

Review

Understanding biodiversity in sorghums to support the development of high value bio-based products in sub-Saharan Africa

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Sorghum [*Sorghum bicolor* (L.) Moench] is one of the most important cereals worldwide with great genetic diversity. Like most small grains it has good adaptation to drought prone and marginal areas where other cereals are not productive. Globally, sorghum has been underutilized compared to other cereal staple crops however, there is growing interest in sorghum and its related products due to its unique nutritional traits, crop physiology and phenology. Given the genetic variability of sorghum there is great scope to use the crop to produce an array of commodities in the food, feed, industrial and bioenergy sector. This review paper presents sorghum genetic diversity and with special reference to bio-based and value added products such as gluten free, high protein, aromatic, syrup, popping, weaning, pet food, baked products and alcohol free malt beverages that can be explored in Africa to popularize it and improve livelihoods.

Key words: Small grain, sorghum bicolor, value addition.

INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is an important cereal that ranks fifth after rice, wheat, maize, and barley. In sub-Saharan Africa (SSA), it ranks second in importance after maize (Prajapati et al., 2018). Sorghum comprises the main food source from which over half a billion people in developing countries who derive their

energy requirements from it (Oluwafemi, 2020). Sorghum is inherently adapted to hot and dry areas which give it an edge over other crops in such hostile environments. Consequently, the importance of the crop is now being released in most African countries given the unprecedented changes due to climate change (Boyles et

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al., 2019). Strengthening sorghum production is therefore essential for improving food security and livelihoods in SSA. Globally the utility of sorghum varies with geographical location and technological advances. Accordingly, this review sought to understand the sorghum germplasm resource base in SSA, its characteristics and potential for value addition based on specialty attributes. This is in recognition that the diversification of sorghum products could play a role in transforming livelihoods of people in marginal areas and beyond.

BIODIVERSITY OF SORGHUM

Sorghum belongs to the genus *Sorghum*, tribe Andropogoneae, Poaceae family which is made up three main species namely *S. bicolor*, *S. halepense* and *S. propinquum* (Kunth) Hitchc. (Verma et al., 2017). *Sorghum bicolor* includes all the cultivated sorghums which are Bicolor, Kafir, Caudatum, Durra and Guinea races. These races further have various sorghum use types that include; grain, forage, sweet/syrup, biomass and broom sorghum. These differ in their morphological features of the stem, inflorescence, grain and glumes (Buschmann, 2018).

The center of origin of cultivated sorghum is Ethiopia, from where it was disseminated to other regions of the world (Tesfaye, 2017). Cultivated sorghum is a genetically diverse diploid ($2n = 20$). It is sexually compatible with some of its wild or weedy relatives such as Johnson grass (*Sorghum halepense*) (OECD, 2017). Wide sorghum biodiversity has been reported within and among cultivars at morphological and genotypic level. Plant breeders exploit this biodiversity for crop improvement that meets specific requirements crucial for food and nutrition security and livelihoods (Tesfaye, 2017). Increased loss of crop biodiversity can be attributed among other factors to the promotion of large scale monocultures and the use of a limited number of introduced commercially available sorghum varieties. Crop biodiversity present in sorghum provides the opportunity for development of specialty sorghum types targeting niche markets and end uses. Various natural mutants of sorghums with altered starch, protein and phenolic properties offer benefits for nutrition and/or processing (González, 2005; Weerasooriya et al., 2018). Sorghum kernels vary in size, shape, colour, density, hardness, composition, texture, processing properties, taste and nutritive value (Rooney and Awika, 2005; Rhodes, 2014). This makes them amenable to a wide range of uses, some unique for a cereal which span the food, feed, fuel and various types of novel products.

