International Research Journal of Plant and Crop Sciences (IRJPCS) ISSN 1711-3490, Vol. 6(2), pp. 188-195, November, 2021. Available online at www.advancedscholarsjournals.org © Advanced Scholars Journals

Review paper

Breeding of sorghum crop for resistance and tolerance to drought

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Accepted 21st September, 2021.

Drought is a limiting factor for the production of crops across the entire world. Since sorghum is highly produced from arid to semi-arid tropics, it is one of the stable crops for farmers around those areas. However, there are a number obstacles that retard the product and production system of sorghum in the country. Among these challenges' drought is a series issue. Breeding of crops can improve the capability of the crop to withstand the harsh environments. In the case of sorghum, currently, different varieties that are created with the help of plant breeding effort that are increasing the yield through tolerating drought. Even though, drought is a limiting factor, sorghum can withstand the harsh environments through a number of mechanisms. Stay greenness, solute accumulation, leaf rolling and root characteristics are critical events for drought resistance in sorghum crop.

Key words: Breeding, drought, Stay greenness, environments, solute accumulation

INTRODUCTION

Sorghum [Sorghum bicolor (L.) Moench, [2n = 2x = 20] is the emerging model crop species for the tropical grasses with C4 photosynthesis that's belongs to family poaceae (Dicko *et al.,* 2006). Sorghum is the fifth most important Cereal crop and occupies the second position among the staple food grains in semi-arid tropics. It remains a critical component of food security for more than 300 million in Africa. The reports of Vavilov (Vavilov, 1951) and Doggett (1991) suggested that, sorghum was domesticated and originated in the North-East quadrant of Africa, most likely in the Ethiopian-Sudan border regions and believed to originate from North East of Africa particularly Abyssinia (Harlan, 1972). Sorghum is a multi-purpose crop grown in a diverse agro- ecologies of Ethiopia. It covers 18% of the area of cereal crops and contributing 14.6% of the grain production. Sorghum serves as a dietary staple crop for millions of people, especially in arid and semi-arid farming systems. Additionally, sorghum grain is used as livestock feed and for production of local beverages, while the stalk is used for animal feed, firewood, and as a construction material (McGuire, 2000). Sorghum grows across a wide geographic area at various altitude, day length, rainfall, and temperature regimes. Consequently, it is well adapted to withstand harsh conditions, which are the characteristic feature of tropical regions. The crop requires relatively less water than other important cereals such as maize and wheat.

However, yield potential of the crop is significantly limited due to drought and heat stresses within the tropics and subtropics necessitating sorghum breeding for drought tolerance and productivity (Blum, 2005). Drought is one of the most important factors that affect crop production worldwide. Climate changes will increase the frequency of drought and flood, particularly in many countries in Africa. There is indication that climate change may lead to a change in the frequency and severity of drought events. For instance, by 2050, water shortages are expected to affect 67% of the world's population (Ceccarelli et al., 2004). Drought can occur at any stages of the crop development. However, in the arid and semi-arid tropics, the probability of drought is highest at the start and end of the growing season. Drought stress at the beginning of the growing season will severely affect plant establishment.

If drought occurs at flowering, or in the grain filling stages, it may result in reduced yield, or complete crop failure (Tumwesigye and Musiitwa, 2002).

Drought stress is a serious agronomic problem contributing to severe yield losses worldwide. This agricultural constraint may nevertheless be addressed by developing crops that are well adapted to drought prone environments. Drought tolerance depends on the plant developmental stage at the onset of the stress syndrome, which in sorghum may happen during the early vegetative seedling stage, during panicle development and in post flowering, in the period between grain filling and physiological maturity.

Drought contributes to poor performance and crop yield in sorghum. Especially, Countries in arid and semi-arid tropics usually experience insufficient, unevenly distributed, and unpredictable rainfall. At one-point rain may be abundant and perhaps wasted through runoff; in some years much rain may fall completely outside the growing season. In other years, in adequate mid-season rain may fall after crops have germinated, causing crop failure. Although drought stress at the beginning of the growing season may severely affect plant establishment, plants tend to recover soon when late rain fall levels are adequate (Ramu et al., 2008).

