SELECTION METHODS AND GENETIC VARIABILITY FOR TRAITS RELATED TO DROUGHT RESISTANCE IN SORGHUM

M.Sc. Thesis

by

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Abstract

Moisture stress is one of the most important abiotic problem contributing significantly to yield loss in arid and semi-arid environments. This problem is alleviated by developing crops that are well adapted to moisture constraint areas. Sorghum (*Sorghum bicolor* (L.) Moench) is an important drought tolerant crop in such areas and is a good crop model for evaluating mechanisms of moisture stress.

In the first study, 31 random inbred lines of sorghum derived from crosses of staygreen x senescence parents and five check varieties were used to study the effect of high surface temperature on seedling emergence. Two soil covers (charcoal and kaolin) and control were used to modify the temperature to observe their effects on seedling germination. At 2 cm soil depth temperature in charcoal treatment was high and showed partial or complete failure of germination in some genotypes under study. However, few genotypes such as ICSV 112 and SSD 66 were tolerant to high temperature germination in the charcoal treated soil.

In the second study, a set of 22 random inbred lines with two check genotypes of sorghum was characterized under irrigated and non irrigated (stress) conditions for the genetic variability of traits associated with post flowering drought tolerance and for potentially related components of grain development. Different characters were used to estimate the post-flowering drought tolerance. Among these traits, yield and staygreen were identified with a major effect under moisture stress. The staygreen and moderate staygreen lines showed better yield performance than senesced lines under

the prolonged mid-season and terminal drought. This suggests that there are some underlining mechanism that controls the expression of staygreen under post-flowering drought and contribute to yield in drought and control (wet) treatments.

Declaration

I, Tesfamichael Abraha, here by declared that the thesis entitled "SELECTION METHODS AND GENETIC VARIABILITY FOR TRAITS RELATED TO DROUGHT RESISTANCE IN SORGHUM" which was done at the International Crops Research Institute for the Semi-Arid Tropics, Patencheru, India submitted to the Royal Danish Veterinary and Agricultural University for the partial fulfillment of Masters of Science in Plant Breeding and Genetic Resources is the result of me. Moreover, I declared that this thesis or any part of this thesis has not been published before under any circumstances.

Tesfamichael Abraha

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CHAPTER I

1.0 INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is an important crop in Semi-Arid Tropics (SAT). It is the source of staple food crop for Africa, South Asia, and central America. It is grown in the USA, Australia and other developed countries for animal feed.

Sorghum is used in the preparation of different types of food, and an unleavened bread is the most common food made from sorghum flour. Sometimes the dough is fermented before the bread is prepared. Flour is also boiled to make porridge. It can be also prepared into different biscuits. Beer is prepared from sorghum grain in many parts of Africa. Besides these products, popped and sweet sorghum which are parched are also eaten (House, 1980). The sorghum plant makes good feed for animals. Chopped stem and foliage are used for silage hay, pasturage or as a green crop feed directly to the animals. The stem is also used as fuel and building materials.

Little is known about when *Sorghum bicolor* was first domesticated. However, Doggett, (1965) indicated that the domestication and origin of sorghum was probably in the northeastern part of Africa extending from the Ethiopia-Sudanese border westward up to Chad before 5,000 years.

Sorghum is the fifth major cereal crop in the world after wheat, rice, maize and barley. It is cultivated in about 44.4 Million hectares which produces a total of 63.5 Million MT of grain (FAO, 1998). This makes sorghum to represent four percent of the total cereal production. Though this figure is small, there are countries where sorghum is of great importance and takes larger share of total cereal production. To name a few: Burkina Faso (53%), Sudan (72%), Chad (41%), Cameroon (40%), Botswana (84%), and Rwanda (52%). In Africa as a whole, sorghum represents 18% of the total production (Dendy, 1995).

In Eritrea sorghum ranks first in the contribution towards national economy and diet, and forty five percent of the bulk total food production for the nation comes from sorghum. It is cultivated annually over approximately 130,000 hectare producing approximately 62,000 MT of grain (FAO, 1997). Like other African countries grain sorghum is used for human consumption, while leaves and stalks are commonly fed to animals. However, priority is given for grain production than to animal feed.

