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ROLE OF SORGHUM GENETIC DIVERSITY IN TACKLING DROUGHT EFFECT IN ETHIOPIA

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Abstract: **Sorghum is the most important cereal crop in the world and has superior drought tolerance and broad adaptation. Sorghum is an important food security crop mainly in semi-arid and tropical parts of the African countries. Sorghum is indigenous to Ethiopian as far as its domestication has long time and genetic diversity exhibited variation among cultivated and wild relatives of the crop concentrated in the country. The existence of tremendous amount sorghum variability in cultivated and wild relatives revealed that Ethiopia is a country of origin for sorghum and exhibiting native genetic variation to drought, disease and insect resistance. Currently, sorghum is the third important cereal crop in both area coverage and production becoming the second in 'injera' making after 'tef' in Ethiopia. Ethiopia has a diverse sorghum germplasm which adapted to a range of altitudes and rainfall conditions. Characterization and identification of sorghum germplasm which provide desirable traits for genetic improvement is a basis in plant breeding. DNA based molecular marker and PCR based are the best to characterize and identify sorghum genotypes which provide desirable traits as compared to field experimental evaluation due to time and environmental effect. Genetic improvement is the cost-effective means of enhancing sorghum productivity for different end-uses. A better understanding of the genetic diversity in sorghum would greatly contribute to crop improvement with a view to food quality and other important agronomic traits. Sorghum is a high-yielding, nutrient-use efficient, and drought tolerant crop that can be cultivated on over 80 per cent of the world's agricultural land. However, a number of biotic and abiotic factors are limiting grain yield increase. Drought is a major limiting factor to agriculture and considered as the most important cause of yield reduction in crop plants. Identification of genetic factors involved in plant responses to drought stress will provide a solid foundation to breed plants with improved drought resistance. The excellent drought characteristics of sorghum make it one of the most important foods and feed crops in the arid and semi-arid regions of the world. Sorghum is an important resource to the national economy and it is essential to assess the genetic diversity in existing sorghum germplasm for better conservation, utilization and crop improvement. Sorghum is a drought-tolerant crop with a vital role in the livelihoods of millions of people in marginal areas. Ethiopia is one of the origins and centers of genetic diversity of sorghum. As sorghum ranks fifth in global cereal production, the study of its genetic diversity from its center of origin is important for its improvement.**

Keywords: **Genetic diversity; Sorghum; Drought; Productivity; Stay-green.**

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1. INTRODUCTION

Sorghum (*Sorghum bicolor (L.) Moench;* 2n=20) is the fifth most important cereal crop globally after maize, wheat, rice and barley (FAO, 2019). Sorghum is self-pollinated crop species and belongs to Poaceae family with a genome size of 730 Mb (Paterson *et al*., 2009). Sorghum is a C_4 plant with higher photosynthetic efficiency and higher abiotic stress tolerance (Reddy B.V.S and Stenhouse J.W, 1994). The origin and the early domestication of sorghum took place in northeaster Africa approximately 5000 years ago (Mann *et al*., 1983). Ethiopia is the country of origin for sorghum and has large sorghum genetic diversity for future genetic improvement for desirable traits (Vavilov, 1951). It is widely grown in the arid and semi-arid tropics, because of its unique adaptation to harsh and drought prone environments (Adugna, 2007). Sorghum is a major staple food crop in Ethiopia, exhibiting extensive genetic diversity with adaptations to diverse agro-ecologies. Sorghum has a remarkable wide adaptation and tolerance to high temperatures, high evaporative demand, inadequate and erratic rainfall and soils of poor structure, low fertility and low water holding capacity (Teshome *et al*., 2007).

Sorghum is the main staple food crop for more than 500 million people in Africa, Asia and Latin America particularly in semi-arid tropical regions where drought is the major limitations to food production (Ejeta, 2005). About two third of sorghum grain produced worldwide is used for human consumption in developing countries (Ejeta, 2005). Sorghum is the most important grain crop within the past decade in the world with yearly production of 60 million tones. Among the 44 million hectares of land devoted to global sorghum production, about 90% of it contributed by developing countries with largest share from Africa and Asia (Leder, 2004). Ethiopia is one of the origins and centers of diversity of Sorghum (*Sorghum bicolor (L.) Moench*). This crop is an important food crop and is widely grown in the highland, lowland and semiarid regions of the country (Abdi *et al*., 2002). It is important for food, feed, fiber and fuel across a range of agro-ecosystems. Sorghum also used as raw material by industries to produce different products including starch, fiber, dextrose syrup, biofuels and alcohol (Mahmood, T *et al.*, 2010). Sorghum is a tight clustering and overlapping C_4 drought tolerant plant with high water use efficiency. Ethiopian sorghum is well known for its high lysine content and grain quality, shoot fly resistance, grain mould resistance and cold tolerance as the result of high genetic diversity.

