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Breeding for Resistance to Drought: A Case in Sorghum (*Sorghum bicolor* (L.)Moench)

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ABSTRACT

Drought tolerance in sorghum was estimated in several ways: evaluation of grain yield under drought, the stability of yield, rate and duration of grain fill, seed weight, stay green and associated traits. Cultivars that tolerate pre-flowering water deficit are advantageous for the reason that yield components such as stand, tiller number, the number of heads, and especially the number of seed per head are determined during this period. Green leaf area at maturity is used as an indicator of post-anthesis drought resistance in sorghum breeding programs. For a successful selection of sorghum for drought resistance, the presence of considerable magnitude of variability in the available germplasm is a prerequisite. There is a positive correlation between drought tolerance and root length in sorghum. Moreover, water stress at seedling stage significantly affects the root to shoot ratio that seedling under water stress cause an increase in root length with a reduced diameter. In addition, numerous seedling traits have been suggested as important relative to drought tolerance including root weight, lateral root number and root-to-shoot ratios. Therefore, the root to shoot ratio and its characteristics can be an indication of selection criteria for sorghum in respect of drought resistance. Molecular markers linked to QTL 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. Therefore, in this study the scientific results were evaluated and summarized.

Keywords: Drought; Sorghum; Drought resistance; Marker assisted selection; QTL

INTRODUCTION

A 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 [1]. But from an agricultural point of view, its working definition would be 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 the full genetic potential of the plant [2]. It affects plant growth, survival and productivity in the world [3, 4]. Its effect is more pronounced in the semi-arid tropics (SAT), where rainfall is generally low and erratic in distribution.

Drought is a complex trait thought to be controlled by many genes. Efforts have been underway to determine the genetic and physiological mechanisms that condition the expression of drought resistance in crop plants. This information has particular importance in the development of superior genotype and to devise a sound breeding approach for the improvement of the trait [5].

Sorghum (*Sorghum bicolor* (L.)Moench) is one of the most important cereal crops grown in arid and semi-arid parts of the world. It evolved in semi-arid tropical Africa where it is still used as a major food cereal. Sorghum is extensively adapted to semi-arid environments. The crop can successfully grow in areas that are too marginal for major cereals. Developing countries account for roughly 90% of the world's sorghum area and 77% of the total output [6].

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In Eastern Africa, more than 70% of sorghum is cultivated in the dry and hot lowlands where soil fertility low, poor stand establishment, in addition to serious water deficit are among the major production constraints [7]. According to Bramel-Cox et al. [8], Ethiopia is the centre of origin and diversity for sorghum. In Ethiopia, sorghum is grown as one of the major food cereals. It is utilized in various forms such as for making local bread (Injera) and for preparation of local alcoholic beverages (tela and areke). It is also consumed as roasted and boiled grain. Sorghum stover is used as feed for animals and as housing and fencing material. Sorghum is annually cultivated at 1.3 million ha contributing 1.7 million MT to annual grain production in the country [9]. It is grown in the major agro-ecological zones including the lowland, mid and high altitude areas of the country [10]. But it is predominantly cultivated in dry areas that cover nearly 66% of the total area of the country [6]. Because of the recurrent drought, other cereals rarely give harvestable yield in these areas.

However, the productivity of the crop is very low, only about 1.4 tonnes/ha [9]. But experimental result indicated that yield of up to 3.5 tonnes/ha is possible on farmers' fields in major sorghum growing regions of the country [6]. This still is very low when compared with the yield of 7 to 9 tonnes/ha obtained under intensive management, indicating that drought is one of the prime factors reducing sorghum yield in semi-arid regions [11]. In Ethiopia rainfall in major sorghum growing regions has always been inadequate and its distribution is erratic [12]. As a result, the crop suffers from water deficit at least for certain periods of time during the growing season. In addition to its direct effect on yield, drought also pre-disposes the crop to other yield-limiting factors such as pests and diseases [13]. Stem borer and stalk rot diseases, particularly charcoal rot, are highly associated with the occurrence of drought. Though farmers have their own traditional ways of coping with the problem such as through the use of mulch, intercropping, and employing various types of soil and moisture conservation practices, none of them was adequate to substantially increase yield [14]. Research centers have also recommended a number of soil and moisture conservation practices, which include tillage operations, mulching and others to reduce the effect of drought [15]. Efforts have also been made to develop early maturing sorghum varieties that are adapted to areas where moisture scarcity is detrimental to sorghum production. By doing this, early maturing sorghum varieties are currently available for use under such environments. Integration of appropriate moisture conservation methods with these varieties has produced satisfactory results [14]. Wide genetic variations exist among sorghum germplasm for tolerance to drought indicating the potential to develop new sorghum cultivars that may be better adapted to drought condition. Therefore, the objective of this review is to summarize both the classical/conventional and technological approaches for sorghum resistance breeding.

