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SIGNIFICANCE OF SWEET SORGHUM AS A MULTI-PURPOSE CROP FOR SUB-SAHARAN AFRICA

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ABSTRACT

There is great interest in sweet sorghum (*Sorghum bicolor* L.) for promoting resilience in rural livelihoods in Sub- Saharan Africa (SSA). Unlike other crops, sweet sorghum is a multi-purpose crop for grain, feed, fodder, chewing, syrup and biofuel production. The objective of this paper is to analyse information on the diversity within the crop, its adaptation and plant breeding efforts in SSA. We also discuss opportunities that exist in SSA that make the crop an attractive alternative. It is clear from the review that the crop has a wide genetic base, hence significant improvements can be made on a number of preferred traits. The review further outlines four possible production models for the economic development of the sweet sorghum industry in Sub-Saharan Africa; which are (i) production for supply to urban chewing markets, (ii) syrup production, (iii) biofuel production and (iv) fodder production. Although current research focuses on production of ethanol for biofuel, other potential uses such as production for chewing, syrup and fodder cannot be overlooked for most SSA farmers. A lot has to be done on the research front before biofuel production from sweet sorghum can be profitable and technically feasible. Future plant breeding efforts can be tailor made to deliver cultivars with peculiar traits for various end-uses.

Key Words: Biofuel, dual purpose crop, *Sorghum bicolor*

RÉSUMÉ

Il existe un grand intérêt pour le sorgho doux (*Sorghum bicolor* L.) pour promouvoir la résilience des moyens de subsistance ruraux en Afrique subsaharienne (ASS). Contrairement à d'autres cultures, le sorgho sucré est une culture polyvalente pour la production de céréales, d'aliments pour animaux, de fourrage, de *mastication*, de sirop et de biocarburant. L'objectif de cet article est d'examiner les informations sur la diversité au sein de la culture, son adaptation et les efforts de sélection végétale en ASS. Il traite également des opportunités qui existent en ASS et qui font de cette culture une alternative attrayante. Les résultats de l'examen montrent que la culture a une large base génétique, ce qui permet d'apporter des améliorations significatives à un certain nombre de caractères préférés. L'examen décrit en outre quatre modèles de production possibles pour le développement économique de l'industrie du sorgho sucré en Afrique subsaharienne ; qui sont (i) la production pour l'approvisionnement des marchés urbains de *mastication*, (ii) la production de sirop, (iii) la production de biocarburants et (iv) la production de fourrage. Les questions clés émergeant de la discussion sont les suivantes ; la recherche actuelle se concentre sur la production d'éthanol pour le biocarburant, bien que ce soit une bonne priorité pour la recherche, cela ne devrait pas éclipser d'autres utilisations potentielles de la culture telles que la production pour la *mastication*, le sirop et le fourrage qui peuvent être la seule option pour la plupart des agriculteurs d'ASS. Beaucoup reste à faire sur le front de la recherche avant que la production de biocarburants à partir de sorgho sucré puisse être rentable et techniquement réalisable, en particulier pour les petits exploitants agricoles dans la plupart des pays d'ASS. Par conséquent, les futurs efforts de sélection végétale peuvent être adaptés pour fournir des cultivars avec des traits particuliers pour diverses utilisations finales.

Mots Clés : Biocarburant, culture à double usage, *Sorghum bicolor*

INTRODUCTION

Sweet sorghum (*Sorghum bicolor* [L.] Moench) is a food security and income earner crop, particularly in the arid and semi-arid regions of Sub-Saharan Africa (SSA), which constitute 43% of the arid and semi-arid land worldwide (Nasidi *et al.*, 2019). Sweet sorghum is a widely adaptable crop (Jiri *et al.*, 2019); although, its production in the SSA is constrained by limited product portfolio, which ultimately impedes penetration as a major food in urban markets in the region (Deribe and Kassa, 2020).