COMPARATIVE PERFORMANCE OF SORGHUM

The adaptation of sorghum is due to its unique crop

physiology, phenology and phenotypic plasticity (Boyles et al., 2019). Being a unique C4 plant, sorghum has high photosynthetic efficiency in drier and hotter areas compared to other cereals (Kanbar et al., 2019). Morphologically sorghum has several characteristics that enable it to adapt to drought stressed environments such as a deep extensive root system, thick waxy cuticles, narrow leaf sizes and leaf rolling (Hasanuzzaman et al., 2013; Takele and Farrant, 2013; Schittenhelm and Schroetter, 2014; Hadebe et al., 2017). Various physiological traits and responses such as stay green traits, pronounced osmotic adjustment and stomatal regulation give sorghum greater adaptive ability to drought prone environments than other cereals (Thomas and Howarth, 2014; Hadebe et al., 2019). Furthermore, sorghum is adapted to marginal environments such as saline, infertile, alkaline and waterlogged soils (Muui, 2014). Sorghum is easier and less expensive to cultivate, requires fewer pesticides and fertilizers and has lower greenhouse gas emissions on a life-cycle basis than maize (Kanbar et al., 2019). Accordingly, sorghum is a suitable alternative in many places where most cereal crops are not adapted.

CHEMICAL COMPOSITION OF SORGHUM

The nutrient composition of sorghum is comparable to that of other cereals (Table 1) making it a suitable crop choice to complement dietary and energy needs for populations in areas where other cereals are not well adapted.

Sorghum contains approximately 4.4 to 21.1% protein, 55 to 75% starch, 0.5 to 7.6% lipids, 0.7 to 4.2% soluble sugars and 1 to 6% crude fiber on a dry weight basis. Approximately 80, 16 and 3% of the protein is contained in the endosperm, embryo, and pericarp, respectively. The endosperm is made up of 80 to 82% starch, which is comprised of 70 to 80% branched amylopectin and 20 to 30% amylose (Ratnavathi and Patil, 2014). The starch for waxy, glutinous sorghum is almost 100% amylopectin with no amylose. Sorghum grain also contains some anti-nutritional factors such as tannins and phytins. These bind to proteins and other nutrients present in grain making them unavailable for the intestinal absorption, thus inhibiting their digestibility (Queiroz et al., 2015).

COMMON AND PROSPECTIVE USES OF SORGHUM

More than 35% of world sorghum production is dedicated to human consumption, while the rest is for animal feed, brewery and other industrial products (Kangama, 2017). Besides the traditional use of sorghum at household level there are several raw materials derived from the crop such as starch, fiber, dextrose syrup, biofuels, edible oils

Table 1. Comparative analysis of nutrient composition of sorghum versus other staple cereals.

| Cereal type | Protein (g) | Fat(g) | Crude fibre (g) | Carbohydrate (g) | Energy (kcal) | Calcium (mg) | Iron(mg) |
|---------------|-------------|--------|-----------------|------------------|---------------|--------------|----------|
| Rice (brown) | 7.9 | 2.7 | 1.0 | 76.0 | 363 | 33 | 1.8 |
| Wheat | 11.6 | 2.0 | 2.0 | 71.0 | 348 | 30 | 3.5 |
| Maize | 9.2 | 4.6 | 2.8 | 73.0 | 358 | 26 | 2.7 |
| Sorghum | 10.4 | 3.1 | 2.0 | 70.7 | 329 | 25 | 5.4 |
| Pearl millet | 11.8 | 4.8 | 2.3 | 67.0 | 363 | 42 | 11.0 |
| Finger millet | 7.7 | 1.5 | 3.6 | 72.6 | 336 | 35 | 3.9 |

Source: Muui (2014).

and gluten free feed (Muui, 2014). Furthermore, crop residues provide sources of building materials, and fuel, particularly in the semi -arid tropics (SAT). In Africa, white and red sorghum have been traditionally used to produce opaque low-alcohol beers such as lager and stout on a large industrial scale. The darker sorghums are usually avoided because of high levels of tannins; however some farmers prefer them because it is believed that the tannins play a defensive role against fungi, insects and birds (Ramatoulaye et al., 2016). Farmers doing field work mostly prefer tannin sorghum porridge because they remain full for longer periods. The slower digestibility of tannin sorghums is most likely related to the binding that occurs between the tannins, proteins and other components of the grain (Rooney and Awika, 2005). Worldwide for consumption purposes, sorghum is used to make various boiled, steamed, baked, fermented and deep fried products (Arendt and Zannini, 2013).