Biotechnological Approach for Drought Resistance

Three breeding approaches for drought resistance have evolved. The first is to breed for high yield under optimum (water-stress-free) condition. As the maximum genetic potential of yield is expected to be realized under the optimum condition and a high positive correlation exists between performance in optimum and stress conditions [16], a genotype superior under optimum level will also yield relatively well under drought condition. This is the basic philosophy of this approach.

However, the concept of expression of maximum genetic potential in optimum condition is debated [17] as genotype-environment interaction may restrict the high yielding genotype to perform well under drought. Thus, the second approach, i.e., to breed under actual drought condition has been suggested [18].

The second approach suffers from the problem that the intensity of drought is highly variable from year to year and as a consequence, environmental selection pressure on breeding materials changes drastically from generation to generation. This problem compounded with low heritability of yield makes for the complicated and slow breeding programme[19].

An alternative approach to the above two would be to improve drought resistance in high-yielding genotypes through the incorporation of morphological and physiological mechanisms of drought resistance. However, transferring drought resistance in high-yielding genotypes is complicated due to lack of understanding of the physiological and genetic basis of adaptation in drought condition. In contrast, improving the yield potential of an already resistant material may be a more promising approach, provided there is genetic variation within such a material. Simultaneous selection in the non-stress environment for yield and in a drought condition for stability may be done to achieve the desired goal of evolving drought resistant genotype with high yield.

As such, the breeding methodology to be applied for drought resistance is the same as that applied for other purposes. In general, pedigree and bulk method could be used for self-pollinated crops and recurrent selection for cross-pollinated crops. However, if the transfer of few traits relating to drought resistance to a high-yielding genotype is the aim, then backcross is the appropriate methodology. On the other hand, biparental mating (half-sib and full-sib) maintains the broad genetic base as well as provides the scope to evolve the desired genotype of drought resistance [20]. The success of any breeding programme depends on the availability of the screening technique, especially for drought resistance.

The techniques for gene transformation of crop plants have been applied for identification of genes responsible for drought resistance and their transfer [21]. Mainly two approaches, namely targeted and shotgun approach facilitate genetic engineering to obtain transgenic plants conferring drought resistance.

Marker-assisted selection for drought resistance

In most breeding programmes, 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 markers associated with osmotic adjustment, stay green, root traits has been achieved[22].

Screening techniques for drought resistance

Any effort for genetic improvement in drought resistance utilizing the existing genetic variability requires an efficient screening technique, which should be rapid and capable of evaluating plant performance at the critical developmental stages and screening a large population using only a small sample of plant material [23]. Drought resistance is the interactive result of different morphological, physiological and biochemical traits and thus, these different components could be used as selection criteria for screening appropriate plant ideotype. A combination of different traits of direct relevance, rather than a single trait, should be used as selection criteria [24].

The importance of developing a reliable screening technique for drought resistance was realized very early and different techniques have been used since then [25]. As the loss of yield is the main concern for the crop plant from the agricultural point of view, plant breeders emphasize yield performance under moisture stress condition. A drought index which provides a measure of drought based on loss of yield under drought-condition in comparison to the moist condition has been used for screening drought-resistant genotype [26]. An artificially created water-stress environment is used to provide the opportunity for selecting superior genotype out of a large population[27]. Visual scoring or measurement for maturity, leaf rolling, leaf length, angle, root morphology and other morphological characters of direct relevance to drought resistance are also taken into consideration.

Drought as major constraint to sorghum production

In most areas where crop production is dependent on rainfall, there is always the risk of crop failure or yield loss due to moisture stress. In the semi-arid tropics, the loss mainly arises from the availability of low moisture to support growth and development of crops [28]. In these 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 [2]. Sorghum is mainly grown in areas of inadequate rainfall and is the principal source of food for millions of people living in these areas.