Sorghum is a subsistance crop and is frequently grown by small farmers with few inputs under rainfed conditions of Semi-Arid Tropics. There are vast differences in sorghum production in different parts of the world, the average yield ranging from 500 to 1000 kg ha^{-1} in semi-arid tropics in unfavorable conditions, and 3000 – 4000 kg ha^{-1} are obtained under better conditions. The differences in yield are due to variability in distribution of dry matter in the plant, responses to environments with different levels of stress and different biotic factors like pests, diseases, striga, and birds. However, drought stress is the major limiting factor in sorghum crop production in semi-arid tropics (Peacock, 1980).

Drought is the primary factor contributing to crop yield limitations around the world (Boyer, 1982). Although many crop species have been shown to posses genetic variation for drought tolerance, selection for tolerance while maintaining maximum overall productivity has been a challenge (Rosenow *et al.*, 1981). There are several explanation for this problem. First, drought tolerance has been defined in several ways and the lack of a simple screening procedure has slowed down the selection of improved genotypes. Some researchers use grain yield *per se* to quantify drought tolerance, but selecting for grain yield under drought condition is not efficient (Clarke *et al.*, 1992). Grain yield integrates the plant response to the environment over the entire crop season and may not efficiently discriminate between drought tolerant and susceptible genotypes. An alternate measure of drought tolerance is based on the stability of yield or some other trait across drought and non-drought environments (Fischer and Maurer, 1978). The problem with stability measurements is that selection for stability can lead to stable but poor yielding lines under optimal conditions (Clarke *et al.*, 1992). Selection for drought tolerance should ideally integrate high yield potential with stability of agronomic performance across drought prone environment. The second difficulty in selecting for drought tolerances is that genotypes must be screened for tolerance in controlled environments where drought can be routinely imposed. Testing under dry-land condition is difficult because specific drought condition cannot be easily and reproducibly imposed. Finally, drought tolerance is subject to strong environmental variation and genotype x environment interaction (Clarke *et al.*, 1992). Genotypes selected for adaptation to drought in one environment may show poor adaptation in other dry environment unless the two environments are very similar. Genotypes selected solely for adaptation to drought often display poor grain yield potential under optimal conditions (Blum, 1979; Rosenow and Clark, 1981).

Crop establishment in sorghum is affected by a number of factors related to the seed and its growing environment. Major limiting factors to crop establishment are emergence, drought susceptibility, response to available nutrients and susceptibility to salinity (Maiti, 1993). Despite the level of environmental adaptation sorghum displays failure of seedling emergence due to abiotic stress and is a major problem. The environmental sensitivity of a plant varies through out its development (Levitt, 1980), but the seedling phase is particularly vulnerable. Without adequate germination, no seedling establishment is possible. In the semi arid tropics, drought is usually associated with high soil surface temperature affecting the seedling emergence.

Evidence from different approaches indicates that water stress reduces the yield potential in sorghum. The magnitude of this reduction varies according to the degree of interaction between the drought stress, stage of development, plant density, genotype, duration and temperature (Simpson, 1981). The stage of growth at which moisture stress occurs is the most important in determining the response of sorghum to soil moisture stress. Evaluation of sorghum germplasm has identified genotypes that are drought tolerant during one growth stage but are susceptible at other stages (Rosenow and Clark, 1981).

Three distinct stages of growth can be identified in sorghum.

I. Seedling establishment (early vegetative stage), growth stage one (GS 1).

II. Pre-flowering (panicle differentiation till flowering), growth stage two (GS 2)

III. Post-flowering (grain fill to physiological maturity), growth stage three (GS3)

Drought resistance at the seedling establishment or early vegetative stage (GS1) is obviously an important trait, especially in the harshest environment. Drought at this stage can result in failure of seed germination, reduction in growth, death of seedling and significant loss of stand.

The pre-flowering response occurs when plants are under moisture stress prior to flowering (GS2), especially from panicle differentiation or shortly there after until flowering which results in leaf rolling, delayed flowering, poor panicle exertion, reduced panicle size and failure of development of secondary branches, spiklets or florets.