Sweet sorghum is a term that distinguishes cultivars of the species *Sorghum bicolor* that have juicy and sweet stalks (Hunter and Anderson, 1997). Any sorghum with 10–25% sugar in stalk juice at grain maturity is considered a sweet sorghum (Hunter and Anderson, 1997). The crop has high water, nitrogen and light efficiency, broad agro-ecological adaptation and a rich genetic diversity for useful traits, compared to sugar cane (Woods, 2001; Vinutha *et al.*, 2014). As a result, the crop has spread into all parts of the world where its sweet stems are either chewed as a snack, processed into syrup (Legwaila *et al.*, 2003; Rao *et al.*, 2013), or processed into ethanol for use as bioenergy (Ratnavathi *et al.*, 2016).

Given the urgent need to promote resilience in the face of climate change, value add agricultural products and improve rural livelihoods of communities in SSA where sorghum is an important crop, there is great interest in sweet sorghum for use in various products (Woods, 2001; Mangena *et al.*, 2018; Nasidi *et al.*, 2010, 2019). Unlike other crops, sweet sorghum is a multi-purpose crop that can be economically grown for grain, feed, fodder, chewing, syrup and biofuel production (Rao *et al.*, 2013; Makori, 2014). The objective of this paper is to review information on the diversity within the crop, its adaptation and plant breeding efforts in sub-Saharan Africa. It also discusses opportunities that exist in sub-Saharan Africa that make the crop an attractive alternative.

PLANT MORPHOLOGY AND JUICE CHARACTERISTICS

Sweet sorghum is characterised by tall high biomass juicy stems that typically have lower grain yield compared to grain sorghum (Ritter *et al.*, 2007). The plant has concentrations of sugar ranging from 10 -25% (Hunter and Anderson, 1997; Sagnard *et al.*, 2011). The sugar content in sweet sorghum stalks is measured in Brix units, which represents the percent soluble sugars (Mathur *et al.*, 2017).

The pith and rind of the stalk contain approximately equal masses of dry matter, with most of the fermentable sugar and moisture in the pith. The stalk constitutes 70 - 90% of the dry matter (Ratnavathi *et al.*, 2016).

Cellulose and hemicellulose are present in similar ratios in the pith and bark, but almost all the lignin in the stalk is in the bark. The sugar consists of predominantly sucrose (75%) a non-reducing disaccharide and two reducing monosaccharides; glucose and fructose. The accumulation of sucrose initiates at flowering and picking at physiological maturity (Ratnavathi *et al.*, 2016). The presence of substantial quantities of the reducing sugars glucose and fructose, coupled with the activity of the invertase enzyme make the juice unable to produce good quality jaggery and refined sugar (Ratnavathi *et al.*, 2016). Sweet sorghum juice is most suitable for ethanol and syrup production due to its readily fermentable saccharides.

The main advantage of sweet sorghum is that it produces more raw fermentable sugar under marginal conditions that are not suitable for producing either sugar cane or sugar beet (Whitfield *et al.*, 2012). Given the marginal production conditions that characterise SSA production systems, sweet sorghum offers a great potential for bridging up nutritional and feed and fodder requirements among the most vulnerable households in SSA.

GENETIC DIVERSITY

Sweet sorghum cultivars are polyphyletic and are known to exist in all the five common races of *Sorghum bicolor* [L.] Moench by Harlan & Wet (1972), which are bicolor, guinea, caudatum, kafir, and durra (Hunter and Anderson, 1997; Ritter *et al.*, 2007; Sagnard *et al.*, 2011; Whitfield *et al.*, 2012). Many cultivars of sweet sorghums are widely grown in SSA and continue to be grown primarily for chewing, offering diversity that is preserved *in-situ* (Harlan and Wet, 1972; Legwaila *et al.*, 2003). However, such diversity is highly threatened by droughts and shifts in farmer food and fodder preferences (Upadhyaya *et al.*, 2017). Most of the sweet sorghums stored in gene banks worldwide originated from SSA and Asia; with the eastern horn of Africa particularly Ethiopia and Sudan being important centres of domestication and diversity (Upadhyaya *et al.*, 2017). A study in 1987 isolated 983 sweet stalked sorghums by chewing test from over 9000 Sorghum World Collections maintained at the International Crops Research Institute for Semi-Arid Tropics (ICRISAT) (Ratnavathi *et al.*, 2016). The US National Plant Germplasm System has a collection of 2180 accessions of sweet sorghum. These offer a great potential for exploitation by National Agricultural Research Systems (NARS) in breeding programmes (Cuevas *et al.*, 2015). In addition to this, it is estimated that there are over 4000 sweet sorghum cultivars grown throughout the world offering a wide genetic base for the crop (Rutto *et al.*, 2013).