In Africa over 24 million hectares of land is allotted for sorghum production annually with a mean yield of 0.8 tones/ha [29]. Although several factors such as low soil fertility, poor pest and disease control and low yielding potential of local varieties contributed to low yield, much of the reduction in yield is thought to be due to severe drought stress [3]. Efforts have been underway to mitigate the effect of recurrent drought through soil and moisture conservation and tillage practices and development of varieties adapted to the dry land condition. Previous reports indicated that significant morphological and genetic variability attributes to drought tolerance were detected among African sorghums [30].

Mechanisms of Morphological and Physiological Responses of Sorghum to Drought Resistance

Drought tolerance/resistance is a complex trait influenced by several plant factors. Thus the genetic improvement of drought tolerance through plant breeding that focused on yield *per se* is considered an arduous task. However, parallel efforts should be made to improve simultaneously inculcating other drought-tolerant traits [31]. Drought tolerant crops respond to water deficit through different morphological and physiological mechanisms such as drought escape, dehydration avoidance, and dehydration tolerance [32]. **Drought escape** is defined as 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 pre-anthesis assimilates to grain. **Drought avoidance** is the ability of plants to maintain relatively high tissue water potential despite a shortage of soil-moisture by avoiding the negative effect of drought, whereas drought tolerance/dehydration tolerance is the ability to withstand water-deficit with low tissue water potential. They may develop effective root system for moisture absorption, reduced transpiration loss of water through leaf rolling and folding and via regulating stomatal opening. Plants also overcome water stress by regulating solute concentration in the cell, a phenomenon known as an osmotic adjustment [17], while others withstand low tissue water potential and maintain cellular and metabolic integrity under conditions of tissue water desiccation [5]. A single plant may possess one of these drought tolerance mechanisms or may have combinations of two or more of these mechanisms [33].

Sorghum is known for its ability to tolerate drought better than most food cereals and yet is the most affected crop by drought [34]. Efforts have been going on to improve drought tolerance of sorghum in order to enhance dryland agriculture. Significant progress has been made in identifying key traits for drought tolerance and in understanding the reaction of genotypes to drought at different stages of growth. In an effort to better understand the underlying mechanisms scientists have dissected drought tolerance into pre-flowering and post-flowering stress tolerance which is perhaps regulated by different genetic mechanisms [35]. Cultivars that tolerate pre-flowering water deficit are advantageous for the reason that yield components such as stand, tiller number, the number of heads, and especially the number of seed per head are determined during this period [36]. These are important components of both yield and water use efficiency [37]. Pre-flowering leaf photosynthetic rate correlates with biomass and grain production under both well watered and water-limited conditions, whereas, post-flowering drought tolerance expressed when moisture stress occurs during grain filling stage. Post-flowering drought stress in susceptible genotypes may become very severe in that it interferes with fixation of CO_2 and the subsequent translocation of carbohydrate to the grain. The drought that occurs during grain filling stage usually results in rapid premature plant senescence [38].

Post-flowering drought tolerance is expressed by the ability of a plant to maintain photosynthetically active leaf area after physiological maturity, a character known as stay green or non-senescence [35]. Most crops are sensitive to water deficits in a period between flowering and seed development. The effect of moisture stress at this stage is more pronounced when it is associated with lodging resulting from weakening of the base of the stem [39]. Symptoms of post-flowering drought stress in susceptible genotypes include premature plant death, leaf senescence, stalk collapse and lodging, and reduction in seed size. Tolerance to terminal drought stress is mainly associated with the ability of plants to retain green leaves and stem thereby reducing drought-induced senescence and production of normal grain [40]. Senescence is expressed by loss of chlorophyll followed by progressive decline in the photosynthetic efficiency. It is a normal physiological process in plants which starts from lower leaves and progress to the upper leaves during maturation. Early onset of senescence due to post-flowering stress accelerates the rate of senescence by driving many processes in the same direction of normal senescence [41].

Maintaining Green Leaf Area in Sorghum Improve Yield under Drought

A mechanism of resistance, known as stay-green [42],as indicated by maintenance of green stems and upper leaves when water is limited during grain filling. Green leaf area at maturity is used as an indicator of post-anthesis drought resistance in sorghum breeding programs in the USA [43]and Australia [31]. Green leaf area at maturity and its components have been found to vary with both water regime and genotype [40].The critical issue is whether retention of green leaf area underpost-anthesis drought actually increases grain yield in stay-green compared with senescent hybrids. Positive associations between green leaf area duration and grain yield have been observed in a range of cereals, including wheat, *Triticumaestivum* L.maize, *Zea mays* L. and sorghum [31,44].