Drought can have major consequences on growth, development and yield of crops by affecting several physiological, morphological and biochemical processes. It is the major cause of poor crop performance and low yields, and sometimes it causes total crop failure. Sorghum highly requires water during in early growth and flower initiations stages. Sorghum production is constrained by several biotic, abiotic and socio-economic factors. Amongst the most important abiotic constraints, drought is the most important. Drought can occur at any stages of the crop development. However, in the arid and semi-arid tropics, the probability of drought is highest at the start and end of the growing season. Drought stress at the beginning of the growing season will severely affect plant establishment. If drought occurs at flowering, or in the grain filling stages, it may result in reduced yield, or complete crop failure (Blum, 1996). Therefore, understanding of the Breeding mechanisms and genetic control of drought in sorghum is important as a base for improving the production and productivity of the crop across its growing areas. Even if drought is one of the limiting factors for the production of sorghum in the world, sorghum has its own physiological adaptation mechanisms to overcome the drought to give attainable yield for the farmers.

Breeding of crops can improve the capability of the crop to withstand the harsh environments.

In the case of sorghum, currently, different varieties that are created with the help of plant breeding effort that are increasing the yield through tolerating drought. Molecular markers linked to QTL (quantitative trait loci) for drought tolerance could be used in increasing efficiency of breeding efforts to select sorghum germplasm with enhanced drought tolerance once these markers are identified through carefully monitored characterization of appropriate germplasm under stress conditions.

Breeding sorghum for drought tolerance is vital for the breeding to alleviate adverse effects of drought in order to boost production and productivity in the country. Therefore, the objective of the review is to understand the breeding and adaptation mechanisms of sorghum for drought prone areas and to know the breeding strategy for tolerance to drought in sorghum and the ways sorghum can tolerate harsh environments to give attainable yield.

LITERATURE REVIEW

Drought

Drought is an extended abnormal dry period that occurs in a region consistently receiving below average rainfall. Drought is one of the major abiotic stresses in the world. Globally, agriculture is the biggest consumer of water. The growth, development, and reproduction of plants require sufficient water. Drought is a complex environmental stress and major constraint to crop productivity (Mishra and Singh 2010; Farooq et al., 2012).

Drought is a combination of stress effects caused by high temperatures and a lack of water (Campos et al., 2004). Evapo-transpiration is the major driving force that affects the soil, plant, and atmospheric continuum of the hydrologic cycle. In earlier studies, predictions of drought were mainly based on the amount and distribution of precipitation. However, in recent studies soil moisture balance and soil characteristics have been introduced in the assessment of drought. Lack of adequate soil moisture, or water deficit, affects the ability of plants to grow and complete a normal life cycle (Moussa and Abdel-Aziz, 2008).

Drought can have major consequences on growth, development and yield of crops by affecting several physiological, morphological and biochemical processes. It is the major cause of poor crop performance and low yields, and sometimes it causes total crop failure. In the tropics, the probability of drought is highest at the start and the end of the growing season.

Water stress from anthesis to maturity affects numerous morphological and physiological activities of plant resulting extensively reduces in crop yield and productivity (Bray, 1997; Hallajian, 2016).

Drought as Major Constraint to Sorghum Production

In most of the area where crop production is highly dependent on rainfall, there is always a risk of crop failure or yield loss due to moisture stress or drought. In the arid and semi-arid tropics, the loss mainly arises from the availability of low moisture to support growth and development of crops.

In these areas, moisture is usually inadequate for crop growth because of low precipitation and erratic distribution and poor moisture storage capacity of soils. In severe cases, the stress could lead to total crop loss (Sinha SK, 1986). Sorghum is mainly grown in areas of inadequate rainfall and is the principal source of food for millions of people living in these areas.

