (1988).
7. National Research Council. Lost Crops of Africa, Vol 1, Grains, National Academy Press, Washington, D.C. (1996).
8. Jordan, W.R. and Sullivan, C.Y. Reaction and resistance of grain sorghum to heat and drought. In 'Sorghum in the Eighties, Vol 1,' (J.V. Mertin, ed), ICRISAT, Patancheru, India (1982), pp 131-142.
9. Nguyen, H.T., Xu, W., Rosenow, D.T, Mullet, J.E. and McIntyre. Use of biotechnology in sorghum drought resistant breeding, part A. In 'Proceedings of the International Conference on the Genetic Improvement of Sorghum and Pearl Millet,' Lubbock, USA, INTSORMIL and ICRISAT (1997) pp 412-424.
10. International Crops Research Institute for the Semi-Arid Tropics and Food and Agriculture Organization of the United Nations. The World Sorghum and Millet Economies, ICRISAT, Patancheru, India and FAO, Rome (1996).
11. Hermia, J. and Rahier, G. The 2001 mash filter: A new technology for sweet wort production. *Ferment* **5** (1992) 280-286.
12. Serna-Saldivar, S. and Rooney, L.W. Structure and chemistry of sorghum and millets. In 'Sorghum and Millets: Chemistry and Technology', (D.A.V. Dendy, ed), American Association of Cereal Chemists, St. Paul, USA (1995) pp 69-124.
13. Emmambux, M.N. and Taylor, J.R.N. Sorghum kafirin interaction with various phenolic compounds. *Journal of the Science of Food and Agriculture* (2003) in press.
14. Price, M.L. and Butler, L.G. Tannins and Nutrition, Station Bulletin No. 72, Purdue University Agricultural Station, USA (1980).
15. Daiber, K.H. Treatment of cereal grain, South African Patent 7514957 (1975).
16. Armad·, R., Andersson, H., Bardocz, S. and Serra F. 'Polyphenols in Food,' Office for Official Publications of the European Communities, Brussels (1998).
17. Verbruggen, M.A. Glucuronarabinoxylans from sorghum grain, PhD Thesis, Wageningen Agricultural University, Wageningen, Holland (1996).
18. Hugo, L.F., Rooney, L.W. and Taylor J.R.N. Fermented sorghum as a function ingredient in composite breads. *Cereal Chemistry* (2003) in press.

19.Mertz, E.T., Hassen, M.M., Cairns-Wittern, C., Kirleis, A.W., Tu, L. and Axtell, J.D. Pepsin digestibility of sorghum and other major cereals. *Proceedings of the National Academy of Sciences, USA* **81** (1984) 1-2.
20. Duodu, K.G., Taylor, J.R.N., Belton, P.S. and Hamake, B.R. Mini review: Factors affecting sorghum protein digestibility *Journal of Cereal Science* (2003) in press.
21. Taylor, J.R.N. and Robbins, D.J. Factors affecting beta-amylase activity in sorghum malt. *Journal of the Institute of Brewing* **99** (1993) 413-416.
22. Mmapaptsi, M.D. and Maleke, J.M. Development of and institutional support systems for sorghum-milling technology. In 'Drought-Tolerant Crops for Southern Africa', (K. Leuchner and C.S. Manthe, eds), ICRISAT, Patancheru, India (1996) pp 7-18.
23. Gomez, M.I. Comparative evaluation and optimization of a milling system for small grains. In 'Cereal Science and Technology: Impact on a Changing Africa', (J.R.N. Taylor, P.G. Randall and J.H. Viljoen, eds), The CSIR, Pretoria (1993) pp 463-474.
24. Murty, D.S. and Kumar, K.A. Traditional uses of sorghum and millets. In 'Sorghum and Millets: Chemistry and Technology', (D.A.V. Dendy, ed), American Association of Cereal Chemists, St. Paul, USA (1995) pp 223-281.