Green leaf area at maturity is accepted as a key indicator of post-flowering drought tolerance in sorghum [31]. Green leaf area and grain yield have been shown to be positively associated. Genetic variability exists among sorghum genotypes for no senescent (stay green) property and the relationship of this trait to drought tolerance has been well understood. Visual scoring of stay green trait should be done at or right after physiological maturity. The scoring procedure is relatively easy and not time consuming but it is subject to individual bias and the difference in ratings among individuals [45]. Visual ratings for percentage green leaf area and a number of green leaves were highly correlated with measured green leaf area under drought stress [46]. Consequently breeding for stay green trait is becoming a fundamental strategy for increasing crop production in water-limited conditions [47]. Progress has been made in the genetic improvement of post-flowering drought tolerance of sorghum through manipulation of the stay-green trait [48]. Genotypes possessing the stay-green trait maintain more photosynthetically active leaves than genotypes not possessing the trait [43]. The longevity and photosynthetic efficiency of the leaves of stay green plant were shown to be associated with the nitrogen status of the leaves [49], increased leaf area at maturity and higher transpiration efficiency [47].

As cited by Nguyen et al. [50] field performance evaluation containing hybrids derived from parental lines containing senescent and no senescent trait under severe post-flowering conditions revealed that hybrids from not stay green parents showed about 20-55% lodging percentage compared to less than 10% lodging in the hybrids with one stay green parent. The stalks of stay green genotypes have the capacity to transport water continuously under drought condition [51]. They also reported that the relative water content in the apical leaves of sorghum lines containing stay green trait was about 81% whereas it was only 38% in the non-stay green lines. The accumulation of sugar is also associated with the greater function of leaf area during grain filling period thereby reducing dependence on the stored sugar for grain filling [52]. Besides the grain, stalks of sorghum are sought for animal feed in developing countries. The stay-green trait might add value to the stalks that may enhance the quality of stalk as feed sources. Results of some previous studies indicated that content and concentration of non-structural carbohydrate in the stay green plant after grain harvest has been relatively higher than in the non-stay green types [13,53].

Genetics and Genetic Improvement of Drought Resistance in Crop Plants

Genetics

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) characteristics.

The identification of genes responsible for morphological and physiological traits and their location on a chromosome has not been possible, but their inheritance pattern and nature of gene action have been reported. Polygenic inheritance of root characters is reported by Ekanayake et al. [54]. According to Armento-Soto et al. [55], the long root and high root numbers are controlled by dominant alleles and thick root tip by recessive alleles. However, leaf rolling and osmotic adjustment have shown monogenic inheritance. Tomar and Prasad [56]reported a drought resistance gene, *Drt1* in rice, which is linked with genes for plant height, pigmentation, hull color and awn, and has a pleiotropic effect on the root system. Similarly, in cow pea drought resistance is reported to be controlled by a single dominant gene [57].

Genetic basis of drought response in sorghum

As discussed in the previous sections, different morphological and physiological mechanisms contribute to overcoming the effect of drought in crop plants [5]. Information regarding the genetic basis of these different mechanisms has been very limited. However, a large amount of genetic variability has been reported among sorghum germplasm for their reaction to drought. Genotypes expressing a various degree of stay green trait have been identified [35,52]. However, the heritability of this trait from different genotypes was not consistent. In some backgrounds it appeared to be regulated by dominant genes (e.g. B35), whereas in the others it appears to be recessive (e.g. R9188) [58]. In another study in the stay-green trait in line B35 it was reported to be affected by a major gene that exhibits a different level of dominant gene action depending on the environment in which the materials are evaluated [59]. The broad sense and narrow sense heritability estimates were 0.80 and 0.60, respectively, indicating that the stay-green trait is highly heritable and progress from selection can be attained [59].