Studies done in SSA show a wide genetic base available for sweet sorghums (Abd El-Razek and Besheit, 2009; Nasidi *et al.*, 2010; Mangena *et al.*, 2018). This implies that populations of sweet sorghum can respond to selection; hence significant improvements can be made on a number of farmer or processor preferred traits.

ADAPTATION

Sweet sorghum is highly adaptable under wide annual rainfall regimes with an optimum of 550 to 800 mm (Rao, *et al.*, 2013). It can tolerate a temperature range of 12-37 ^{o}C, although the preferred optimum temperature for growth and photosynthesis is 32-34^{o}C (Rao *et al.*, 2013). Sweet sorghum can be grown from sea level to an altitude of 2500 meters for cold tolerant cultivars (Rao *et al.*, 2013). The crop can grow in a variety of soil types, conditions and can tolerate varying degrees of biotic and abiotic factors and stresses (Nasidi *et al.*, 2019).

Sweet sorghum has a well-developed root structure that can extend up to 2 m below ground level; thus, making it efficient in moisture extraction from the soil (Mathur *et al.*, 2017). Furthermore, it has the ability to become dormant, especially at the vegetative phase under adverse conditions; and can resume growth after relatively severe drought. The crop is, however, susceptible to sustained flooding, but survives temporary water logging much better than maize (Rao *et al.*, 2013).

Sweet sorghums have a relatively short life cycle, averaging 4 months; less input requirements, low cost of cultivation and C4 photosynthesis; all giving it high radiation use efficiency (Mathur *et al.*, 2017). Like most field crops, yield of sweet sorghum responds to good agronomic practices such as early planting, optimum plant density, tillage and moderate fertiliser application, especially nitrogen. Conservation agriculture has been reported to increase yield and enhance soil quality under limiting water conditions of SSA (Malobane *et al.*, 2018). Sweet sorghum has a growing period of about 4 months, which is 8-12 months less than that of sugar cane and water requirement of about 8000 m^3, which is 4 times lower than that of sugarcane (Reddy *et al.*, 2005).

PLANT BREEDING EFFORTS

Sweet sorghum production in SSA largely relies on seed carry over from previous seasons and materials grown are non–descript (Legwaila *et al.*, 2003; Naoura *et al.*, 2020). There is lack of improved seed in virtually all sub- Saharan countries; yet limited cultivars have been commercially released (Legwaila *et al.*, 2003). Moreover, there are various sorghum collections in gene banks that contain traits for sugar content and juiciness in their stalk (Upadhyaya *et al.*, 2016). There is, therefore, a great need to breed improved cultivars for sustainable and optimum use of the crop (Mathur *et al.*, 2017).

Globally, a number of sweet sorghum cultivars has been released; notable among these cultivars are 'Brandes', 'Dale', 'Keller', 'Ramada', 'Rio', 'Roma', 'Theis' and 'Vani' (Prasad *et al.*, 2019). Within SSA, notable breeding activities have been spearheaded by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Patancheru in Andhra Pradesh, India. According to Reddy *et al*. (2005) sweet sorghum breeding was initiated in 1980 with the evaluation of 70 germplasm accessions and two landrace lines IS 6872 and IS 6896 with high stalk sugar content and biomass were selected in 1981. Later research identified several sweet sorghum lines from Nigerian and Zimbabwean lines. The ICRISAT sweet sorghum research ended in the early 1990s due to changed focus driven by and the changing needs of national agricultural research systems (NARS).