Effects of Drought on Growth and Development of Sorghum

In the semi-arid tropics where dryland farming is practiced, drought is a common phenomenon that occurs at different periods during the growing season. There is also a high season-to-season variability of rainfall, temperature, and radiation in the tropics. Agricultural conditions greatly vary in topography, soil, existing agricultural practices, and other associated biotic stress factors (Chapman et al., 2000b). Drought is a combination of stress effects caused by high temperatures. Evapo-transpiration is the major driving force that affects the soil, plant, and atmospheric continuum of the hydrologic cycle. In earlier studies, predictions of drought were mainly based on the amount and distribution of precipitation (Blum, 2011). However, in recent studies soil moisture balance and soil characteristics have been introduced in the assessment of drought. Lack of adequate soil moisture, or water deficit, affects the ability of plants to grow and complete a normal life cycle. Drought can have major consequences on growth, development and yield of sorghum by affecting several physiological, morphological and biochemical processes. It is the major cause of poor crop performance and low yields, and sometimes it causes total crop failure. In the tropics, the probability of drought is highest at the start and the end of the growing season. Drought can occur at both seedling, pre-flowering and post-flowering stages of development, and has the most adverse effect on yield. Drought stress at the seedling stage of development will severely affect plant establishment. If it occurs at flowering, or in the grain filling stages, it may cause reduced yields, or complete crop failure. Researchers have classified drought as either pre- or post- flowering stress.

The reactions of genotypes to these stresses are variable and controlled by different genetic mechanisms. Pre-anthesis moisture stress has effects on yield components such as stand count, tillering capacity, number of heads and number of seeds per head, while post-anthesis moisture stress affects transpiration efficiency, CO_2 fixation and carbohydrate translocation.

Photosynthesis occupies a prominent position in the metabolism of higher plants and its rate is regarded as the primary factor regulating plant biomass production and crop productivity.

Photosynthesis is one of the main metabolic processes that determine crop production and is directly affected by drought stress. Drought severely reduces grain yield in many cereal growing regions, which results in fluctuations in the world food supply. Grain yield is the product of many growth processes occurring throughout the developmental stages of the plants. In the Gramineae family, these processes include the number and growth rate of inflorescences and the number and growth rates of the seed set.

Physiological Mechanism of Drought Tolerance in Sorghum

Drought tolerance can be defined as drought avoidance, recovery, survival and resistance. These drought tolerance mechanisms are associated with plant survival and production. Drought avoidance is defined as the ability of plants to conserve water at the whole plant level through decreasing water loss from the shoots or by more efficiently extracting water from the soil (Ludlow and Muchow, 1990). However, drought tolerance is defined as the ability of plants to withstand water deficit while maintaining appropriate physiological activities to stabilize and protect cellular and metabolic integrity at tissue and cellular level. In sorghum drought resistance, therefore, involves the interaction of different morphological structures, physiological functions, and biochemical expressions (Borrell et al., 2006).

Figure 1: Sorghum performance in arid environments

Leaf Rolling and Stomata Conductance

Stomatal conductance and leaf rolling are strongly associated with leaf water potential. In plants, especially, in sorghum stomatal conductance and leaf rolling have been found to be reliable physiological indicators of drought tolerance (Kadioglu and Terzi, 2007). These two mechanisms are controlled by different factors, where stomatal conductance is controlled by soil moisture dependent root signals, while leaf rolling is controlled by leaf water potential. The strong correlation of leaf rolling and leaf water potential allows breeders to use leaf rolling as a visual scoring criterion for selecting for drought resistance in plants. The rolling of leaves usually occurs following the reduction in leaf water potential. However, the degree of leaf rolling depends on the ability of the plant to adjust osmotically at low leaf water potential. Plants with high osmotic adjustment develop less leaf rolling, and hence, reduced leaf rolling is considered as an indicator of a greater degree of desiccation avoidance, through a deep root system. Drought tolerant genotypes exhibit lower stomatal conductance associated with increased leaf temperature, which gives rise to high transpiration efficiency and lower carbon isotope discrimination. The drought susceptible genotypes, on the other hand, show higher stomatal conductance and lower leaf temperature results in lower transpiration rates.

Characteristics of Root

Roots are the primary plant organ affected by drought stress and other environmental stresses of the soil (Prince et al., 2002). Sorghum crown roots grow about 2 to 3 cm per day and root growth is mainly affected by the amount of carbon partitioned to the roots, although it varies with environmental and genetic factors. Sorghum roots may grow to depths of 1 to 2 m at the booting stage, and can efficiently extract water to a lateral distance of 1.6 m from the earth. Root growth in sorghum terminates at flowering stage; however, it is more prominent in a senescent than in non-senescent sorghum genotypes (Robertson et al., 1993). Genotypes that have large number of seminal roots, large vessel diameter in both seminal and nodal roots showed better survival rate under drought stress conditions. Habyarimana et al. (2004) found that the drought tolerance traits displayed by the genotypes were related to drought avoidance mechanisms. These, in turn, are associated with deep root system, which enables sorghum to exploit moisture from the deeper soil horizons.