Drought stress during post-flowering stage (grain filling, GS3) cause a rapid decrease in grain and stalk yield and increases its susceptibility to pests and diseases. Post-flowering stress results in premature plant (leaf and stem), death or plant senescence, stalk collapse, lodging and reduction in seed size (Rosenow *et al.*, 1997).

Any mechanism, which confers tolerance to drought during any of these stages of development in sorghum, is beneficial. For example stay green is one mechanism or trait that confers post-flowering drought tolerance in sorghum by delaying plant leaf senescence under terminal moisture stress.

The objectives of these investigations were:

1. To select sorghum genotypes (varieties) that emerge well under high soil surface temperature and to see variability in soil cover treatments.
2. To assess genetic variability for tolerance from prolonged mid-season (GS2) and terminal drought (GS3).
3. To work out correlation among the drought related and morphological traits.

CHAPTER II

2.0 LITERATURE REVIEW

Drought is one of the most important abiotic constraints limiting production in semi arid tropics of the world. Sorghum is an important crop in such areas showing excellent drought adaptation traits. Sorghum is a native to sub-Saharan Africa and has been cultivated for centuries as a staple crop in much of the semi-arid tropics. Substantial genetic variability for drought exists within the sorghum gene pool. It is currently the fifth most important cereal crop after wheat, rice, maize and barley. It is primarily food source in many developing countries while in America sorghum is grown primary as feed for cattle and poultry (Mitchell *et al.*, 1997).

The literature available on drought tolerance with special reference to sorghum is reviewed below under the following headings.

2.1. Effect of temperature on seedling emergence of sorghum

2.2. Drought and drought resistance

2.3. Growth stages and drought stress in sorghum

2.4. Drought tolerance mechanisms in sorghum

2.4.1 Drought escape

2.4.2 Drought avoidance and tolerance

2.4.3 Osmotic adjustment in relation to drought in sorghum

2.5. Staygreen and its influence on drought resistance in sorghum

2.6. Influence of drought traits on yield and yield components.

2.1 Effect of temperature on seedling emergence of sorghum

There are several factors affecting seedling emergence of sorghum. These include depth of planting, seed size and genotype, soil temperatures, soil crust, tillage, moisture availability and harvest of immature seeds. High soil surface temperature is one of the major factors for poor emergence. In semi-arid tropics where sorghum is grown, air temperature often exceed 40^0C and even higher temperatures ($>50^0C$) may be experienced on the soil surface. The ability of sorghum seedling to emerge and establish rapidly is essential to the success of any genotype. Each plant has a minimum and maximum temperature at which no seed germinates. Peacock (1982) reviewed that the optimum temperature at which high germination occurring ranges from 21^0C-35^0C. Moreover it would appear that the supposedly lethal temperature for germination ranges from 40^0C-48^0C. Above the optimal temperature, however, both the final percentages of germination and germination rate fall rapidly. This great sensitivity to supra optimal temperature suggests that small difference in soil temperature at the time of germination may have profound effects on germination and hence establishment of the crop. Wilson *et al.* (1982) confirmed that there is genetic variation in the ability to emerge even when the soil surface temperatures are as high as 55^0C. In a study at ICRISAT (1980), seedling emergence was noted with a set of 50 genotypes in a wide range of soil surface temperatures. Charcoal, light kaolin, heavy kaolin and bare soils were used as surface covers to modify temperatures. In the charcoal treatments, where temperature reached 65^0C at 0.5cm depth, there was no emergence, but most seeds have emerged in the control. Wilson *et al.* (1982) demonstrated that delayed and poor emergence were associated with high surface temperature. They observed that the plumule of the susceptible genotype bent laterally after reaching high soil surface temperatures in the charcoal while the coleoptile of the tolerant genotype have emerged.

2.2 Drought and drought resistance

Droughts are an inevitable and recurring feature of world agriculture and despite our improved ability to predict their onset and modify their impact, drought remains the single most important factor affecting world food security and the condition and stability of the land resource from which that food is derived (Turner and John,1986).