Sorghum is the important cereal crop around the world and hence understanding and utilizing the genetic variation in sorghum accessions are essential for improving the crop. A good understanding of genetic variability among the accessions will enable precision breeding. It is a major food crop in Sub-Saharan Africa and South Asia and is the staple food for the most food insecure people in the world (Bibi A *et al* . , 2010). Besides being an important food, feed, and forage crop, it provides raw material for the production of starch, fiber, dextrose syrup, biofuels, alcohol, and other products. Sorghum was domesticated in African continent, particularly in Ethiopia, from where it was introduced to other regions of the world with diverse agro-climatic conditions (Li R *et al*., 2010). Therefore a wide diversity is found within and among the sorghum cultivars at both phenotypic and genotypic level (Hart G. E *et al*., 2001). Knowledge of genetic diversity of a crop usually helps the breeder in choosing desirable parents for the breeding program and gene introgression from distantly related germplasm. The more diverse genotypes or accessions can be crossed to produce superior hybrids with resistance to abiotic and biotic stresses.

Understanding the wealth of genetic diversity in sorghum will facilitate further improvement of this crop for its genetic architecture (Jayaramachandran M *et al*., 2011). Ethiopian sorghum landraces exhibit native genetic variation for drought resistance (Borrel *et al*., 2000), having huge source of high lysine (Singh and Axtell, 1973), good grain quality and resistance to disease and insect (Hebede, Y, 1991), post flowering drought tolerance (stay-green trait) (Borrel *et al*., 2000). Nowadays, the world food demand is increasing with the increasing world population and climate change. Hence sorghum is expected to play significant role in the area where other cereal crops are rarely produced due to water scarcity. As food-grade, special attention is given to sorghum because it is gluten-free and contains high levels of health-promoting phytochemicals (Asif *et al*., 2010). Sorghum has been improved to a great extent for grain yield (Adebo *et al*., 2018) and is primarily used as a food crop in developing countries (Bawazir, 2009). Sorghum is one of the most important cereal crops supporting the lives of millions of people across the globe and particularly in the developing world (Zhanguo *et al*., 2017). Sorghum is used for biofuel production (Dutra *et al*., 2013), beer production (Smith and Frederiksen, 2000) and silage (Pinho *et al*., 2015). Sufficient genetic diversity is required for plant breeding programs to assist production of new improved cultivars against various stresses and increase of yield (Abrams *et al*., 2015).

Sorghum is one of the most important cereal crops grown in arid and semi-arid regions of the world. Sorghum is produced for its grain which is used for food, feed and stalks for fodder and building materials in developing countries, while it is used primarily as animal feed and in sugar, syrup and molasses industry in developed countries (Dahlberg, J *et al*., 2012). It is major food and nutritional security crop to more than 100 million people in Eastern horn of Africa (Gudu *et al*., 2013) including Ethiopia, providing a principal source of energy (70% starch), proteins, vitamins and minerals (Duodu *et al*., 2003). Despite its importance, sorghum production and productivity are constrained by the use of low yielding cultivars, which are susceptible to biotic and abiotic stresses. These stresses include; drought, stem borer, grain mold and the parasitic weed- striga (Belu *et al*., 2008). Among the abiotic factors, drought is the major cause for low productivity of the crop (Asfaw, 2007). Worldwide, the annual yield loss due to drought is estimated to be around 10billion US dollar (Mutava, 2009). In Ethiopia it is a major problem leading to food shortages and challenging small-holder farmers in Ethiopia to produce enough sorghum grain when rainfall is low and erratic. The effect of drought on crop yield is dependent on the stage of plant development. Assefa *et al*. (2010) has reported that water stress occurring during the vegetative stage alone could reduce yield by > 36% and > 55% at the reproductive stage. In Ethiopia, complete yield loss due to drought was recorded in some parts of the country, such as Mehoni area (EIAR, 2014).

Because of its drought adaptation capability, sorghum is preferred crop in tropical, warmer and semi-arid regions of the world with high temperature and water stress. With the thrust of climate change looming large on the crop productivity, sorghum being a drought hardy crop will play an important role in food, feed and fodder security in dry land economy (Mishra *et al*., 2015). Ethiopia being first rank among countries that have contributed germplasm collections to the initial world collections of sorghum at ICRISAT (Rao *et al*., 1989). Landraces or farmers varieties have been found to have higher variability and stability (adaptation over time) in marginal environments, encompassing a population of genes and alleles that are adaptable to natural and human selection pressures (Ceccarelli, S *et al* . , 2004).

The existence of the different sorghum landrace accessions, which can respond to the recurrent moisture stress, is expected to provide an opportunity in screening and identifying best drought tolerance accessions with relatively stable yield. Genetic variability in crops has strong impact on crop improvement program and conservation of genetic resources (Assar *et al*., 2005). The genetic variability of cultivated species or varieties and their wild relatives together form a potential and continued source for the development of improved crop varieties (Ahalawat *et al*., 2018). A better understanding of the genetic diversity in sorghum would greatly contribute to crop improvement with a view to food quality and other important agronomic traits. Hence, understanding and utilizing the genetic variation in sorghum accessions is essential for improving the crop. Therefore, the objective of this review was to understand the critical importance of genetic variability sorghum in overcoming the drastic effects of drought at arid and semi-arid areas.

2. SORGHUM ORIGIN, DOMESTICATION AND DISTRIBUTION

Ethiopia is the country of origin for sorghum and has large sorghum genetic diversity for future genetic improvement for desirable traits (Vavilov, 1951). The origin of Sorghum is Africa and it is has a character of adapting the continents climate both in terms of resistant to drought and ability to withstand periods of water-logging (Kimber, 2000). The domestication of sorghum has its origins in Ethiopia and surrounding countries, commencing around 4000-3000 BC (Dillon *et al*., 2007). In early 200 AD sorghum made its way into Eastern Africa from Ethiopia via the local tribes (Ng'uni *et al*., 2011). Some archaeological evidence also indicates that cereal domestication practice was introduced from Ethiopia to Egypt about 3000 BC (Doggett, 1965). There are also suggestions that cultivated sorghum was domesticated by selections from a wild progenitor, subspecies verticilliflorum, about 5000- 7000 years ago (Purseglove, 1972).