SPECIALTY SORGHUM AND NOVEL PRODUCTS

A specialty crop is a plant that can be cultivated and used by people for food, medicinal or aesthetic purposes and to produce some novel products. A wide range of uses and sorghum types exist worldwide that can be adopted by farmers and communities in Africa to improve their livelihoods and nutrition. Sorghum is a gluten-free cereal that can serve as an alternative to wheat for people with celiac disease (Schaffert et al., 2012). In the developed countries sorghum was primarily used a feed crop but now there is growing demand for gluten free food products (Mofokeng et al., 2017). The lack in Vitamin A in diets causes blindness especially in children. There are some sorghum types with yellow grain and they are referred to as yellow sorghums which can be used to solve this problem especially in poor communities. Yellow sorghums derive their colour from carotenes and xanthophylls that are vitamin-A precursors (Rooney and Awika, 2005). This special type of sorghum is more popular in Nigeria. In Ethiopia there is an elite type of sorghum which is highly nutritious and very palatable. Its

taste has been described as that of roasted chestnuts. Analysis of this type of sorghum showed that it contained thirty percent more protein than other sorghums and the protein had twice the normal level of lysine (Afify et al., 2012). Other types of sorghums with small white seeds can be boiled like rice. These sorghum type belongs to the guinea race and very little is known about this interesting type of sorghum (Young et al., 1993). In some parts of Sri Lanka and India there is some sorghum which have an aroma of basmati rice. Basmati rice is Asian rice with a fragrance and is sold worldwide as a highly priced specialty. The discovery and breeding of such aromatic sorghums might open up opportunities as they can become specialty foods of high value. This will in turn help to improve markets and boost the acceptance and consumption of sorghum (National Research Council, 1996).

Some sorghum type pop like popcorn is found in parts of Africa and Asia. Popping in its nature enhances flavour, is nutritionally desirable and saves a lot of energy as it is rapid and hydrolyses the vitamins and proteins slightly as compared to boiling (Golubinova et al., 2017). In India and even in certain parts of Binga in Zimbabwe, sorghum is eaten like green mealies. The panicle is harvested at soft dough stage (milky stage) when the grains are still sweet. This is either boiled or roasted and the sweet grains make a very pleasant meal (National Research Council, 1996). Sweet sorghums have high soluble sugar content and dry matter yields; these are normally referred to as sorghos. In the United States, these sorghums are used to produce sorghum syrup, similar to molasses. In Southern Africa, sweet sorghum is popular but commercial seed are rarely available and farmers resort to the informal seed sector to access planting material at subsistence level. These, however, have a great potential for the production of renewable fuels. Syrup and sugar can be readily produced from these sweet sorghums. Sweet sorghum types which contain enough fructose which prevents crystallization are selected to make syrup while those that contain sucrose and can readily crystallize are used for sugar production (Dahlberg et al., 2011).

OPPORTUNITIES FOR SPECIALTY SORGHUMS

Strengthening sorghum production is considered essential for improving food, nutrition security and livelihoods in developing countries and Africa in particular. In most African countries, the current product portfolio of sorghum is milled flour for food and beer brewing. New niche markets for bio based sorghum products may have ripple effects, reorient plant breeding programmes and stimulate more demand by various stakeholders for the crop (Suad and Maarouf, 2015).