25. Rooney, L.W. and Waniska, R.D. Sorghum food and industrial utilization. In 'Sorghum: Origin, History, Technology, and Production', (C. Wayne Smith and R.A. Frederiksen, eds), John Wiley & Sons, New York (2000) pp 689-729.
26. Taylor, J. and Dewar, J. Fermented products: Beverages and porridges. In 'Sorghum: Origin, History, Technology, and Production', (C. Wayne Smith and R.A. Frederiksen, eds), John Wiley & Sons, New York (2000) pp 751-795.
27. World Health Organization. Fermentation: Assessment and Research, WHO/FNO/FOS 96.1, WHO, Rome (1996).
28. Kazanas, N. and Fields, M.L. Nutritional improvement of sorghum by fermentation. *Journal of Food Science* **46** (1981) 819-821.
29. Hassan, I.A.G. and El Tinay, A.H. 1995. Effect of fermentation on tannin content and in vitro protein and starch digestibilities. *Food Chemistry* **53** (1995) 149-151.
30. Taylor, J. and Taylor, J.R.N. Alleviation of the adverse effects of cooking on protein digestibility in sorghum through fermentation in traditional African porridges. *International Journal of Food Science and Technology* **37** (2002) 129-138.
31. Marfo, E.K., Simpson, B.K., Idowu, J.S. and Oke, O.L. Effect of local food processing on phytate levels in cassava, cocoyam, yam, maize, sorghum, rice, cowpea and soybean. *Journal of Agricultural and Food Chemistry* **38** (1990) 1580-1585.
32. Gashe, B.A. Involvement of lactic acid bacteria in the fermentation of tef (*Eragrostis tef*), an Ethiopian fermented food. *Journal of Food Science* **50** (1985) 799-800.
33. Olatunji, O. Developed technologies for substitution of locally grown cereals in selected food products. In 'Cereal Science and Technology: Impact on a Changing Africa', (J.R.N. Taylor, P.G. Randall and J.H. Viljoen, eds), The CSIR, Pretoria (1993) pp 509-523.
34. Taylor, J.R.N. and Dewar, J. Developments in sorghum food technologies. In 'Advances in Food and Nutrition Research', Vol. 43 (S.L. Taylor, ed), Academic Press, San Diego, USA (2001) pp 217-264.
35. Okolo, B.N. and Ezeogu, L.I. Enhancement of amylolytic potential of sorghum malts by alkaline steep treatment. *Journal of the Institute of Brewing* **102** (1996) 79-85.

36. Dewar, J., Taylor, J.R.N. and Orovan, E. Effect of alkaline steeping on water uptake and malt quality in sorghum. *Journal of the Institute of Brewing* **103** (1997) 283-285.
37. Daiber, K.H. and Taylor, J.R.N. Opaque beers. In ‘Sorghum and Millets: Chemistry and Technology’, (D.A.V. Dendy, ed), American Association of Cereal Chemists, St. Paul, USA (1995) pp 299-323.
38. Palmer, G.H. Cereals for malting and brewing. In ‘Cereal Science and Technology’ (G.H. Palmer, ed) Aberdeen University Press, Aberdeen, UK (1989) pp 61-242.
39. Olatunji, O., Jibogun, A.C., Anibaba, T.S., Oliyide, V.O., Ozumba, A.U., Oniwinde, A.B. and Koleoso, O. Effect of different mashing procedures on the quality of sorghum beer. *Journal of the American Society of Brewing Chemists* **51** (1993) 67-70.
40. Ogundiwin, J.O. and Ilori, M.O. Development of stout from sorghum malt. *Lebensmittel Wissenschaft und Technologie* **24** (1991) 182-185.
41. Nile Breweries. The “Eagle” has Landed, Nile Breweries Ltd, Jinja, Uganda, 3 March (2003).
42. Ethiopian Ministry of Information. Local and International Coordinated Efforts are Imperative to contain the Drought-induced Food Crises, Ethiopian Ministry of Information, Addis Ababa, 15 November (2002).