Early domestication of sorghum was associated with changing the small-seeded, shattering and open panicles toward improved types with larger, non-shattering seeds and more compact panicles. Stable, high-yielding sorghum varieties have been recently developed through breeding or improvement programmes utilizing sorghum landrace varieties from Africa, India and China. This has involved selecting traits such as photoperiod insensitivity, reduced height (to reduce lodging), drought tolerance, pest and disease resistance (Reddy *et al*., 2004). Domesticated sorghum is drought tolerant with an extensive root system, a waxy bloom on the leaves that reduces water loss, and the ability to stop growth in periods of drought and resume growth under suitable environmental conditions. Sorghum requires rainfall of 500 to 800 mm throughout the growing season and can withstand temporary water logging (Balole and Legwaila, 2006). Domesticated sorghum tolerates a range of soil types including heavy Vertisols, light sandy soils, loams, and sandy loams and soil p H levels from 5.0 to 8.5 (Balole and Legwaila, 2006).

Then, it was distributed along the trade and shipping routes around the African continent and through the Middle East to India at least 3000 years ago. It then journeyed along the Silk Route into China (Dicko *et al*., 2006). It was first taken to North America in the 1700-1800's through the slave trade from West Africa and was re-introduced in Africa in the late 19th century for commercial cultivation and spread to South America and Australia (Yitayeh, 2019). Currently sorghum is widely found in the dry lowland areas of Africa, Asia (India and China), the Americas and Australia (Dicko *et al*., 2006). It is an economically, socially and culturally important crop grown over a wide range of ecological habitats in Ethiopia, in the range of 400-3000 m.a.s.l (Teshome *et al*., 2007). Sorghum is a unique cereal crop in the lowland areas due to its drought tolerance (Kebede Y, 1991).

The presence of a diverse population of wild and cultivated sorghum in Ethiopia reveals that Ethiopia is the primary center of origin and center of diversity (Mekibeb, 2009). Most probably sorghum is grown in arid and semi-arid parts of the world where it extensively adapted to semi-arid environmental conditions that can be able to successfully grow in areas that are too marginal and difficult to the other cereal crops (Geremew *et al*., 2004). Besides sorghum known as one of the most drought tolerant crop species and which have the habit of adaptability to different agro-ecologies and taken as an important model system for studying physiological and molecular mechanisms underlying drought tolerance (Amelework *et al*., 2015). The climatic condition of the different agro-ecological zones plays vital role in geographical distribution in sorghum growing and production percentage like, high temperature, dry spell and erratic rainfall favors the production of the sorghum due to its genetically drought resistant properties and its ability to grow in hot dry agro-ecologies with relative advantage where other food crops such as rice and maize find it difficult to grow successfully (Alade *et al*., 2017).

2.1 Sorghum Genetic Diversity

Genetic variability is defined as the variability observed in a given crop plant that can be attributed to genes that encode specific traits and can be transmitted from one generation to the next (Acquaah, 2007). Genetic variability can be created in nature through hybridization and recombination, mutation, and modification of chromosome number and structure. The genus sorghum presents broad genetic diversity, including wild and cultivated species, divided into five basic morphological races (bicolor, caudatum, durra, guinea and kafir) and into ten other intermediate races, which are various combinations involving the five basic races (Harlan and De Wet, 1972). Knowledge of genetic diversity of the genetic material is very critical in crop improvement (Warburton *et al*., 2008). Genetic variation, generally considered a key component in broadening gene pools in any given crop population, is critical to the success of yield improvement programmes (Nyadanu, D and Dikera, E, 2014). Genetic variability is the occurrence of differences among individuals due to differences in their genetic composition and the environment in which they are raised. Sorghum is a crop species with a wealth of genetic variability, which may have originated from the sympatric co-evolution and intercrossing of the cultivated and wild species in Africa (Tesso *et al*., 2008).

The diversity of new sorghum types, varieties and races created through the movement of people, disruptive selection, geographic isolation and recombination of these types in different environments would have been large (Dillon *et al*., 2007). The high level of genetic variability in sorghum could also be related to the rate of out crossing in the species, which can reach up to 30% depending on the head type. However, the predominantly selffertilizing nature of the crop could help to fix and maintain novel genetic variations in the population (Rooney, 2004). Being an indigenous crop with tremendous amount of variability (Asfaw, 2007), Ethiopia serves as the global reservoir for sources of favorable genes of various crops to which it is the Vavilonian center of origin and diversity including sorghum (Vavilov, 1951), ranking first among countries that have contributed sorghum collections at ICRISAT (Rao *et al*., 1989). All the races, except Kafir, and the corresponding intermediate races are naturally found in Ethiopia (Teshome *et al*., 1997, Stemler *et al*., 1977).

