DEVELOPMENTS IN AFRICA'S CEREAL CROPS - POTENTIAL SUSTAINABLE RESOURCES FOR BREWING IN TROPICAL AND SUB-TROPICAL COUNTRIES

Prof John R N Taylor
Dept of Food Science, University of Pretoria, Lynnwood Road, Pretoria 0002, South Africa
John.taylor@up.ac.za

ABSTRACT

Africa is the centre of origin and still today the major producing area for several cereal crops, notably sorghum, various millet species and African rice. These traditional African cereals have been called 'Orphan Crops', or even 'Lost Crops'. Today, their valuable agronomic qualities of low water usage and disease-tolerance are now being recognised, and breeding programmes are being undertaken to develop improved varieties, which have potential as ingredients in brewing lager beer.

The use of sorghum in Africa and countries such as the USA and Australia as both adjunct and malt in lager and stout brewing is a highly successful development and has been well documented. New types of sorghum are being developed with improved nutritional quality and also have potentially improved brewing quality. In particular, lines with high protein digestibility are being developed both by conventional breeding and genetic engineering techniques such as Africa Biofortified Sorghum. Research indicates that such types could yield improved free amino nitrogen and extract in brewing.

A completely different type of sorghum is sweet sorghum, which has a stem rich in sucrose, just like sugar cane. In fact, sweet sorghum can be considered as a type of sugar cane. The difference is that sweet sorghum is cultivated under dry land conditions in the same areas as conventional cereals. Worldwide, there is intense interest in sweet sorghum for bioethanol production, as it is potentially the cheapest source of fermentable carbohydrate.

Finger millet, named because the plant head resembles the fingers of the hand, is widely cultivated in East Africa. It has some potentially very useful characteristics with respect to brewing. Research has shown that like sorghum, some finger millet species contain condensed tannins. Malts of the tannin-containing varieties have quite high diastatic power. Specifically, the beta-amylase activity of these types is much higher than in sorghum.

Africa has its own species of rice, African rice, which is cultivated on a small-scale in tropical West Africa. Scientists led by Dr Monty Jones, director of the Forum for Agricultural Research in Africa (FARA), who received the World Food Prize for this work, have crossed African rice with conventional Asian rice. The hybrid is called NERICA (New Rice for Africa). It combines the high yield potential of conventional rice with African rice's resistance to biotic stresses and good nutritional quality. In West Africa, NERICA has become a highly successful crop for small-scale commercial farmers.

To exploit the potential of these African cereals for brewing and for the benefit of Africa, a supply chain management approach is required involving all stakeholders, including farmers, grain traders, brewing companies, national agricultural research systems and government.

Keywords: ***brewing, food security, sorghum, millet, african rice***

INTRODUCTION

Sub-Saharan Africa has the highest incidence of extreme poverty and hunger of anywhere in the world. This is as a result of insufficient staple food being produced and far too little economic activity[18]. The United Nations Millennium Development goals (United Nations, 2008) have been created to address this and other issues. Regarding improving food security, between 1990 and 2015, the goals are: to halve the proportion of people whose income is less than one dollar a day; to achieve full and productive employment and work for all, including women and young people; to halve the proportion of people who suffer from hunger.

Africa is fortunate in having indigenous cereals: sorghum, the millets and wild rice. These crops have unique agronomic and end-use qualities, which could contribute significantly to food security and sustainable economic development in Africa.

Fig. 1 Sorghum (top), pearl millet (bottom left), finger millet (bottom right)

Quantitatively, sorghum and the millets: pearl millet (*Pennisetum glaucum*) and finger millet (*Eleucine coracana*) ***(Fig. 1)*** are very important crops in Africa, with 27.2 and 17.2 million tons being produced in 2007, respectively[7]. These figures represent 18.7 and 11.7% of total African cereal production, respectively. Their importance to food security, however, varies greatly from country to country ***(Fig. 2)***. As can be seen, the countries with the highest proportion of sorghum and millet production are in the Sahel region of West Africa and North Africa around the Sahara Desert, the Horn of Africa, in South-west Africa around the Kalahari and Namib Deserts and in East Africa. Generally, these are areas of very low rainfall, less than 500mm per year. In these areas, sorghum and pearl millet predominate as food crops on account of their unique ability to produce a crop under conditions of low rainfall and in the case of sorghum, it is drought-tolerant[10].