In a diallele study conducted to estimate the inheritance of the stay-green trait by dissecting into two components which determine the occurrence of the trait, it was suggested that inheritance of the onset of senescence was additive, whereas for the rate of senescence a slow rate was completely dominant over the fast rate [60]. Another study on the genetic basis of osmotic regulation revealed the existence of significant variation among different sorghum genotypes [61]. A biparental progeny genetic study revealed that two independent major genes (*oa1* and *OA2*) were involved in the regulation of osmotic adjustment in sorghum [62]. Another study conducted using a different population set, a monogenic inheritance has been reported to control the trait.

Quantitative Trait Loci (QTL) Mapping and Analysis of Drought Tolerance

A number of studies have been conducted to identify and map quantitative trait loci (QTL), regulating both pre-flowering and post-flowering drought tolerance. Molecular markers linked to QTL 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. Such an approach provides a more systematic mode for identifying specific traits that contribute to drought tolerance. However, the number of QTLs associated with drought tolerance was different in different backgrounds. A mapping based on multi-location data of recombinant inbred lines derived from the cross SC562 × Tx7000 revealed nine QTL regulating the stay-green trait that was distributed over seven linkage groups [39]. Moreover, they have also identified four QTL for the pre-flowering drought tolerance and for lodging. Earlier Tunistra et al. [63] reported two QTL with major effect on yield and stay green trait under post-flowering drought stress. Three QTL which accounts for 34% of the total variance in stay green trait were identified [64]. Another study conducted with the population derived from B35 × Tx7000, revealed four genomic regions associated with the stay-green trait which accounts for 53.5% of the phenotypic variance [65]. Inbred lines developed from TX7078 and B35, having a distinct reaction to moisture stress, were examined to investigate the genetic basis for drought tolerance. In a population derived from TX7078 × B35, six QTL associated with pre-flowering tolerance and eight additional QTL associated with yield and yield components were identified [66]. In the same study, thirteen QTL associated with post-flowering drought tolerance were reported of which two of them were associated with grain yield and stay green traits possessing pleiotropic effects both under drought and irrigated conditions. Moreover, seven QTL associated with duration of grain filling, which accounts for 51% of the phenotypic variability has been obtained. Markers associated with stay green and seed weight were more stable and consistent across environments [66].

Phenotypic Selection for Drought Tolerance

We have made slow but significant progress via 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. 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 was 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 QTL marker analysis and introgression.

Development of Hybrid Sorghum for Marginal Environments

The use of early maturing sorghum varieties is encouraged to overcome the drastic effect of drought in SAT regions where either seasonal rainfall is short or its distribution is erratic. These varieties may not be necessarily superior to long maturing cultivars, but give more stable yield under water stress environments. Though a number of early maturing varieties are now available for much of the SAT regions, their contribution to enhancing total production is minimal. This might be because selections were made among traditional cultivars with a major emphasis on maturity rather than combining early maturity with high yield potential [11]. Therefore, much of the increase in total production in Africa comes from the increased land area. The situation is quite different in other parts of the world. In India, the production area declined by 37%, but yield increased by 80% [67]. Also in developed countries, average production has been increasing and total area decreasing. This was perhaps due to increased development of hybrid cultivars that have much higher yielding potential than open-pollinated varieties.

Globally estimated area planted with hybrid sorghum was 48% which contributed to a minimum of 40% yield advantage over open-pollinated varieties. Hybrid cultivars of sorghum are often preferred because they give higher yield and have more stable performance under a wide range of environmental conditions [68]. They have the advantage of giving higher grain yield than open-pollinated varieties both under optimum and stress environments with the advantage being higher under stress environment [30]. In Kenya hybrid sorghum reported to give up to 50% yield advantage over open-pollinated varieties under extreme drought situations (https://www.africancrops). The performance of hybrids tested for several years at MARK exhibited a consistent yield advantage of over 100 % compared to standard checks [68]. A recent report confirmed that hybrids exhibited 68-131% yield more than the open-pollinated check variety. Commercial production of hybrid sorghum became only possible after the discovery of cytoplasmic male sterility system in the 1950s [69].