Information on the nature and magnitude of genetic variability present in a crop species is thus important for developing effective crop improvement program. The amount of the total genotypic and phenotypic variability that exists in a crop germplasm dictates the initiation of crop improvement programs, of the total variability present in a population the genetic component is the most important to the breeder as it could be transmitted to the progeny. In addition, proper management of this type of variability can produce permanent gain in the performance of the crop concerned (Welsh, 1981). Phenotypic variability is the observable traits of variation present in a population and it is a combined effect of genotypic value and environmental deviation. Genotypic variations, on the other hand, is the component of variation which is due to the genetic differences among individuals within a population and is the main concern of plant breeding (Allard, 1960).

Sorghum is a cereal crop having a large genetic diversity and most of its accession is derived from farmers' selection over years from different location, under a wide range of environments (Billot *et al*., 2013). This adaptation characteristic of sorghum to diverse agro-climatic conditions is as results of sorghum having a source of favorable alleles that could be used in breeding programs (Morris *et al*., 2013). As far as farmers' interest to their accessions, the local landraces based hybrids are better in adaptation and acceptability (Camara *et al*., 2006). More over as sorghum has a large genetic diversity, it is a great opportunity for breeder and it requires again an effort on researches to develop new drought tolerance sorghum crops which will withstand the harsh environmental conditions (Msongaleli *et al*., 2017). There is wide genetic variation for physiological and yield traits associated with tolerance to limited moisture stress within sorghum genotypes and these traits can be used for identifying drought tolerant genotypes of sorghum (Mutava *et al*.,2011).

Table 1: Ethiopian sorghum races presented according to their ecological distribution (Modified from Stemler *et al*., 1977)

Ethiopian Sorghum landraces	Ecological Distribution	Major Growing Regions/Zone
DURRA	Eastern highland regions and midelevation terrace of the north	North Wello, South Wello, East Harerghe
CAUDATUM	Hot dry valleys and lowland savannas in N and W Ethiopia	Metekel, Central and South Tigray, Gambella (Z1)
DURRA-BICOLOR	S-W Highland regions where Temp. and raining higher than N and E regions	Jimma, Illubabor, West Wollega
BICOLOR and GUINEA	Rift valley regions of Ethiopia	North Shewa, Benchi Maji, East Shewa*

2.2 Importance and Constraints to Sorghum Production

Sorghum is the fifth most important cereal crop in the world, after wheat, maize, rice and barley grown in arid and semi-arid parts of the world (FAO, 2019). In developing countries more than 500 million people relied on sorghum for their principal food sources (Burke *et al*., 2013). In Africa, sorghum is still largely a subsistence food crop (Troyer, A.F and Wellin, E.J, 2009). In Ethiopia, sorghum is the third primary staple food crop after tef and maize (CSA, 2014).The highest proportion (74%) of the grain produced is consumed at the household level, with the remainder being used for sale and seed purposes (CSA, 2014). Sorghum grain is preferred next to tef, a small cereal grain crop, for the preparation of the staple leavened bread (injera). The grain is also used for the preparation of local beverages (Tella and Areke). In addition, the stover is used as animal feed (green chop, hay, silage, and pasture), fuel wood and construction (fencing and roofing material) purposes. Sorghum grows in a wide range of agro-ecologies most importantly in the moisture stressed parts where other crops can least survive and food insecurity is rampant (Asfaw, 2007).

The productivity of sorghum in Ethiopia is very low as compared to another developed countries and farmers fields in major sorghum growing regions of the country (Geremew *et al*., 2004). Sorghum production and productivity in the country are constrained by several biotic and abiotic factors. Among the biotic factors are Striga, diseases (grain mold, anthracnose, rust and smut), insect (stalk borer, midge, and shoot fly) and Quellea birds (Wortmann *et al*., 2006) whereas the important abiotic constraints include low soil fertility (nutrient deficiency) and drought (EIAR, 2014). Sorghum production constraints vary from region to region within Ethiopia. Drought and Striga in north and north eastern parts, quelea birds in the Rift Valley and Southwest lowlands (Wortmann *et al*., 2006), soil infertility and drought were seen as a major constraints in the eastern parts of the country (Shiferaw *et al*., 2015). However, drought and striga are the most important problems across regions. Among abiotic factors drought is a major constraint in sorghum production worldwide and is considered as the most important cause of yield reduction in crop plants. In Ethiopia, over 80% of sorghum is produced under severe drought to moderate drought stress conditions. Complete yield loss was observed in some parts of the country (EIAR, 2014).

2.3 Drought and Effect of Drought Stress on Sorghum

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. The mechanisms that enable this crop to survive under these harsh conditions are complex and not well understood. Agricultural drought, namely water deficiency, adversely affect plant and crop production by reducing leaf size, stem extension and root proliferation, disturbing plant water and nutrient relations, and inhibiting water-use efficiency. During periods of severe drought, these losses can be much higher and can potentially result in complete crop failure. Drought is a major constraint in sorghum production worldwide and is considered as the most important cause of yield reduction in crop plants (Sabadin *et al.*, 2012; Besufekad and Bantte, 2013), especially in water-limited areas of the world including parts of eastern and southern Africa.