In Africa, sorghum and millets are mostly grown as food crops by subsistence farmers. However, brewing with sorghum to produce lager and stout, often referred to as clear beer as opposed to traditional African opaque beer, has been conducted on a large, commercial scale in Africa since the late 1980s, notably in Nigeria[20]. Brewing with sorghum is also now taking place in East and southern Africa.

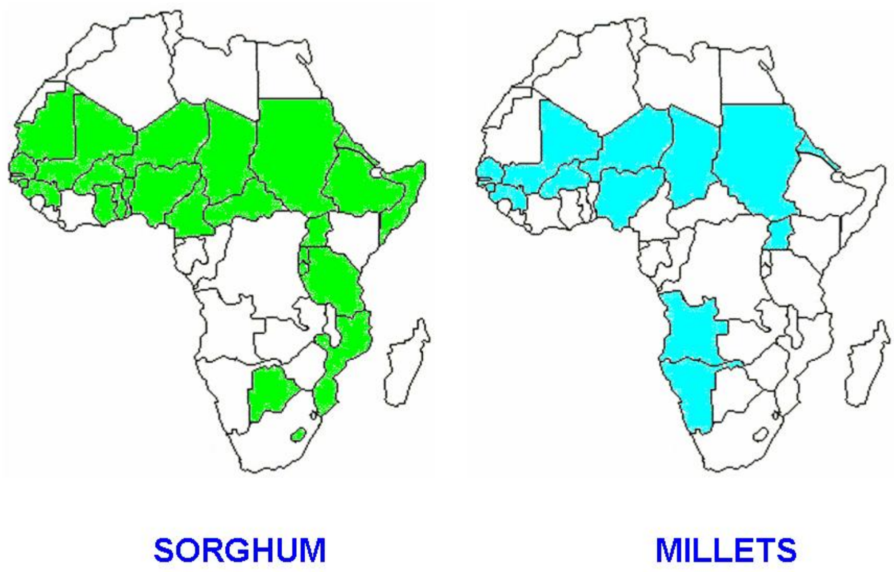

Fig. 2 Countries in Africa where sorghum and millets comprise 10% or greater of their cereal production

This paper will examine recent research that addresses the weaknesses of sorghum and millet as brewing ingredients. The brewing potential of wild rice hybrids and sweet and forages sorghum will then be briefly considered. The paper will conclude by looking at the issue of brewing with locally grown African cereals as a driver for sustainable economic development.

Free amino nitrogen

Probably the major problem when brewing with sorghum is that of very low free amino nitrogen (FAN) levels. The levels of FAN in sorghum grain wort mashed with commercial enzymes are considerably lower than those obtained with sorghum and barley malt. In order to achieve levels of FAN considered adequate (130-150mg/litre) to support optimal yeast growth and fermentation efficiency[14], unacceptably high levels of proteolytic enzymes need to be employed[8].

The low levels of FAN attained when using exogenous proteolytic enzymes can be attributed primarily to the factors that contribute to the low digestibility of kafirin, the sorghum storage protein[4], which accounts for around 70% of total grain protein. It has been found that FAN can be improved in sorghum mashing by the addition of a reducing agent ***(Fig. 3)***. Undoubtedly this improvement is caused by the breaking of intra- and inter-molecular disulphide bonds involving the kafirin[5,6]. This presumably allows better access of proteolytic enzymes to the kafirin and proteins, permitting improved protein digestion.