In 2002 ICRISAT renewed breeding sweet sorghum as a result of increased need to produce fuel. Notable projects are the SWEET fuel project that was done in South Africa, in partnership with the Agricultural Research Council- Grain Crops Institute ARC-GCI (Braconnier, 2014). ARC identified one Open Pollinated Variety, OPV007 as a very good producer of sugar and fodder, as well as five cultivars excellent for biomass, syrup yields and sugar contents. Some of these cultivars showed also a good tolerance to mid-season and/or terminal drought stress such as SSP081 and Hunnigreen (Braconnier, 2014).

USES OF SWEET SORGHUM

In SSA, sweet sorghum is mainly utilised for chewing and the grain is usually of poor quality (Legwaila *et al.*, 2003; Naoura *et al.*, 2020). Most sweet sorghum research in SSA posit on the potential benefits in bioethanol production (Woods, 2001; Nasidi *et al.*, 2010) in comparison with sugarcane (Abd El-Razek and Besheit, 2009; Nasidi *et al.*, 2010; 2019).

The discussion centres on attributes that make sweet sorghum the best choice for bioenergy production (Mathur *et al.*, 2017). While ethanol production promises great potential, this may not be a priority for most of SSA farmers who grow sweet sorghum. In order to ensure increased utilisation, development of the crop should mainstream these current uses of the crop, since to most SSA countries will be the only option presently and the near future (Legwaila *et al.*, 2003).

In SSA, four production models for the economic development of the sweet sorghum industry are possible; namely (i) production for supply to urban chewing markets; (ii) syrup production; (iii) biofuel production; and (iv) fodder production. These are discussed in greater details as follows:

Production for urban chewing markets. Sweet sorghum is extensively consumed as a snack in most SSA countries (Legwaila *et al.*, Naoura *et al.*, 2020). Farmers who can easily access urban markets, with good road networks and closer to urban areas, supply to these markets. The major limitation of sweet sorghum is fast sugar degradation during storage resulting in a short shelf life after harvesting (Ratnavathi *et al.*, 2016). The other challenge is that farmers rely on non-descript and not uniform landraces with harder rinds and barks (Balole, 2001; Naoura, 2020). Breeders should target to improve traits such as shelf-life and easy to remove bark, soft easy to chew pith and early maturation of grain, in order to satisfy the needs of this market. Cultivars that have high sugar content at maturity can be ideal for the chewing market since farmers can harvest the grain for food and for feed. To counter the limitations of a short shelf life, the sugar is extracted to make syrup and the United States of America has a strong history of syrup production and their industry continues to rely on sweet sorghum syrup as a sweetener (Winberry, 1980; Regassa and Wortmann, 2014).

Syrup production. Traditionally, sweet sorghum has served as a syrup crop in developed countries, especially the USA (Winberry, 1980; Regassa and Wortmann, 2014). Sweet sorghum syrup is a natural alternative sweetener in breakfast, confectionery and dairy industries. This syrup, unlike sugarcane sweeteners, has a better nutrient profile, is rich in iron, calcium and zinc (Nyoni *et al.*, 2020). There is need for vigorously promotion of utilisation of sweet sorghum syrup in various products in SSA in order to increase the demand for the product.

The boom in the United States syrup industry of the mid-19th and early 20th centuries (Winberry, 1980) provides significant positive lessons for SSA countries. The syrup production model appeals to farmers who do not have easy access to urban markets, due to limitations of poor road conditions and distances to the markets (Berg *et al.*, 2018). Usually, these farmers are in areas where fuel wood can be sustainably harvested for syrup processing. Such farmers need support to acquire simple juice extraction and syrup making machines. The resultant syrup can be locally aggregated in collection centres such aggregation schemes which are already available in SSA for other agriculture cash crops, for example cotton (Bingen, 2006). Availability of labour and energy resources on farm, in most SSA countries can valorise the sweet sorghums industry in SSA. Subsidised local juice extraction and syrup processing machines can be deployed among resource smallholder farmers for syrup production.