Drought tolerance was found to be highly associated with root characteristics such as root thickness, root length density, number of thick roots, root volume, and root dry weight. It was also found that number of thick roots, root thickness, and root length density were highly associated with leaf water potential and field visual drought scoring using drying leaf. Drought stress adapted sorghum genotypes are often characterized by deep and vigorous root systems. Drought is often associated with nutrient availability and the capacity of roots to absorb the available nutrients. Ludlow and Muchow (1990) indicated that greater root activity under intermittent drought should enhance crop stability by reducing the incidence of water deficits.

Osmotic Adjustment, Dehydration Tolerance and Transpiration Efficiency

Osmotic adjustment is another major physiological drought adaptive mechanism in plants (Izanloo et al., 2008). Sorghum and millet landraces, which are collected either dry or humid environments show variation in osmotic adjustment. Landraces that come from drier regions show greater osmotic adjustment than landraces from humid regions. The assumption is that through the course of evolution the drier environments provided sufficient selection pressure for osmotic adjustment. Landraces with higher osmotic adjustment are characterized by their dwarf nature with high rates of transpiration and low rates of leaf senescence under stress. Osmotic adjustment improves crop productivity through delaying leaf rolling and leaf tissue death (Blum, 1996). As leaf rolling and leaf senescence decreases, the effective leaf area for photosynthesis increases. In a study on sorghum genotypes, those with high osmotic adjustment exhibited a 24% higher yield than genotypes with low adjustment, when exposed to a post-anthesis drought stress (Ludlow et al., 1990). The yield difference observed was both in grain size and grain number, and it was associated with higher harvest index. Similarly, a 20% dry matter yield increase has been observed in legume species that maintained turgor through osmotic adjustment. In general, yield reduction of stressed plants compared with non-stressed plants is due to the plant’s additional energy requirements for osmotic adjustment (Blum, 2005). Dehydration tolerance is the capacity of the plant to maintain higher turgor potential in the plant cell under moisture stress conditions.

Dehydration tolerance is usually measured by tissue’s water level, which is expressed in terms of water potential (Blum, 2011). To maintain high level of water potential under drought condition cell membrane stability is highly associated.

Transpiration efficiency (TE) is referred as the biomass accumulation per unit water transpired. The variation in the TE within species has been demonstrated for different C3 plant species such as tomato, sunflower, barley, rice, wheat, beans and cotton (Xin et al., 2008). Genetic variation in TE has also been found in sorghum using gas-exchange properties, traditional lysimetric assays, and field evaluation. Among sorghum genotypes significant variation in TE and water treatments has been observed. Sorghum genotypes with low internal CO2 concentration and enhanced photosynthetic capacity may be associated with high TE. High TE was strongly correlated with increased biomass accumulation, rather than with reduced water use (Xin et al., 2008).

Solute accumulation and storage sugar

Solutes are low-molecular-weight and highly soluble compounds that are usually nontoxic even at high cytosolic concentrations. Generally, they protect plants from stress through different means such as contribution towards osmotic adjustment, detoxification of reactive oxygen species, stabilization of membranes, and native structures of enzymes and proteins (Farooq et al., 2009). Accumulation of free proline in water-stressed sorghum leaves is related to the ability of a cultivar to recover from stress, possibly due to proline's role as a source of respiratory energy in the recovering plant. Grain formation and development in crop plants is dependent on assimilates produced by photosynthesis after anthesis or assimilates stored mainly in the stem before anthesis. A relatively high photosynthetic rate during grain filling under water stress was observed in drought resistant cultivars relative to susceptible cultivars. Moreover, the drought susceptible cultivars were much more reliant on remobilization of pre-anthesis assimilates stored in the stem to fill the grain as opposed to the resistant cultivar (Inoue et al., 2004).