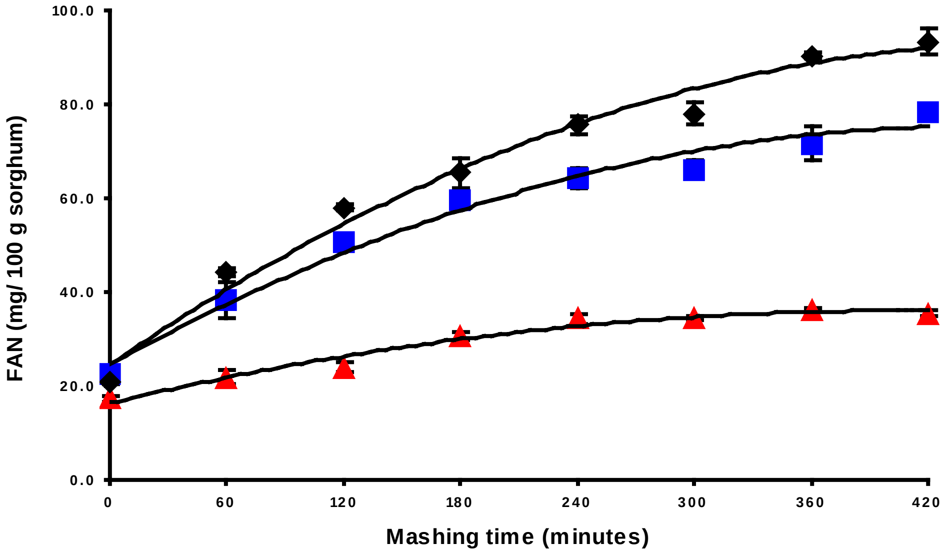

Fig. 3 Effects of mashing milled whole grain sorghum at 40°C with exogenous protease and reducing agent on FAN production. Error bars show ± one standard deviation.
triangles = sorghum alone;
squares = plus exogenous protease;
diamonds = plus exogenous protease and reducing agent

New lines of sorghum with improved protein digestibility have been developed. A mutant sorghum line has been described where the protein bodies, the organelles of kafirin storage, were invaginated thus apparently allowing better access by proteolytic enzymes[15]. It has been found that this mutant does indeed give somewhat increased

FAN production when its grain is mashed with endogenous proteolytic enzymes. Also, when the high protein digestibility mutant is malted, its malt has somewhat higher levels of FAN (**Table I**).

TABLE I
Effect of mashing with high protein digestibility sorghum on fan production (mg fan/100g sorghum)

	GRAIN PLUS PROTEASE			***MALT***		
Sorghum type	**FAN at start of mashing**	**FAN at end of mashing**	**FAN production**	**FAN at start of mashing**	**FAN at end of mashing**	**FAN production**
Normal A	**22.6**	**45.0**	**22.4**	**73.1**	**83.6**	**10.5**
Normal B	**24.3**	**44.3**	**20.0**	**50.4**	**57.6**	**7.2**
High Protein Digestibility C	**22.7**	**51.2**	**28.5**	**83.3**	**96.1**	**12.8**
High Protein Digestibility D	**24.9**	**53.4**		**103.4**	**120.1**	**16.7**

Another novel sorghum is Africa Biofortified Sorghum. ABS is a sorghum line with improved nutritional value. Its improved traits have been produced by genetic engineering. ABS is intended to help alleviate malnutrition in Africa[1]. It is being developed under the auspices of the Bill and Melinda Gates Foundation Grand Challenges in Global Health initiative. One of ABS's nutrient traits is improved protein quality, in terms of the content of the essential amino acid lysine. Research has shown that ABS has also considerably improved protein digestibility. Hence, ABS will probably yield considerably higher levels of FAN than conventional sorghum.

Extract

Because sorghum does not have a hull, it should in theory give higher extract than barley. However, several factors can limit extract production in sorghum. The high proportion of disulphide bond-crosslinked kafirin storage proteins and extensive polymerisation of the kafirins on cooking can cause poor hydrolysis of starch in sorghum vitreous endosperm flour[5]. Additionally, the gelatinisation temperature range of sorghum starch (67-81°C) is far higher than that of barley malt starch (51-60°C)[20]. For starch to be rapidly hydrolysed by amylase enzymes the starch granules must fully hydrate to disrupt the internal molecular structure (gelatinise), then break down and the starch molecules become solubilised. These changes in starch are referred to as pasting. The pasting properties of a very wide range of different sorghum types have been explored. It was found that the pasting properties in terms of viscosity vary greatly ***(Fig. 4)***. Grain hardness seems to play a major role, with floury (soft) endosperm grains giving higher viscosity. The high protein digestibility mutants also seem to give higher pasting viscosity. As yet, no varieties have been found with substantially low pasting temperature.