Biofuel production. The sugars in sweet sorghum in the form of stalk juice is extractable and directly fermentable to produce ethanol. It is estimated that one hectare of sweet sorghum can produce up to 8000 litres of ethanol per year (Woods, 2001; Ratnavathi *et al.*, 2016). The adaptive features of sweet sorghum and low input requirement, compared to sugarcane, make it one of the leading candidates for biofuel feedstock in the world (Mathur *et al.*, 2017; Malobane *et al.*, 2018). Unlike sugarcane, the crop can uniquely provide two crucial socio-economic interventions. Firstly, it can significantly address the growing need for renewable energy to substitute fossil fuel-based energy resources, through production of ethanol as a biofuel. Secondly, it does not compete with food crops for arable land as it can produce the much-needed grain and at the same time allow use of marginal lands leading to their conservation (Mathur *et al.*, 2017). Research, however, is yet to solve the twin technical challenges of using sweet sorghum for biofuels, which include (i) a short harvest period for the highest sugar content; and (ii) fast sugar degradation during storage (Ratnavathi *et al.*, 2016).

Since sorghum production in SSA is mostly by smallholder farmers, smaller processing and fermentation plants are more appropriate. Accordingly, there is still room for technology in order to make this a viable venture for this category of farmers.

Biofuel production from sweet sorghum has been proposed for SSA by many scholars (Woods, 2001; Nasidi *et al.*, 2010), especially during sugarcane fallow periods (Woods, 2001). According to Woods (2001), about 10% of land area under sugarcane in SSA would theoretically be available for sweet sorghum production. In order to increase area under sweet sorghum, there is need to consider contracting small-holder farms as out-growers of existing processing plants. This, however, may be limited to smallholder farms in proximity to sugar processing plants.

Sweet sorghum for fodder. Sweet sorghum is a versatile crop that can be used for fodder, forage and silage making (Yucel and Erkan, 2020); and has for long been used as livestock forage resources (fermented fodder) (Podkówka and Podkówka, 2011; Getachew *et al.*, 2016). Although inferior in forage yield and quality to maize, when growing conditions are optimum, sorghum exhibits superiority in areas of low rainfall and low plant nutrition (Getachew *et al.*, 2016). Sweet sorghum forage is preferred by livestock and is likely to be consumed in greater quantities when in the form of green chop or hay.

Sweet sorghum can be used directly or through the development of fodder hybrids (Soujanya *et al.*, 2018). In more intensive production, fodder cultivars are usually crosses between grain and sweet sorghums and the resultant product has a higher sugar content than ordinary sorghums and are less liable to cause cyanide poisoning in ruminants (Suttie, 2000).

Due to the integrated crop-livestock farming systems predominant in SSA (Duncan *et al.*, 2013), sweet sorghum production can have ripple effects to communities in the region. Other than relying on low quality crop residues, improved cultivars of sweet sorghum stands to provide the much needed grain and the crop residues can be harvested for production of high quality silage and hay.

CONCLUSION

Sweet sorghum is a high potential multi-purpose crop in SSA, offering opportunities for meeting community needs by complementing the constrained supply of grain for human food, fodder and silage, as well as biofuel. Broadening research efforts to focus on other products from sweet sorghum can be beneficial to small holder farmers in SSA. A lot has to be done on the research front before biofuel production from sweet sorghum can be profitable and technically feasible, especially for smallholder farmers in most SSA countries. While ethanol yield is a good priority for research, this should not overshadow other potential uses of the crop such as production for chewing, syrup and fodder which may be the only option for most SSA farmers.

Future plant breeding efforts can be tailor made to deliver cultivars with peculiar traits for various end-uses. Dual purpose cultivars that give high stem juice yield, brix and grain will be a bonus to SSA farmers. There is scope for taking lessons from the 19th century boom in the American syrup industry and remodel it to suit the SSA context. This will work mostly in an agro-ecology context applicable for small scale farmers where local home grown solutions are preferred as the world wrestles with climate change and new transboundary challenges such as Covid 19, crop pests and diseases.

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