The crop growth and development are constantly influenced by environmental conditions such as stresses which are the most important yield reducing factors in the world. Drought is the most important abiotic factor limiting growth, adversely affect growth and crop production and one of the most important environmental stresses, especially in warm and dry areas of crop yield are limited. Drought is actually a meteorological event which implies the absence of rainfall for a period of time, long enough to cause moisture-depletion in soil and water deficit with a decrease of water potential in plant tissues. But from agricultural point of view, drought is the inadequacy of water availability, including precipitation and soil-moisture storage capacity, in quantity and distribution during the life cycle of a crop plant, which restricts the expression of full genetic potential of the plant. It acts as a serious limiting factor in agricultural production by preventing a crop from reaching the genetically determined theoretical maximum yield. Increased crop yield is required to meet the needs of future population growth, but drought causes significant yield reductions for rainfed and irrigated crops.

Drought is the availability of inadequate water including precipitation and soil water storage capacity, in quantity and distribution during the life cycle of a crop plant, which inhibits the expression of full genetic potential of the plant (Mitra, 2001). It is the major cause of poor crop performance and low yield, and sometimes it causes total crop failure. Drought is also unpredictable in its timing of occurrence, duration and intensity. In the tropics, the probability of drought is highest at the start and end of the growing season. Short duration drought stress mostly reduces grain yield while prolonged drought stress leads to complete death of plant. Drought stress occurs at different stages of growth and adversely affects and yield parameters which lead to reduction in yield. The extents of yield loss caused by drought stress vary with sorghum genotypes and their stage of growth (Reddy *et al.*, 2004). Water stress at the vegetative stage and reproductive stage alone can reduce yield by more than 36%, and 55% respectively (Assefa, *et al.*, 2010). In addition to its direct effect on yield, drought also predisposes the crop to other yield limiting factors such as pests and diseases (McBee, 1984).

Drought response in sorghum has been classified into two distinct stages, pre-flowering (panicle differentiation to flowering) and post-flowering (flowering to grain development) (Sanchez *et al.*, 2002). Pre-flowering drought tolerance responses of sorghum includes reductions in panicle size, seed number, grain yield, seed set, plant height, leaf rolling, irregular leaf erectness, delayed flowering and flower abortion. Post-flowering drought tolerance encompasses stalk logding, reduced seed size, susceptibility to charcoal rot, reduced biomass, loss of chlorophyll, degradation of photosynthesis, reduced seed weight, reduced grain number, reduced hundred seed weight and premature leaf and stalk senescence (Burke *et al.*, 2010). Post-anthesis drought stress is considered more detrimental to grain yield regardless of the stress severity because photosynthesis per unit leaf area is decreased leading up to 70 % yield loss (Abraha *et al.*, 2015).

For instance, by 2050, water shortages are expected to affect 67% of the world's population (Ceccarelli *et al.*, 2004). Climate extremes are expected to increase with climate change, which may negatively affect crop production (Troy, 2003). In most areas where crop production is dependent on rainfall there is always risk of crop failure or yield loss due to moisture stress. In the semi-arid tropic areas, moisture is always inadequate for crop growth because of low precipitation and erratic distribution and poor soil moisture storage capacity of soils. In severe cases the stress could lead to total crop loss (Sinha *et al.*, 2018). Drought is the major limiting factors for yield stability in the semi-arid tropics, where rainfall is inadequate, non-uniform and erratic in distribution (Hamblin *et al.*, 2005). Worldwide, the yield loss each year due to drought was estimated to be around USD 10 billion (Mutava, 2009).

2.4 Sorghum Drought Resistance Mechanisms

Drought resistance is a complex trait, expression of which depends on action and interaction of different morphological (earliness, reduced leaf area, leaf rolling, wax content, efficient rooting system, awn, stability in yield and reduced tillering), physiological (reduced transpiration, high water-use efficiency, stomatal closure and osmotic adjustment) and biochemical (accumulation of proline, polyamine, trehalose, etc., increased nitrate reductase activity and increased storage of carbohydrate) characters. Due to its inherent nature, sorghum has drought resistant mechanisms that make it better fit in moisture stressed areas and less competition from other crops. Sorghum is the single most important cereal in drought prone areas and the climate-resilient crops that can better adapt to climate changes (Reddy *et al.*, 2007). Sorghum is one of the most drought tolerant crop species and is an important model system for studying physiological and molecular mechanisms underlying drought tolerance (Sanchez *et al*., 2002). Plants including sorghum resist drought stress by either of drought escape, drought avoidance or drought tolerance mechanisms. Drought tolerance in sorghum is a complex quantitative trait controlled by many genes coding for various traits contributing towards tolerance (Blum, 1979). Development of molecular markers and their use in Quantitative Trait Loci (QTL) analysis has become a powerful tool for studying the inheritance of complex traits and helps for improving drought tolerance in crops (Suji *et al*., 2012).

Drought tolerance can be defined as a plant's ability to maintain physiological functions when little or no water is available to the plant (Mitra, 2001). Plants respond and adapt to and survive under drought stress by the induction of various morphological, physiological and biochemical responses. However, a plant may exhibit more than one of these strategies to cope with drought stress. There are evidences that sorghum is drought tolerant than other cereal crops. Sorghum had a greater ability to extract water from deeper soil layers compared to maize (Farre *et al*., 2006). Sorghum avoids effects of moisture stress at critical stages by delaying or hastening development. Early in the vegetative stage, delays its growth; when recovered it has the ability to compensate yield by producing tillers. If water stress occurs late in the growth stage, hastens its growth and quickly passes to the next developmental stage (Yared *et al*., 2014). The development of high yielding and stable varieties for the drought prone area requires a continuous supply of new germplasm as a source of desirable genes.