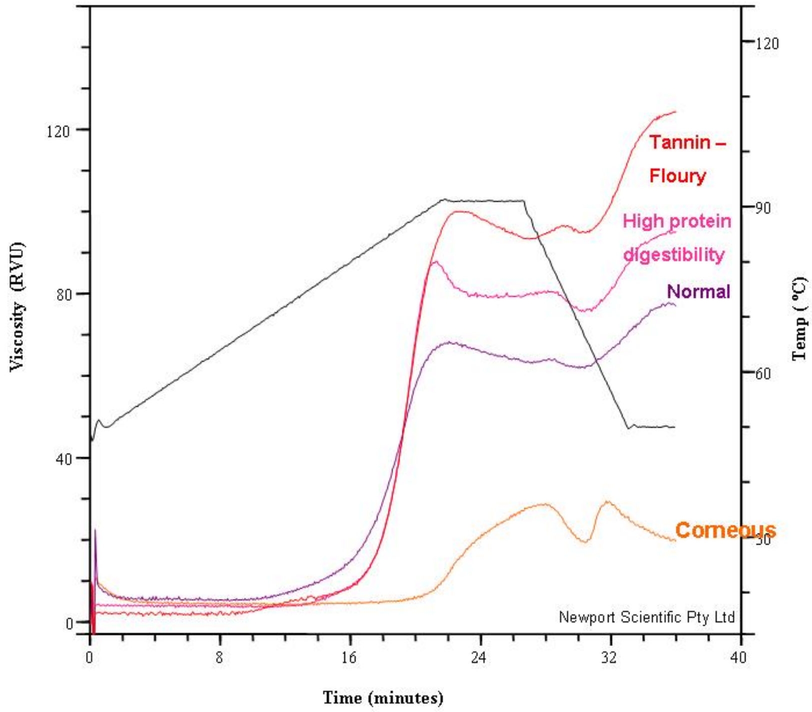

Fig. 4 Pasting properties of different types of sorghums

Malt amylase activity

A major problem with sorghum malt, as an alternative to barley malt, is that its amylase activity, specifically the beta-amylase activity, is much lower[3,19,13]. Malted millet has been investigated as an alternative. Millet in the form of malt is probably a much better option than using unmalted millet. This is because pearl millet grain has a high fat content and finger millet grain has a very high fibre content. Both these factors will adversely affect extract if millet is simply used as an adjunct. A positive reason for brewing with millet malt is that their beta-amylase activity seems quite high. It has been shown that pearl millet malt has quite high beta-amylase activity, approx. 200-400 Betamyl units/g, several times the level in sorghum[16] and hence intermediate with barley malt. With regard to finger millet malt, it has been found that certain varieties also have relatively high beta-amylase activity similar, if not higher, than pearl millet malt (**Table II**). Interestingly both the diastatic power and beta-amylase activity of finger malts are related to the phenolic content. Varieties containing high levels of phenolics have higher diastatic power and beta-amylase activity. In fact, the high phenolic finger millet varieties contain tannins, which are located in the testa[17], just like tannin sorghums. It has also been observed that tannin finger millet varieties show higher Germinative Energy and that their malts have lower levels of fungal contamination than non-tannin varieties.

TABLE II Phenolic content, diastatic power and beta-amylase activity of finger millet malts compared to sorghum and barley malts			
Finger millet variety	**Phenolic content (g/100g)**	**Diastatic power (SDU/g)**	**Beta-amylase activity (Betamyl units/g)**
G35	0.1	24	81
ICMFM95001	0	21	97
95G198W	0	19	109
FNL 0069	0.3	54	543
P283	0.7	71	608
Gulu early	0.8	74	562
FNL 0072	0.9	69	319
Zim Mnnursery	0.7	56	231
FMV1	1.3	54	238
FNL 0051	1.4	72	406
Nanjala Brown	1.1	65	294
Okhale-1	1.7	57	315
Sorghum (non-tannin)	Not measured	43	78
Sorghum (tannin)	Not measured	52	91
Barley	Not measured	154	1323

NERICA

In West Africa there is an indigenous species of rice, called wild rice (*Oryza glaberrima*), which is only distantly related to the common rice (*Oryza sativa*). Although wild rice yields poorly, it is very resistant to the biotic stresses in the African tropical environment. A team of scientists led by Dr Monty Jones, now director of the Forum for Agricultural Research in Africa (FARA), crossed wild rice and common rice to produce NERICA, the New Rice for AfrIca[2]. NERICA combines the high yield potential of common rice with African rice's resistance to biotic stresses. NERICA has been highly successful in West Africa from where it was originally bred and is now being evaluated in east Africa. Dr Jones jointly received the World Food Prize in 2004 for this work.