Ethanol production

The negative impacts of fossil fuels on the environment have revived the drive for alternative sources of energy such as ethanol. Plant based sources of energy have the advantages of providing cleaner fuels which are renewable and their production can be integrated with food production. Compared to sugarcane and maize, sorghum is able to thrive with less water. Yan et al. (2011) reported that about four percent of US ethanol was being produced from sorghum grain while ninety five percent of ethanol was produced from maize. More fuel ethanol can be produced from sorghum given the advantages it has over maize and sugarcane. It is however noteworthy that production of plant based sources of energy should not compete with food crops given the challenges of food security particularly in Africa. A study done by Kim et al. (2012) revealed that even the panicle, bagasse and leaves of sweet sorghum varieties can be fermented and as well be used to produce ethanol. This was supported by Wright et al. (2016) who concluded that sweet sorghum bagasse had favourable fuel value compared to sugarcane bagasse. Furthermore, bagasse can be used to reinforce wood composites, as a fertilizer, hay and paper production (Ashori, 2008; Bluemmel et al., 2009; Ghanbari et al., 2014). Besides the use for ethanol production, sorghum juice can be used to produce bio-plastics and beverages (Pabendon et al., 2017). Sorghum producing countries can also adopt the technologies used by other countries and use this crop to produce fuel which is currently very scarce and expensive (Tang et al., 2018).

Waxy and heterowaxy sorghums

The starch of waxy and heterowaxy sorghums is composed of 0 and 17% amylose respectively and almost 100% amylopectin. This is attributed to the absence or inactivation of granule-bound starch synthase (GBSS) (Pedersen et al., 2005). In sorghum, the waxy trait is recessive controlled by alleles wx^a alleles. In waxy wx^a the GBSS is absent and in waxy wx^b there is reduced activity

of the GBSS (Funnell-Harris et al., 2015). Waxy sorghums are superior to non-waxy ones dry matter, feed efficiency and gross energy digestibility (Ezegou et al., 2005). Since amylopectin has low viscosity, it can therefore be easily digested by amylases due to a lower gelatinization temperature. This natural waxy mutation renders the starch with low amylase more amenable for use for feed, food, and grain-based ethanol (González, 2005).

Functional foods production

Products such as gluten-free foods, flakes, weaning foods and noodles can be produced from sorghum using various technologies. Most of these uses take into cognizance the nutrient properties of sorghum like comparatively high levels of niacin, vitamin B and fibre (Edia, 2018). There is high sensory acceptance, antioxidant activity and dietary fibre in sorghum derived breakfast cereals compared to wheat based ones (Anunciação et al., 2017; Lopes et al., 2018). A good example of a ready to eat cereal made from sorghum is Morvite, a pre-cooked sorghum with added vitamins, citric acid, and sweeteners. This is an instant porridge formulation taken after the addition of warm or cold water (Taylor, 2004).

Weaning foods

Weaning is a transition where the infant diet changes from liquid milk to semi-solid food. Such semi-solid food is called 'weaning food'. The weaning food is expected to be easily digestible, high in energy density and low in bulk. A study done by Aloysius and Ajawubu (2013) revealed that sorghum can be blended very well with Bambara nuts (*Voandzeia subterranea* (L.) Vigna) to produce a weaning food which is rich in proteins. This was observed to prevent protein energy malnutrition which is prevalent especially in children living in rural communities of developing nations. Blending sorghum based weaning foods with legumes and oil seeds supplements make them a complete diet for infants (Usman et al., 2016).

Baked products

In Germany and other parts of Eastern Europe, tannin containing varieties are used to make confectionary products like chocolate cakes, cookies and muffins, or molasses cookies as they are believed to be more healthy (Taylor et al., 2006). In wheat flour blends, sorghum can improve nutrition, food quality and health functions for example in pasta. Moreover, sorghum is

slowly digested as compared to other cereals and this is advantageous for diabetics as it helps in reducing obesity (Rooney and Awika, 2005; Teferra and Awika, 2019).