2.4.1 Drought Escape

Drought escape is the ability of a plant to complete its life cycle before serious soil and plant water deficits develop. This mechanism involves rapid phenological development (early flowering and early maturity), developmental plasticity (variation in duration of growth period depending on the extent of water-deficit) and remobilization of parenthesis assimilates to grain. Drought escape is the ability of plants to avoid drought by completing their life cycles before the onset of a dry period to sustain some reproduction (Manavalan *et al*., 2012). Early matured sorghum genotypes have less evapo-transpiration when compared to late maturity genotype because of smaller leaf area which can help limit further water loss. Some sorghum cultivars also escape drought through remobilization of stem reserves. Sorghum has a developmental plasticity, which delay or postpone their development during stress and resume their development with the start of rain. Due to deep and extensive root formation, sorghum can escape drought (Tari *et al*., 2013).

2.4.2 Drought Avoidance

Drought avoidance is the ability of plants to maintain relatively high tissue water potential despite a shortage of soil-moisture. Mechanisms for improving water uptake, storing in plant cell and reducing water loss confer drought avoidance. Drought avoidance is performed by maintenance of turgor through increased rooting depth, efficient root system and by reduction of water loss through reduced epidermal (stomatal and lenticular) conductance, reduced absorption of radiation by leaf rolling or folding and reduced evaporation surface (leaf area). The mechanisms that confer drought resistance by reducing water loss (such as stomatal closure and reduced leaf area) usually result in reduced assimilation of carbon dioxide. Consequently, crop adaptation must reflect a balance among escape, avoidance and tolerance while maintaining adequate productivity.

The drought avoidance mechanism avoids a low water status in tissues during water stress by maintaining cell turgor and cell volume. This is achieved either through aggressive water uptake by an extensive root system, leaf rolling, through reduction of water loss from stomatal transpiration and other non-stomatal pathways such as cuticular transpiration (Ludlow and Muchow, 1990). Most sorghum genotypes have a thick waxy cuticle that limits water loss during periods of water deficit, which reduce water loss from leave. The resistant sorghum lines showed more leaf-rolling than the susceptible lines in water stress condition, reducing the effective area of the uppermost leaves by about 75% (Matthews *et al*., 1990).

2.4.3 Drought Tolerance

Drought tolerance is the ability to withstand water-deficit with low tissue water potential. To improve drought tolerance trait, breeding requires fundamental changes in the set of relevant attributes, finally emerging as something named drought tolerance. 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 (Rosenow *et al*., 1996). In particular, post-flowering drought stress can result in significant reductions in crop yield (Rosenow *et al*., 1996).

Drought tolerance is a mechanism through which sorghum maintains metabolism even at a lower water potential. This mechanism involves physiological traits including osmotic adjustment, antioxidant capacity and genetic components such as pre-flowering drought tolerance and post anthesis drought tolerance (Subudhi *et al*., 2000).The genetic components are expressed depending on the growth stage of the sorghum plant and are controlled by different genetic elements. Pre-flowering response in sorghum occurs when the plants are under significant moisture stress prior to anthesis and post flowering drought response in sorghum is expressed when moisture stress occurs during the grain filling stage (Rosenow and Clark, 1995).

2.4.4 Stay-Green or Delayed Senescence

Stay-green refers to a drought tolerance mechanism that enables the sorghum plants to tolerate premature senescence under drought stress that occurs during grain filling. The stay-green trait results in greater functional photosynthetic leaf area during grain filling and even after physiological maturity. It is an important component of post-flowering drought response in sorghum (Harris *et al*., 2007). Sorghum genotypes with the stay-green trait continue to fill their grain normally under drought and exhibit resistance to stalk lodging; charcoal rot and higher levels of stem carbohydrates (Borrell *et al*., 2000). Sorghum is the most important crop that has a potential to resist drought as compared to other cereals due to the presence of stay green traits. Stay-green, is a very important traits that used in crop to tolerate drought, which is characterized as a post-anthesis drought resistance trait which contributes in yield improvement and yield stability under moisture stress condition (Tao *et al*., 2003).

Stay-green in sorghum genotypes exhibited high levels of cytokinins which can be enables the crop to reduce a senescence rate due to a higher level of cytokinins (Thomas and Howarth, 2000). In addition, stay-green crop genotypes are also associated with higher leaf nitrogen concentration, especially during the flowering stage (Borrell *et al*., 2000), and which implies that stay-green trait may possibly contribute to higher transpiration efficiency of non-senescent genotypes (Tao *et al*., 2003). In sorghum, stay green is appear to be the combined effect of green leaf area at flowering period, time of onset of senescence and its subsequent rates (Borrell *et al*., 2000). Although a number of traits are identified related to drought resistance however, the stay-green trait is recognized as the most important drought resistance trait in sorghum selection to identify a genotypes with resistance to drought. Stay-green is an integrated drought-adaptation trait in sorghum. Delayed leaf senescence during grain filling is an emergent consequence of dynamics occurring earlier in crop growth. Stay green in sorghum is characterized by the plant's ability to tolerate post-flowering drought stress, thereby delaying the premature leaf and plant death.