Stay Green or Non-Senescence

Leaf senescence is a programmed cell death resulting from drought and other environmental stress factors. It is characterized by loss of chlorophyll and progressive decline in photosynthetic capacity. Premature plant tissue death usually occurs when plants are subjected to water stress during the grain filling period in sorghum. Stay-green, on the other hand, is a post-anthesis drought resistance trait in plants that provides resistance to pre-mature leaf senescence to the plant under severe moisture stress condition during grain filling stage. It contributes to an improved yield and yield stability under moisture stress condition (Tao et al., 2000). Stay-green is associated with a higher level of chlorophyll content, cytokinin, and leaf nitrogen concentration under moisture stress conditions. The stay-green lines show higher levels of chlorophyll content than the normal lines. The visual scoring of leaf and plant senescence for the stay-green response was validated by Xu et, al. (2000). Say-green sorghum lines exhibited high levels of cytokinin, suggesting that the reduced senescence rate of the stay-green lines is in part due to a higher level of cytokinin.

Furthermore, stay-green genotypes are also associated with higher leaf nitrogen concentration, particularly at flowering, and basal stem sugars, than senescent genotypes. Greater green-leaf area duration has been observed to occur in stay green varieties during grain filling stage, and therefore stay-green trait as post-flowering green leaf area duration is important. In sorghum, genotypes with the stay-green trait continue to fill their grain generally under moisture stress conditions.

Figure 2. Stay greenness of sorghum during grain filling stage

Genetics of Drought Tolerance

A number of traits related to drought resistance have been identified and mapped; however, the stay-green trait is recognized as the most crucial drought resistance trait in sorghum. The purpose of studying the genetics of drought resistance in plants is to identify genetic factors that determine the productivity of crops under drought stress conditions. Advances in crop improvement under water-limited conditions are only possible if drought resistance traits are identified and selected for in addition to yield (Borrell et al., 2000a; Sanchez et al., 2002).

Sorghum Breeding for Drought Resistance

Drought is a one of the major limiting factors for crop expansion across the world. Nowadays, efforts are targeted on improving crop genotypes for drought-prone area by evaluating various growth attributes, physiological, biochemical and agronomic performances of different Stay-Green (SG) sorghum accessions. Ethiopian sorghum landraces exhibit native genetic variation for drought resistance even though yet there is no development of sorghum cultivars with resistance to these important stresses. For instance, Afeso and Sorcoll 163/07 sorghum accessions showed better stress tolerance and the Stay green (SG) property in Amhara lowland areas recorded maximum grain yield per hectare (Zelalem et al., 2015). Line B35 is a BC1 derivative of IS12555 dura sorghum from Ethiopia (Harris et al., 2007) shows distinct responses to drought at both pre- and post-flowering stages (Rosenow et al., 1996), being highly resistant to post-flowering drought (stay-green trait), with a relatively low yield.

In contrast, line E36-1 is a high-yielding breeding line assigned to the Guinea caudatum hybrid race of Ethiopian origin (Haussmann et al., 2002). Hence, these Ethiopian materials are the best suggested for improvement in terminal drought areas, serving as donor for high yielder but susceptible to drought prone areas of recipient parents at ICRISAT and USA (Edema and Amoling, 2015). In Ethiopia, being tremendous genetic resource sorghum for drought tolerance landraces are existed, the breeding strategy is mainly focused on screening the landraces and varieties in drought prone areas.

For instance, areas such as Werer, Kobo, Miesso, etc. are representatives used as dry lowland areas for verification of drought tolerant land races or varieties before release (EIAR, 2014).

Marker Assisted Selection for Drought Resistance

Most of the breeding programmes in Ethiopia, the genetic improvement for drought resistance is accomplished through selection for yield and because of low heritability of yield under stress and the spatial as well as temporal variation in the field environment, conventional breeding approaches are slow. Whereas molecular markers such as restriction fragment length polymorphism (RFLP), random amplified polymorphic DNA (RAPD) and isozyme will facilitate development of drought-resistant genotypes more effectively as their expressions are independent of environmental effects. After identification of the molecular markers associated with yield or other morphological traits related to drought resistance, those markers could be used as selection criteria for drought resistance. The application of marker assisted selection in evolving drought resistant genotypes is in an experimental stage; more specifically just identification of RFLP (restriction fragment length polymorphism) markers associated with osmotic adjustment, stay green, root traits has been achieved (Xiao et al ,1998).