Malt beverages

The use of sorghum in tea beverages has not been fully successful and therefore improvements can be made to make grain tea beverages from sorghum. Other novel products which can be produced from sorghum are low calorie and nutritive drinks made from sorghum powders. The powders should be able to infuse with water or milk. Since sorghum is naturally low in fat the drinks may have the potential of being fully accepted by the society given the fact that more people nowadays are more concerned about their health and want to avoid fatty foods. Non-alcoholic beverages such as “Milo” are made from sorghum malt and cocoa. Sorghum mealie meal can also be fermented to produce a non-alcoholic drink known as *Mahewu*. This can also be blended with Bambara groundnut to improve its nutritional quality (Qaku et al., 2020).

Sweet sorghum syrup

Sorghum syrup from the juicy stem can be used as a natural alternative sweetener in breakfast, confectionery and dairy industries. The syrup unlike sugarcane sweeteners has a better mineral nutrient profile rich in iron, calcium and zinc (Ratnavathi and Patil, 2014). Furthermore, biomass of sweet sorghum can also be an alternative livestock feed (Yucel, 2020).

Health benefits

Compared to other cereals, sorghum has “good” carbohydrates that are made up of slowly digestible starch and resistant starch which contributes to a low glycemic index (Teferra and Awika, 2019). Furthermore, some sorghum varieties especially the pigmented ones, contain health-beneficial phenolic compounds. Documented health benefits attributed to phenolic extracts include prevention and treatment of colon cancer, anti-inflammatory activity and antioxidant properties (Vanamala et al., 2018).

Pet food from sorghum

Given the similarity in starch properties with other cereals, sorghum can be used in pet food formulations as an alternative (Di Donfrancesco and Koppel, 2017). Furthermore, by-products from ethanol production can be

used in pig and rabbit as an additive. However, care is needed to be exercised when using red sorghum due to polyphenolic anti-nutritional that require additional ingredients to enhance palatability and digestibility (Yang et al., 2019).

CHALLENGES ASSOCIATED WITH SORGHUM

Lack of sorghum processing technologies to address niche markets is a limiting factor in their utilisation for biobased products (Ratnavathi and Patil, 2014). Pigmented sorghums are particularly rich in phenolic compounds which cannot be digested readily by the human body. Furthermore, preparation of food items from such sorghum is very laborious and time-consuming, for example, to make them palatable, the tannins must be firstly removed by either milling or pounding. The seeds are pounded using heavy poles and this make life difficult especially for the rural communities depending on sorghum as their staple food. This is a barrier to the wider use of this crop and thus it is considered as a poor man’s crops (Rao et al., 2010; Musara et al., 2019). These factors are the reason why other cereals like maize, wheat and rice are favoured because they are can be easily processed and cooked (Ratnavathi and Patil, 2014). Breeding of specialty sorghums such as dual purpose sorghums is a challenge as only a few sorghum genotypes have good combining ability for both high grain yield and high biomass (Chikuta, 2017).

PROPOSED PERSPECTIVES AND DIRECTIONS

Given that water is becoming more and more limiting for agricultural production, sorghum will play a major role in agricultural production systems throughout the world. The potential for sorghum in semi-arid drought prone and marginal areas of Africa is vast. Several bio-based products and downstream industries can develop from the crop. However, cost reductions in the production of this novel value added products and pro-active government policies that promote the use of sorghum are the prerequisites for commercialization of sorghum to take place. In future breeding sorghum, varieties for increased grain yield without regard to quality will be a major mistake. Poor quality grain cannot be made into acceptable value added products. Therefore major stakeholders in crop breeding, that is, Consultative Group for International Agricultural Research (CGIAR) and the National Agricultural Research System (NARS) should not only focus on grain sorghum but also on these specialty types of sorghum. This continued, focused, fundamental and applied research will stimulate demand by various stakeholders in the sorghum production chain. There is also need for promotional campaigns to increase

public awareness of alternative products and processing technologies for the diverse sorghum germplasm. Furthermore, smallholder farmers should be included in the sorghum value chain by empowering them with appropriate planting material, production skills and market linkages. These steps will strengthen the sorghum value chain in Africa and contribute in eradicating hunger and poverty in the continent and even the world at large.

CONFLICT OF INTERESTS

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