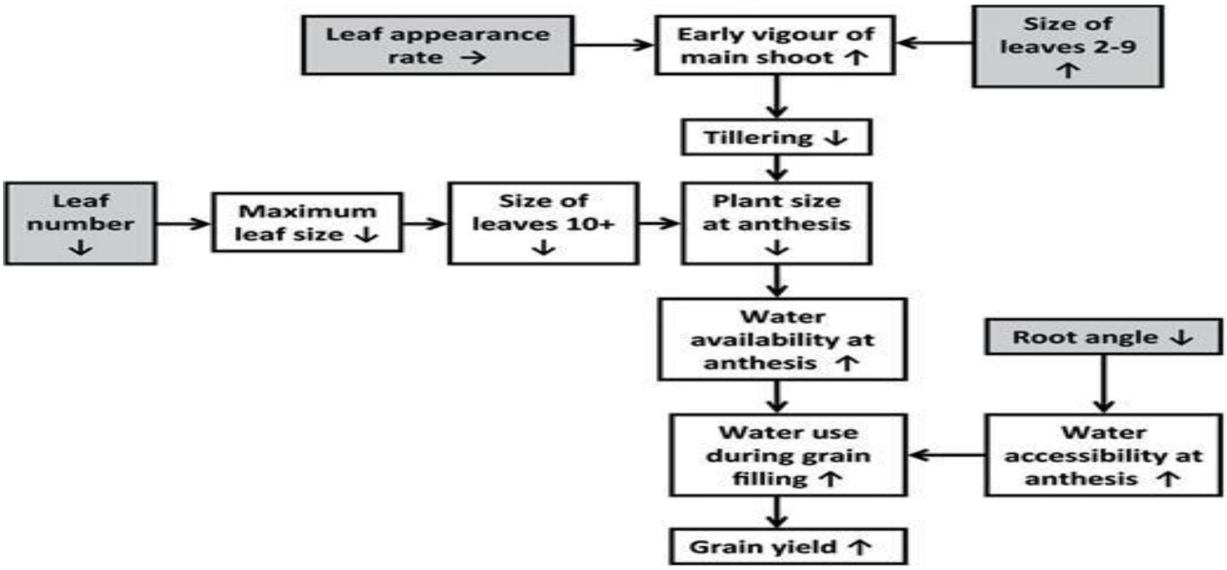

Figure 1: Flowchart of crop physiological processes that determine plant size and crop water use at anthesis

2.4.5 Root Characteristics

Root is the primary plant organ that used to fetch water for crops to facilitate the physiological activities of a crop and which can be affected by drought and environ mental stresses of the soil (Prince *et al*., 2002). The roots of Sorghum grows about 2 to 3 cm per day and can extend to the depth of 1-2m at the booting stage of sorghum growth which can be enables the crop to efficiently extract or fetch water at a distance of 1.6m from the sorghum (Routley *et al*., 2003), although it varies with environmental and genetic factors (Blum, 2004). The drought tolerance traits expressed by a Sorghum crop is naturally related with drought avoidance which have a characteristics of deep root system which enables the crop to fetch water to the deeper soil horizon (Habyarimana *et al*., 2004).The extent of drought stress tolerance is highly associated with root characteristics specially root length which indicates a positive correlation between drought tolerance and root length in sorghum which shows root depth and root length density are drought tolerance contributing traits.

Plant roots are important organs that absorb water and nutrients from the soil and are a center for the biosynthesis and transport of plant hormones such as abscisic acid (ABA) (Arai-Sanoh, Y*et al.* , 2014). The morphological and physiological characteristics of roots affect the growth of plant aerial parts (Arai-Sanoh, Y*et al*., 2014). The roots and aerial parts of crops are interactive and interdependent (Kashiwagi, J *et al*., 2006). Therefore, maintaining high root vitality is essential and changing root structure is more likely to promote crop growth than changing the stems and leaves (Craine, J.M *et al*., 2003). Alteration of root traits to adapt to the surrounding environment and optimize resource utilization plays a vital role in the adaptation of wheat to different environments. The study of Sebastian *et al*. (2016) showed that stronger suppression of crown roots actually may benefit crop productivity under a water deficit. Hammer *et al*. (2009) reported that root structure optimization and water utilization may be the basis for historic advances in yield breeding in the U.S. maize belt.

Hence, to understand what kind of root system is beneficial to crop growth, it is necessary to explore the role of the root system on crop growth and yield production, especially the role of deep roots under adverse conditions such as drought stress. Gewin revealed that deep roots play a vital role in mitigating water stress in many crops (Gewin, V. Food, 2010). Deep roots have a greater ability to absorb water and nutrients than shallow roots and act as the central hub of the water and nutrient cycle (Giambelluca, T.W *et al*., 2016). In addition, deep roots play a key role in crop adaptation to circumstances. Manschadi *et al*. (2006) reported that the roots of drought-tolerant wheat are tighter, more uniform, and longer than those of drought sensitive wheat, and the plants have higher water use efficiency. The deep roots of crops can not only increase yield by improving water and nitrogen uptake but also reduce environmental nitrogen leaching (Thorup-Kristensen, K *et al*., 2012). Therefore, breeders strongly emphasize the role of deep roots in absorbing water and nutrients when developing new varieties (Wasson, A.P *et al*., 2014). Chaves *et al*. (2004) revealed that since deeper soil layers have higher moisture contents in arid environments, deep-rooted plants are more likely to survive under these conditions. Deep roots can absorb more substances, including water and nutrients, in arid environments and maintain the function of the shallow roots through material transport (Bleby, T.M *et al*., 2010). Although some functions of the root system are well known, some of the physiological functions of deep roots and their effects on aboveground crop production have rarely been reported.

