Drought-Resilient Climate Smart Sorghum Varieties for Food and Industrial Use in Marginal Frontier Areas of Kenya

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Chapter 3
Drought-Resilient Climate Smart Sorghum Varieties for Food and Industrial Use in Marginal Frontier Areas of Kenya

Symon M. Njinju, Joseph Onyango Gweyi, and Rose N. Mayoli

Abstract *Sorghum bicolor* (L) is classified globally as the fifth most important cereal crop after wheat, maize, rice, and barley. The demand for sorghum in Kenya is increasingly at 275,000 T per annum against the estimated production value of 150,000 T, providing income to more than 3 million people. Apart from food, Kenya Breweries Limited consistently provides a ready market to a huge amount of sorghum estimated at 60,000 tonnes annually and is expected to rise with time. In Kenya, the sorghum productivity level is at 0.7 t/ha in Arid and Semi-arid Lands areas (ASALs), which is far much below the potential yield ranging between 2 and 5 ton/ha. Sorghum's rich diversity in ASAL areas makes it suitable for adaptability to Climate Smart Agriculture, Technologies Innovations Management Practices. This makes it a worthy crop for supporting livelihoods under the harsh climatic condition caused by climate change. In Kenya, Sorghum crop is usually cultivated at 0–2200 m above sea level in Eastern, Nyanza, and Coastal regions. Being a C4 plant, it has an efficient carbon dioxide fixation that makes it perform well in lower altitude areas with high temperatures, low, intermittent, and unreliable rainfall. Farmers in such areas opt to grow local varieties instead of the high-yielding hybrids due to poverty, inability to afford irrigation facilities, and essential necessities for production. Drought and water stress caused by inadequate and unevenly distributed rainfall in ASALs limit sorghum productivity. Also, pests, diseases, low yields, weeds, local planting seeds, and use of fertilizers are other challenges. On the other hand, enhancement of drought tolerance in arid climatic conditions involves

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mechanisms that maintain plant water status upon which genes and proteins are activated. This process most likely can affect plants resulting in a good number of physiological and biochemical changes that are crucial for growth and survival. Among them, changes in grain weight and protein content may affect the malt quality. As a defense mechanism in response to drought, sorghum landraces native to ASALs are likely to activate and involve participation of numerous proteins that may affect the grain and malt quality. It is imperative to come up with a drought-tolerant sorghum variety with good grain and malt quality and new technologies to be recommended to the stakeholders for improved sorghum production.

Keywords Sorghum bicolor · Drought tolerant · Climate change

1 Introduction

Sorghum bicolor (L) ranks as the fifth most important cereal crop after wheat, maize, rice, and barley globally (Batista et al. 2019). The best-known sorghum varieties are *Sorghum vulgare* and *Sorghum bicolor* L. Moench. *Sorghum vulgare* species accounts for all annual types (Owuama 1999), while *Sorghum bicolor* L. Moench accounts mostly for the cultivated grains in Africa (Taylor 2003). Sorghum production is chiefly exercised in developing countries with 90% of the cultivated lands being located in Asian and African countries. Africa produced a sizeable amount of sorghum yield which accounts for one-third of worldwide production. This production is aided by the fact that Africa experiences tropical conditions (Munda et al. 2019). In Kenya sorghum is mainly grown in Eastern, Nyanza, and Coast regions. This is aided by the fact that sorghum has the capability of performing fairly well under unfavorable weather conditions which dominate in Sub-Saharan Africa (SSA). Also, it can tolerate exposures to waterlogging; in this case, Power et al. (2019) reported that it prominently serves as a viable cereal crop in most food-insecure households. In addition, subsistence farmers in the same regions most of the times lack necessary farm inputs as well as finances to adopt irrigation systems (Glantz 1987; Leichenko and O'Brien 2002). As a result, the crops are mechanically forced to react through production of biochemical responses for compensation (Izanloo et al. 2008; Tekele 2010).

In Kenya, Sorghum is well adapted to the arid and semi-arid lands (ASALs). This accounts for 80% of Kenya's total landmass, which receives less than 750 mm of rainfall annually. It is approximated that sorghum requires about 332 kg of water for 1 kg of dry matter compared to 368 kg and 514 kg of water for similar amount of dry matter in maize and wheat respectively, and this makes it a smart choice for climate smart agriculture. In Kenya, there are approximately 240,000 smallholder sorghum farmers with land sizes that ranges from 0.4 to 0.6 ha (KAVES, 2013). Though mono-cropping is greatly recommended for sorghum, only a few farmers adhere to this directive because of the small pieces of land (KAVES, 2013). The production of sorghum in the country has been rising in the recent past (approximately in the last 10 years from 54,000 tonnes in 2008 to about 180,000 tonnes in 2018 (FAOSTAT, 2019)).