Water stress in mesophytic cultivated species is the most common type of plant stress in most regions of the world, and is the main bottleneck of agricultural development. Drought is the most prevalent environmental stress factor limiting plant growth, survival and productivity (Bohnert *et al.*, 1995; Boyer, 1982). Water stress causes deleterious physiological effects like disruption of membrane structure and impairment of stomatal function (Willmer and Pantoja, 1992), reduction in root growth and reduction in yield (Blum and Arkin, 1984). O ` Toole and Chang (1978) and Gaff (1980) observed that crop plants, unlike xerophytes, use more than one mechanism to resist moisture stress. Drought resistance refers to the ability of plants to survive under drought conditions.

2.3. Growth stage and drought stress in sorghum

The stage of growth development at which drought stress occurs is important in determining the response of sorghum to soil moisture stress. The growth period of sorghum has three distinct phases: The vegetative (GS1), floral initiation (GS2), and grain filling or reproductive period (GS3) (Eastin *et al.*, 1973). The vegetative stage is characterized by continual leaf initiation, establishment of initial root system, and the shoot differentiating into panicle. The floral initiation or panicle development begins by expansion of all the upper leaf internodes and all the culms in case of tillers, development and growth of panicle and panicle components, seed setting, development of secondary branches and continual of root growth. The grain filling is characterized by development and filling of grain, determination of seed size, and number of seeds that attribute to the final yield. Krieg (1983) suggests that dry matter production is strongly influenced by leaf area in GS1, which is again directly dependent on period of GS2. Water stress during this stage inhibits cell expansion thus reducing leaf area. He also indicated that tillers are more sensitive to water stress than the main stems. Lira *et al.* (1989) observed that the most resistant genotypes were those characterized by slow vegetative development. Hay and Walker (1989) observed that water stress during GS1 causes reduced yield due to reduction in number of floral initials produced in GS2.

Stress during GS2 causes yield reduction through reduction in plant size, leaf area and seeds per head (Kreig, 1983). Fischer and Wilson (1976) observed that only 12 percent of the grain weight are contributed by pre- anthesis assimilates. But in conditions of stress the contribution of pre- anthesis assimilates to grain weight increases (Krieg, 1983). Stout *et al.* (1978) and Lewis *et al.* (1974) observed that water stress at GS2 caused decreased growth rates of leaves, panicle and reduced seed number per panicle.

The ultimate grain yield however, is a function of both the time spent by the sorghum crop in GS3 and the rate of dry matter accumulation by the developing grain (Eastin *et al.*, 1973), and about 90 percent of grain yield is due to photosynthesis in the panicle and the four upper most leaves. Sorghum starts senescence at milky stage and may have few functional leaves or dried completely by physiological maturity depending on the genotypes (Vanderlip and Reeves, 1974). Moreover, entire meristematic activity ceases and no more leaf initiation occurs 25 days after pollination (Wall and Ross, 1970). House (1985) observed that as grain begins to dry, the remaining green leaves start senescence, the rate of which is distinct for each variety. Krieg (1983) explained that water stress during GS3 resulted in rapid senescence of lower leaves and consequent reduction in yields due to reduced leaf area, increased stomatal resistance and decreased photosynthesis. The normal activity of the developing panicle is also disturbed. Salam (1995) described that dough stage is the most critical to drought stress after flowering while ripening stage is comparatively less sensitive. Farther it was concluded that sorghum genotypes are more drought tolerant at the pre-flowering stage than at the post-flowering stage.

According to Salam (1995) resistant genotype showed sufficient decrease in leaf water potentials to maintain leaf turgor pressure during critical stages. Rosenow (1987) observed two distinctly different types of stress responses directly related to the stage of growth when stress occurs. One type is pre-flowering which expressed when plants are stressed prior to flowering during head development, while the other is post-flowering drought resistance that expressed when moisture stress occurs during grain filling stage. Lines possessing high level of tolerance at one stage tend to be susceptible at the other stage.