Sorghum is mainly planted in arid and semiarid regions of Asia and Africa, and the planting area in these regions accounts for 85% of the worldwide planting area according to 2018 data (FAO, 2018). However, filling stage is the most important period for yield production, at which drought can lead to severe decline of yield in sorghum (Wang, N *et al*., 2015). Sorghum can feed at least 5 million people in these areas due to its unique drought adaptability and sorghum roots play an important role in its drought tolerance (Zhang, C *et al*., 2019). Wang et al. reported that a higher root activity has been found in the stay green sorghum B35 as compared to non-green-stayed sorghum and is considered as one of the drought-resistant mechanisms under drought conditions. Photosynthetic parameters and osmotic adjustment ability are the principal factors associated with sorghum yield under drought conditions (Wang, N *et al*., 2015). However, research on root systems is time consuming, expensive and difficult because plant roots are hidden under the ground. Therefore, compared with studies of the aboveground characteristics of plants, there are few studies on the physiological functions of underground roots. In recent decades, although the number of root system studies has significantly increased, these studies have mainly been limited to shallow root systems (Maeght, J.L *et al*., 2013) or the effects of different root types on plant productivity (Arai-Sanoh, Y *et al*., 2014). Specifically, little is known about the effects of deep root systems on the aboveground physiology and yield production of sorghum plants (Guo, H *et al*., 2019).

3. CONCLUSION

Sorghum is one of the major cereal crops in the semi-arid tropics where prolonged droughts are frequent. The presence of broad-base genetic variation is prerequisite for any crop improvement. Crop improvement program requires understanding and proper assessment of genetic variability among germplasm collections and efficient utilization of such variability in breeding programs. It is an important step toward reliable grouping of accessions and identification of subsets of core accessions with possible utility for specific purpose. Drought is one of the most important factors that affect crop production worldwide and continues to be a challenge to plant breeders, despite many decades of research. This agricultural constraint may nevertheless be addressed by developing crops that are well adapted to drought prone environments. Understanding the different mechanisms underlying drought tolerance is vital for the breeding to alleviate adverse effects of drought. For instance, heat and drought are the two most important environmental stresses imposing huge impact on crop growth, development, grain yield and biomass productivity. With the increasing expectations of crop yield losses because of the global climate change and the exponential population growth, there is an urgent need to accelerate plant breeding and mining of novel traits for increased yield potential and better adaptation to abiotic stresses to secure the food availability and meet the future demand for agricultural production. Hence, drought tolerant and stay-green genotype selection can be a principle strategy for increasing crop production to meet the mandate of an expected increase in population, particularly under heat and water-limited conditions.

Drought is the primary cause of crop yield loss among abiotic factors around the world. This day, drought is the primary cause of crop yield loss among abiotic factors around the world. It is also a major problem in Ethiopia, leading to food shortages and is a challenge for small-holder farmers to produce enough sorghum grain when rainfall is low and erratic. Drought is a major cause of sorghum yield losses in rain-fed agriculture, especially in the semi-arid and arid agro-ecological zones of Africa and Asia. Drought due to climate change is favoring sorghum production even in areas that were originally favorable for other crop production. Sorghum is the dominant crop in the arid and semi-arid tropics, where drought seriously affects its production. Plant breeding is facing challenge to feed the ever-increasing population with diminishing cultivable land and dynamic climate change. Modern plant breeding has achieved some success in this regard. However, it has resulted in the genetic vulnerability because of narrow genetic base of cultivated varieties in many crops. Hence, there is a need of paradigm shift in plant breeding focusing on diverse genetic resources. Genetic diversity has now been acknowledged as a specific area that can contribute in food and nutritional security. Better understanding of genetic diversity will help in determining what to conserve as well as where to conserve. Genetic diversity of crop plants is the foundation for the sustainable development of new varieties.

Drought is the primary cause of crop yield loss among abiotic factors and it is a major problem in Ethiopia, leading to food shortages. However, sorghum is relatively a drought tolerant crop but drought is still the major constraint for its production. Plant breeding is primarily relies on presence of substantial genetic diversity of crops to address maximum genetic yield potential of the crops and exploitation of the variation through effective selection for improvement. Nowadays, the world food demand is increasing with the increasing world population and climate change. Hence sorghum is expected to play significant role in the area where other cereal crops are rarely produced due to water scarcity. The presence of considerable magnitude of variability in the available germplasm is a prerequisite for a successful selection of sorghum for drought resistance. Sufficient genetic diversity is required for plant breeding programs to assist production of new improved cultivars against various stresses and increase of yield. Therefore, knowledge of genetic variability for drought related traits is the key component in selecting genotype that withstand drought for the future breeding program. Generally, sorghum genotypes characterized by early flowering and early maturity, small number of leaves per plant, small leaf area, erect leaf type, larger stem diameter, small number of productive tiller, small leaf area, high grain yield per unit area and short plant height are most suitable for lowland areas with a limited rain fall and short growing season. Hence, the development of locally adapted improved sorghum varieties to a particular environment is one solution to overcome the challenges of both local adaptation and local farmers' end user requirements.

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