In 2014, statistics showed that sorghum provided income to more than 3 million people in Kenya (MOALF 2014). Besides, it serves as an essential food security crop in semi-arid areas of Africa (Munda et al. 2019). It is estimated that more than half of sorghum production is consumed as food, 1% as livestock feed, about one-fifth is processed, and about 15% lost in the field and after harvest (FAO 2019). The grains and sweet stalk can be utilized in food and non-food sectors for the production of commercially valued products, such as syrups, glucose, modified starches, maltodextrins, jaggery, sorbitol, and citric acid (Ratnavathi et al. 2016). Also, sorghum is used to manufacture wax, starch, dextrose agar, and edible oils (Dicko et al. 2006). Sorghum is a rich source of phytochemicals including tannins, phenolic acids, anthocyanins, phytosterols, and policosanols, which have remarkable impact on human health such that it reduces chances of cardiovascular disease, cancer, and obesity (Awika and Rooney 2004).

Besides, it can be used as a basic ingredient in beer production as malt and adjunct with a big market in the brewing industry in the country. To this end the Kenya Breweries Limited (KBL) is reportedly to be among the top most users of sorghum, thus providing a ready market which stands at 60,000 tonnes of sorghum annually and this is expected to continue rising with a projected increase in beer consumption (Tegemeo, 2018). Statistics reveal that the demand for sorghum is on the rise at an average amount of 275,000 tonnes/year against the estimated production level of 150,000 tonnes (FAO 2019). This was occasioned by sorghum promotion strategy for its use in making beer in Upper and Lower Eastern as well as Western regions. This has enhanced its production and industrial use. Therefore, due to its huge demand by various sectors of the economy, this prompted sorghum to be identified as one of the priority crops for enhancement through research by Kenya Climate Smart Agriculture Project (KCSAP), which is being implemented in various counties including Baringo and Siaya counties (Fig. 3.1).

Drought is one of the most important environmental stresses that critically impairs plant growth and development; this limits plant production and performance immensely than any other environmental factors (Shao et al. 2009). Although sorghum reveals resilience to the effects of water stress, some specific growth stages of its life cycle are more susceptible to water stress than others. For instance, drought inhibits sorghum establishment in early vegetative seedling growth stage through to the reproductive stages (pre- and post-flowering) (McKersie and Leshem 1994; Tuinstra et al. 1997; Kebede et al. 2001; Wani et al. 2012). However, to counter the effects of water stress, plants show coping mechanisms such as avoidance, tolerance, and escape (Tuinstra et al. 1997; Bray et al. 2000). Drought escape mechanisms are revealed when plants complete their life cycle before severe water stress arrives, while avoidance mechanisms are brought up when the plant maintains relatively high quantities of water in their tissues despite there being moisture shortage in the atmosphere (Shashidar et al. 2000). Finally, in drought tolerance, the plants balance between turgor pressure maintenance and reduction of water loss assisting them in surviving incidences of drought stress (Shashidar et al. 2000).