Phenotypic selection for Drought Tolerance

We have been made slow but very significant progress through empirical breeding of sorghum for drought tolerance by breaking the trait of drought tolerance into specific phenological stages. The approach has been to break down the complex trait of drought tolerance into simpler components by studying drought stress expressions at specific stages of plant development stage. We have been particularly interested in midseason (pre-flowering) and late-season (post-flowering) drought expressions in sorghum germplasm. Our rationale is that if individual components associated with a complex trait can be identified, we can measure the contribution of each of the factors or mechanisms independently without the confounding effect of other factors. Using this approach, we can identify sorghum germplasm that is uniquely pre-flowering or post-flowering drought tolerant and few that combine tolerance at both stages. We have developed new improved drought- tolerant sorghum lines in diverse and elite germplasm background. Some of these lines have been officially released and distributed to both public and private sorghum research concerns Several more await release and distribution following further characterization and cataloguing to facilitate specific mode of utility.

The breeding and selection effort were based on reliable phenotypic markers associated with morphological and yield-related symptoms that occur at pre- flowering and post-flowering stages of crop development.

Some of these marker traits are simply inherited and others appear quantitative rendering them amenable to quantitative trait loci marker analysis and introgression (Belete T, 2018).

SUMMARY AND CONCLUSION

Drought is one of the limiting factors for crop production in the world. Mostly, it is common in arid and semi-arid tropics in which sorghum is the major crop produced in the area. Climate changes will increase the frequency of drought and flood, particularly in many countries in Africa. There is indication that climate change may lead to a change in the frequency and severity of drought events. Sorghum is a cereal crop which is produced in these agro-ecologies predominantly. Sorghum is grown in semi-arid to arid regions of the world and serves as the staple food for about half a billion people in sub-Saharan Africa and Asia. The adaptation of grain sorghum to a wide range of environmental conditions has led to the evolution and existence of extensive genetic variation for drought tolerance. Consequently, sorghum is expected to play an increasingly important role in agriculture and meeting world food demand in the face of climate change, land degradation and increasing water scarcity. Drought is a complex phenomenon, and is considered one of the most significant factors limiting crop yields around the world and continues to be a challenge to plant breeders, despite many decades of research. Underestimating the genetics and the physiological mechanisms underlying drought tolerance is vital for the breeding to alleviate adverse effects of drought in order to boost productivity. As a result, it is well adapted to withstand harsh conditions, which are the characteristic feature of tropical regions. The crop requires relatively less water than other important cereals such as maize and wheat. Sorghum breeding in Ethiopia has a long history which was more than four decades began in the mid of 1950s at the Alemaya College of Agriculture with collaboration work of Oklahoma State University and started sorghum breeding on local collections and USA introduced materials for their adaptability and yield to highland environments. Later after establishment of ESIP in 1972 and fully funded by IDRC, sorghum breeding in the country become formal and about 5,500 sorghum landraces were collected by ESIP in 1980s served as home for the popular zera zera (caudatum race) type sorghums in sorghum improvement at ICRISAT. Nationally, ESIP also made good progress with the release of Awash 1050 and Gambella 1107 (E 35-1) varieties. In 1982 Institute of Agricultural Research (IAR), now the Ethiopian Institute of Agriculture Research (EIAR) was established and sorghum breeding started in advancing way. Improving drought tolerance in this crop would increase and stabilize grain production and contribute to the food self-sufficiency efforts, particularly in areas receiving a low amount of rainfall and recurrently affected by drought. Therefore, exploiting the genetic potential latent by using both conventional and technological approach to develop resistance varieties is unquestionable. Efficient screening techniques are pre-requisite for success in selecting desirable genotype through any breeding programme.

Exploration of wide genetic variation of relevant characters, consideration of more genes at a time to transfer through breeding or genetic engineering method, assessment of polypeptides induced under drought and multidisciplinary approach should be included in the future research programmes for sorghum drought resistance.

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