Different male sterility systems which include A1, A2, A3 and A4 have been identified in sorghum [70]. But the A1 sterility system is widely used in hybrid sorghum program [71]. The A2 cytoplasm can be potentially useful for hybrid seed production provided that suitable A2 sterile females and corresponding restorer are identified. However, the A3 system was kept out of use because of limited source of fertility restoration genes and the A4 cytoplasm is not sufficiently characterized [71]. Due to expanded use of hybrids, sorghum yield in the United States has improved over 300% between the 1950 s and 1990s. Following the advent of hybrids in USA 35-40%, the genetic gain was estimated on grain sorghum [72]. Hybrid cultivars, besides their superior yielding potential over the pure line varieties, have a strong role in motivating private seed growers to engage in commercial seed production [73]. In Sudan, there was a significant turnaround in seed production following the release of Haggen Dura-1 (HD-1), the first commercial hybrid released in 1983. This cultivar has excellent grain quality and stable performance in areas where lack of moisture limits production. Thus the acreage under this cultivar increased from year to year with the current statistics showing 1 million ha of land put to the cultivation of this hybrid [29]. Considering the advantages of hybrid sorghum, several national programs in the semi-arid regions have shown increased interest in hybrids [74].

Research on sorghum hybrid development in Ethiopia began in the mid-seventies, with an objective of developing sorghum hybrids for the low altitude and moisture stress ecological zones. Series of A and B lines were introduced along with suitable restorers for hybrid development from abroad. Best looking and agronomically suitable A and B lines were identified [68]. He also mentioned that introduction of fertility restorer line (R-line) has since 1977 and the best combiners have been identified. Hybrid parents need to be genetically complementary for vigor and yield-associated traits, but not for other often recessive traits that would adversely affect height, maturity, grain qualities or resistance. The task of hybrid development is gaining momentum through strong collaborative research with INTSORMIL and other national and international research programs. Recent efforts research efforts aimed at studying the digestibility, drought and Striga tolerance of the introduced hybrids have been undertaken. Meanwhile, hybrid development activities using male sterile female lines found to have better adaptation and locally adapted and high yielding male parents are being conducted. So far four hybrids found to be better performing in the drier areas have been identified and included in the verification trial.

Selection for Grain Yield in Sorghum under Moisture Stressed Environments

Sorghum is an important food crop in the semi-arid tropics(SAT), where rainfall is generally insufficient and erratic and soil fertility status is very poor [75].According to Kawano and Jennings [75] to improve and stabilize crop production in these areas, the genetic potential of crop germplasm needs to be adjusted to available environmental resources. Strategies are available for improving performance in moisture deficit soils of the SAT. One of the approaches assumes that selection of plant genotypes under optimal moisture supply may maximize genetic gain in low input production environments. Testing the usefulness of this approach will be important both in the stress-prone SAT as well as in temperate environments where stress is infrequent but farmers often look for ways to reduce production costs [76,77].

A review by Bramel-Cox et al. [8] presented conflicting results regarding the usefulness of selection under non-stress conditions to identify genotypes for use in low input environments. The amount of genetic progress from selection for broad adaptation in both favorable and adverse production conditions diminishes as the intensity and frequency of stress increases in the unfavorable production environments [8]. These conclusions were drawn from sorghum studies which were conducted in either moisture stress or limited soil fertility. However, crop breeders in the semi-arid tropics most frequently confront a combination of moisture and nutrient stresses in their target production environments. Therefore, evaluating breeding materials under both limited moisture and nutrient supply may increase the chance of identifying lines which are adapted to one or both stress conditions.

The breeding procedure commonly practiced for handling segregating generations affects the rate of genetic progress that can be made under stress. Single plants selected from early segregating generations in nutrient deficient and moisture deficit soils may fail to maintain the same expression in subsequent progeny testing because of the inherent lack of uniformity in the intensity of these stresses in the experimental field during selection as well as the resultant segregation from single plants. To minimize these problems, evaluation and selection for stress tolerance may be delayed until true breeding lines are developed. The use of the single seed descent breeding method which allows rapid attainment of homozygosity may, therefore, be suitable for developing recombinant inbred (RI)lines to be tested under an array of contrasting moisture and nutrient environments.

CONCLUSION

Drought limits the agricultural production the crop plants for example sorghum, by preventing them from expressing their full genetic potential. Three mechanisms, namely drought escape; drought avoidance and drought tolerance are involved in drought resistance. Various morphological, physiological and biochemical characters confer drought resistance. Morphological and physiological characters show different types of inheritance pattern (monogenic and polygenic) and gene action (additive and non-additive).

Among cereal crops, sorghum is a semi-arid crop affecting by drought frequently. It experiences severe moisture stress during its growth in many moisture-stressed areas of the country. 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 potention 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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