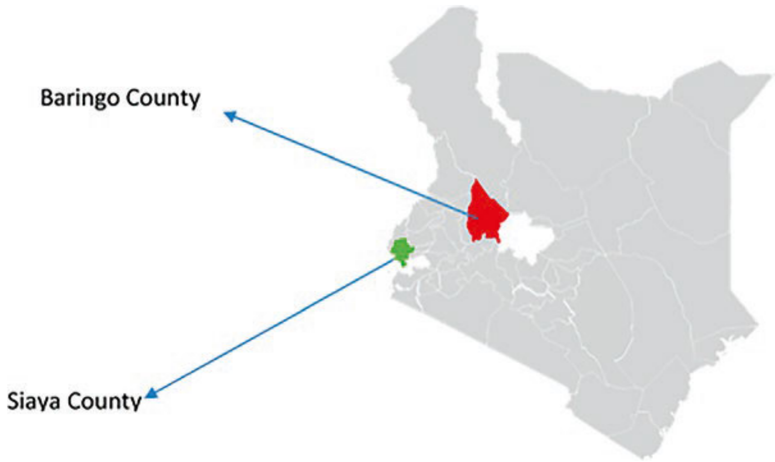

Fig. 3.1 Map of Kenya showing sorghum-growing counties of Baringo and Siaya

Even though water is essential for biological processes, periods of drought have profound effects on physiological processes. Under field conditions that are subject to cyclical changes with unpredictable climatical conditions, intermittent rains may follow a drought period prompting biochemical responses to a rehydration event which is a good indicator of recovery after rehydration. Crops have been found to exhibit a compensatory effect after exposure to such stress (Adalsteinsson 1994; Devnarain et al. 2016). In ASAL environments there is a tendency of intermittent rainfall that interferes with the plant's biophysical processes resulting in stress. Though it is important to have higher drought resistance during drought periods, drought stress in plants is usually transient and the capacity to recover is also very important. Among the important aspects to consider while selecting sorghum varieties for increasing yields and income in the drought-prone areas is compensatory of losses during drought stress.

The drought situation has been exacerbated by the effects of climate change which leads to erratic rainfall and salinity stress in arid and semi-arid regions (ASALs). This is coupled with high incidences of pests and diseases, weeds, high soil salinity, and low soil fertility. In addition, sorghum is less preferred by the farmers as compared to maize which is more susceptible to drought (Riziki and Maina 2013). Furthermore, sorghum production in the country in some areas has stagnated due to lack of adoption of suitable drought-tolerant genotypes (Timu et al. 2014). This has led to low sorghum yields which cannot meet its rising demand. Thus there is an urgent need to utilize well-adapted drought resistant sorghum varieties that would then help in climate change mitigation. This is because well-adapted sorghum can endure high temperatures and drought and can withstand long periods of exposure to waterlogging, hence a good alternative for improving livelihoods.

2 Traits Favoring Sorghum Production in Kenya

Sorghums varieties being grown in tropics are influenced by photo-periodism and thus they are categorized as short day plants. Therefore their response to day length is an important adaptation mechanism. Just like other C4 photosynthetic plants, sorghum has a CO_2 fixation mechanism that is effective prompting it to perform well in low altitude areas experiencing incidences of high temperature and drought (Paterson 2008). The crop is also cultivated in altitude range (0–2200 m) above sea level and has a potential for increased production in Kenya since it has large ASAL areas accounting to 82% of the total landmass (Munyiri et al. 2010) that are characterized by high temperatures and low intermittent and unreliable rainfall. However, all is not lost since some sorghum genotypes both landraces and improved ones are well adapted and can be grown successfully in these areas in combination with viable technologies. This is because sorghum is documented to be drought resistant and produces better yields with minimum precipitation and thus it is one of the crops of ensuring food security (Riziki and Maina 2013). The available local varieties have characteristics none other than high yielding, drought resistance, and early maturity among others (Muui et al. 2019). Additionally, there are several hybrids with special attributes like high yields that have been recommended and released for adoption in Kenya as shown in Table 3.1.

Table 3.1 Hybrid sorghum varieties grown in Kenya

Variety	Grain color	Maturity (months)	Eco zone and area	Special attributes
Gadam	Gray	3.5	Semi-arid lowlands of Machakos, Kitui, Kajiado, Embu, Makueni, Mwingi, Parts of Rift Valley, NEP	Tolerant to birds, stem borers, shoot fly, and foliar diseases
Seredo	Brown	3.5		Wide adaptability
Serena	Brown	3		Wide adaptability
KARI Mtama 1	White	3–3.5		Attractive to birds
KARI Mtama 2	White	3.5		Resistant to birds
E1291	Brown	7	Baringo, Nakuru, Koibatek, Taita Taveta, Narok	Dual purpose, good beverage
E6518	Brown	8		Good beverage
IS76	White	3		Tolerant to stem borers
BJ28	Brown	7		Dual purpose

Source: Greenlife Crop Protection Africa (2019); http://www.kari.org/ENGLISH/Sorghumfood.htm

3 Challenges in Sorghum Production

Despite its critical roles, sorghum production margins in Kenya have stagnated for long, leading to importation of more than one-third of the total consumption. This is because sorghum production is faced with numerous challenges that lead to low yields. The major constraints limiting attainment of high yield include pests and disease, drought, weeds, and marketing. Also, there are issues to do with lack of certified seeds (Muui et al. 2013; Tegemeo, 2018). In addition, there is genotype interaction, environmental factors, and production issues. Drought is one of the main challenges, especially in the ASALs, that hinders growth and yield of sorghum (Cicek and Cakirlar 2002). In actual sense, the permanent or temporary water deficit severely affects plant growth and development more than any other environmental factors (Anjum et al. 2011).