NERICA appears to have potential as a brewing adjunct. The starch amylose-amylopectin ratio shows wide variation[11]. Some lines are quite high in amylopectin, approx. 78% and as a consequence show high pasting viscosity, which should result in good extract. In addition, NERICA has a high protein content[23] which should be valuable for yeast nutrition in brewing recipes where the proportion of malt in the grist is low.

Sweet sorghum and forage sorghum

In addition to regular grain sorghum, there are two other types of sorghum that could, in the long-term, be useful brewing materials. These are sweet sorghum and forage (biomass) sorghum. Both are being very actively researched for bioethanol production. Sweet sorghum has sucrose-rich stem juice like sugarcane. Under conditions of dryland cultivation, *i.e.* how maize and sorghum are normally cultivated, it is in theory the cheapest source of ethanol (**Table III**)[9]. The grain of sweet sorghum and theoretically the stover, can also be used to produce ethanol, hence improving yield.

TABLE III
Ethanol production from sweet sorghum, sugar cane and maize (from ICRISAT, 2006)

	Sweet sorghum	Sugarcane	Maize
Crop duration (months)	4	12	4
Water requirement (m^3x1000)	4	36	8
Grain yield (tons/ha)	2.0	0	3.5
Ethanol from grain (litres/ha)	760	0	1400
Ethanol from stalk juice (litres/ha)	1400	5600	0
Stillage and stover (tons/ha)	4	13.3	8
Ethanol from residue (litres/ha)	1000	3325	1816
Total ethanol (litres/ha)	3160	8935	3216
Maize oil (litres/ha)	0	0	140
Cultivation cost including irrigation ($/ha)	238	995	287
Ethanol cost ($/1000 litres)	75.3	115.5	89.2

Forage sorghums are very tall varieties, up to 6 metres. Forage sorghums have traditionally been grown as feed for cattle. Today, they are being investigated as a source of cellulose for ethanol production (Prof W L Rooney, Texas A&M University, personal communication). In theory, forage sorghums, which like all sorghums are C4 plants, are the most efficient converters of solar energy and carbon dioxide into biomass (cellulose). Agronomic research is concentrating on the development of high-yielding photoperiod- and thermo period-insensitive hybrid cultivars of these sorghum types. At the same time, efficient processes are being developed to produce ethanol from the forage sorghum cellulose (RefO).

CONCLUSION

Sorghum is already an essential brewing ingredient in Africa for lager and stout beers. As seen, sorghum, the millets and possibly NERICA have considerably further potential as brewing materials and to act as a driver for economic development to improve food security. There are, however, many constraints, not least is the fact these indigenous grains are often uneconomical. For example, in Kenya finger millet is five times more costly than maize, primarily as a result of low agricultural productivity. In Africa, millet yields are only 0.8 tons/ha[7]. By comparison, barley yields in Western Europe are 5.6tons/ha. In the case of sorghum, for example in Nigeria, the major user of sorghum in lager and stout brewing, the average yield is 1.4tons/ha compared to 4.7tons/ha in the USA. In the past, scientists have attempted to improve food security in Africa by addressing individual problems, such as breeding of new varieties or developing new food processing technologies. This has been notably unsuccessful. A new more promising approach is to look at the issues holistically, the so-called Supply Chain Management approach where all steps in the chain are addressed together. For example, in the Sahel region of West Africa supply chain management concepts have been applied to millet and sorghum and this has helped result in a rapid increase in the number of processors of sorghum and millets and in the quantities they process to meet the demands of the growing urban population[22].

It is the author's opinion is that international brewing companies operating in Africa will have to be the drivers of this supply chain management approach so that African cereals become sustainable resources for brewing. This will require a partnership involving all stakeholders, including farmers, grain traders, brewing companies, national agricultural research systems and government.

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