In terms of weeds, a study by Muui et al. (2019) revealed that low sorghum yields were attributed to Witchweeds, although the study also captured pests, diseases, and lack of fertilizers as other important negative factors. In ASALs, water stress is classified as a major constraint leading to low yields in ASALs. This water stress is caused by inadequate, erratic, and unevenly distributed rainfall. This is conjoined with other factors such as farmers being poor, and therefore, they are unable to afford irrigation technologies and other necessary equipment due to their poverty-stricken characteristics (Jaetzold et al. 2006). Furthermore, there are limited efforts to deliberately avail and promote sorghum varieties that are suitable and well adapted.

4 Effect of Drought on Sorghum Grain and Malting Quality

Drought stress prompts manifestation of some of the main survival mechanisms, including the genes and proteins getting activated, and these affect many processes such as physiological and biochemical changes that are critical for survival and growth (McDowell 2011). For instance, under water stress, barley grain weight and protein content are known to reduce and increase, respectively, consequently worsening the malt quality (Wu et al. 2017). Sorghum landraces native to ASALs are likely to activate several defense mechanisms that involve participation of numerous proteins in response to drought effects (Gong et al. 2005; Farmer and Mueller 2013; Calzada et al. 2019). Also, such physiological and biochemical mechanisms may affect the sorghum grain and malt qualities desirable to the consumers.

4.1 Grain Quality

The sorghum grain quality to a great extent depends on the grain type. It includes a range of properties that can be defined in terms of physical (moisture content at 12.5%, kernel size), hygiene (fungi and mycotoxin count), and intrinsic (fat content, protein content, endosperm texture, hardness, and starch content) quality characteristics (Ratnavathi et al. 2016). In addition, Ratnavathi et al. (2016) reported the alpha amylase and diastatic activity of different cultivars.

The quality properties of a grain are influenced by their genetic makeup growth period, time of harvesting, handling equipment, drying system, storage practices, and transportation mechanisms (Ratnavathi et al. 2016). Studies have shown that moisture stress has notable effect on the chemical composition of sorghum varieties. Increased drought shows decreased protein and starch content in sorghum grains (Khaton et al. 2016). Grain protein and starch contents also differ with varieties where drought-tolerant varieties have higher quality grains than less tolerant varieties (Khaton et al. 2016).

4.2 Malt Quality

Sorghum primary processing stages involve grading, cleaning, destoning, dehulling, and polishing of the grain to improve its appearance and market price while secondary processing involves its conversation into food products. In sorghum malting, its quality and phenolic contents provide it with important raw material (Embashu and Nantanga 2019). Therefore, it is necessary to select sorghum genotypes fit for brewing considering the malt quality parameters including hot water extract (HWE), malting weight loss (MWL), diastatic power (DP), and free amino nitrogen (FAN). The actual malting procedure involves controlled grain steeping in water, germination in moist air, and drying (Bekele et al. 2012). Its presence assists in mobilizing endogenous hydrolytic enzymes (α- and β-amylases in the grain) to modify the structure of the grain so that it will be readily solubilized during the brewing process to produce fermentable worts of desirable characteristics; flavors, nutrients, and color with a minimum loss of dry weight.

Sorghums' malt quality is highly affected by the malting processes, in particular steeping, germination, brewing conditions, and variety. This remarkably affects the hectoliter weight, crude protein, germination energy, and flour starch amylose content (Bekele et al. 2012). Steeping sorghum grain in dilute formaldehyde and sodium hydroxide enhances the malt quality in genotypes with high levels of condensed tannin by suppressing inhibitory effects on the malt enzyme (Taylor et al. 2006; Beta et al. 2000), while sodium hydroxide increases water uptake by the sorghum grain (Beta et al. 2000). Also, waxy and hetero-waxy varieties have the best malting potential, and thus, they are usually fit in the brewing industry since their soft endosperm texture allows hydrolytic enzymes ingress to starch granules that already have increased gelatinization in comparison with normal non-waxy sorghums (Taylor et al. 2006; Beta et al. 2001).

5 Opportunities for Sorghum Research in Kenya

Globally, there is a huge market potential for sorghum that needs to be exploited. Among the top 10 sorghum producers globally, only the USA and Argentina have notable volumes for exportation. On the other hand, countries like Japan, Mexico, and India still import huge volumes of sorghum to meet domestic consumption (Tegemeo 2018). In Kenya, Sorghum production has increased due to its unexploited potential, which can be harnessed for poverty alleviation, income generation, employment creation, and malnutrition reduction. For these reasons, sorghum cultivation has been revitalized as a traditional high value crop (MOALF 2015). Sorghum production potential in Kenya ranges from 2 to 5 ton/ha against the realized production yield of 0.7 tons/ha which is unlikely to meet the ever-increasing domestic market. It is grown on an estimated area of about 184,654 ha, and this has the ability to support over 25% of Kenyans in food supply and more than 26% for livestock feeds (Fig. 3.2).

Sorghum has become an important crop despite its unique viability. Sorghum can be utilized as a source of food and industries for the production of alcohol, biofuels, and livestock feeds. With the low productivity level, it is expected that the country will not satisfy the demand. Sorghum for consumption has the potential for value addition in manufacturing alternative products, for example, gluten-free flour. Gluten can be availed to patients with gluten-related disorders. Sorghum is preferred as an alternative to maize for making livestock feeds production because it is a bit cheaper to produce. Therefore, the reduction in costs of livestock feeds could have a notable impact on the livestock industry because the cost of feeds is one of the key important factors in the livestock sector.

Sorghum production offers multiple possibilities for selection of genotypes adaptable to both CSA and TIMPs and a wide range of uses. Sorghum has potential to produce a wide range of products like sorghum syrup, baking, brewing, agrochemical, ethanol, and bio-energy (Njagi et al. 2019). Therefore increased sorghum supply will not only provide required raw material for Kenya Breweries Limited,

Fig. 3.2 Hybrid grain sorghum field in Siaya county: demonstrates the high potential for sorghum production in ASALs of Kenya

but also it will create opportunities for other value chain actors. As a consequence, breeders and seed companies will renew their interest in investing in the production of sorghum seeds. Also, production inputs and extension services demand will rise creating more opportunities. Since Kenya has bilateral agreements with countries such as China, Japan, and India who are among the leading countries in utilizing sorghum, this can be a platform for negotiations with an aim of getting more market opportunities for sorghum or its products.

6 Approaches for Resolving Sorghum Shortage and Need for Research

The main approaches should be centered on high investment in inputs such as improved seeds; this is because adoption of modern varieties of sorghum is quite low (Gebretsadik et al. 2014). Also the focus should be on investing in fertilizers and related inputs for enhancement of crop intensification, commercialization, and value additions. Additionally, other factors to be considered include identifying and bringing together all the key stakeholders in the sorghum industry, and this can be achieved through initiatives. Also there should be formation of production cells and farmers will be able to receive trainings and be able to get ready market. Another key issue is marketing, and as a country, the focus should be in investing in the progression of market institutions, processing methods, and innovations that reduce marketing costs. This could be achieved effectively by embedding on the options for enhancing competitiveness and demand creation (e.g., food and non-food uses). Actually, the sorghum venture should be sustainable "market-oriented" enterprise enabled to successfully compete with rest of the crops. Also new technologies such as modelling using Agricultural Production Systems sI-Mulator (APSIM) model to help in designing more resilient and productive farming systems using the diverse sorghum genotypes available in the region. A model by Adiku et al. (2015) on the impact of climate change on productivity of locally important traits could help in developing adaptation and mitigation strategies in sorghum as no blanket approach is applicable.

Research programs should be on proper understanding of the mechanisms that underlie drought tolerance by carrying out research on the physiological and biochemical processes. Although grain sorghum manifests resilience to the effects of water stress, particularly during the growth stages in its lifecycle, the most susceptible stages to drought stress are the early vegetative stage and reproductive stages (that is pre- and post-flowering) where water requirement is on high demand (Anjum et al. 2011; Kebede et al. 2001). Water stress during pre- and post-flowering stages also impacts negatively on grains. Therefore the ability to withstand water deficit and recover after drought at these stages is of importance for increased plant growth and yield. Intensive research should be carried out to understand plant responses to water deficit, because works describing the effects of water stress and re-watering on plants are limited (Takele, 2010). In addition, there are good reports indicating compensatory effects of crops under stress. It would be important to understand such compensatory effects in sorghum genotypes under different water regimes. Some of the main mechanisms for sorghum recovery after drought are suggested to be as a result of the genes and proteins which are activated. This affects many processes in the plants causing physiological and biochemical changes of genotype. These changes include loss of cellular turgor, membrane fluidity and composition, osmotic potential, and protein–protein interaction.

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