2.4 Drought tolerance mechanisms in sorghum

Mechanisms for maintaining plant growth and development in arid areas are complex and not well understood. A wide range of mechanisms of adaptation to water deficits exist among plants. In natural plant communities many of these mechanisms appear to be more important for plant survival than for high productivity (Turner, 1981). An initial assumption when the role of various mechanisms of adaptation to water deficits was evaluated, several physiological and morphological response to water stress were transduced by cell turgor pressure. Thus those adaptive mechanisms that aid in maintenance of turgor, such as osmotic adjustment were considered important in maintaining plant growth through the maintenance of stomata openings, photosynthesis, leaf and root growth. Turner (1979) suggested that the mechanism and strategies of adaptation for plants to survive in water deficit environments could be divided into three categories: Drought escape, drought avoidance and drought tolerance. Blum (1979) observed that sorghum genotypes showed wide variation in drought escape, drought avoidance and drought tolerance mechanisms.

2.4.1. Drought escape

Drought escape is the ability of plants to complete their life cycle before serious soil and plant-water deficits develop. Early maturing genotypes were drought escaping, and had lower evapo-transpiration due to smaller leaf area.

Turner (1979) observed that the mechanism that enable crop plants to escape drought are early maturing, developmental plasticity and remobilization to grain of stem reserves stored before anthesis. With regard to developmental plasticity, Ludlow and Muchow (1990) pointed out that adaptation of annual crop genotypes to the expected length of the growing season is the single most important aspect to enhance both survival and production in arid environment. In nature drought escapers are characterized by rapid phenological development after the incidence of rain and extension of the reproductive phase of development while good soil moisture conditions prevail.

Domestication of native species for crop production like sorghum usually results in a shortening period of flowering for ease of harvesting (Turner and John 1986) and the development of cultivar with differing times to mature in order to match the period of growth with the available soil moisture.

In using drought escape as a solution, some of the potential yield is sacrificed in return for improved stability under stress. This is serious; especially when the moisture environment is un-predictable and may vary to a large extent between years. The more predictable, the environment; the more growth duration can be optimized. The reduced yield potential in early genotypes may be compensated for, to some extent by increasing plant density (Blum, 1970). Early maturity involves a reduced total seasonal evapo-transpiration simply because of the short growth period. However, as growth duration is generally linked with the leaf number and often with leaf size, early genotypes have a small leaf area index and thus they show reduced evapo-transpiration during most growth stages, up to the point where a full ground cover is achieved (Blum and Arkin, 1984).

2.4.2 Drought avoidance and tolerance

Drought resistance is a phenotypic expression of a number of morphological and physiological mechanisms. Ludlow and Muchow (1990) defined these characteristic and mechanisms as traits. They further stated that drought resistance is not due to single trait, but is the combination of mechanically linked traits called strategies. Plants with avoidance strategy show enhanced water up take through deep roots and reduced water loss by stomata closure, leaf rolling and leaf area reduction (Ludlow *et al.*, 1985). In drought avoiding types, the root resistance to water up take was reduced. Cultivars resistant to drought possess higher amount of epicuticular wax on leaves and sheath. Turner and John, (1986) pointed out that osmotic adjustment allows continued root growth in drought avoiding cultivars that enable them to explore a greater volume of soil for water from higher depths in low water potential areas. Factors which avoid dehydration by reducing water loss, such as decrease in stomatal conductance, leaf rolling and a decrease in leaf area are all processes that decrease productivity (Turner, 1979). They may increase water use efficiency by reducing water loss at critical times of the day when the vapour pressure deficits are large, but allow photosynthesis to continue in the early morning or late afternoon when vapour pressures are less severe. Through sensitivity to vapour pressure deficits, mid day closure of stomata can occur independent of bulk leaf turgor, resulting in an improved water use efficiency. Like wise leaf rolling appears to reduce water loss in the critical period of day (around mid day). The degree of leaf rolling appears to depend on the turgor of the leaf cells (Begg, 1980). Sorghum avoids dehydration very effectively during dry spells, with a combination of mechanisms that enhance water up take and mechanism that minimize water loss. The result of avoiding dehydration is the maintenance of turgor which is essential for shoot and root growth and all metabolic processes, during mild stress. During severe water stress, it results in the maintenance of cell volume, so essential for cell survival. Compared with other crops except sunflower, sorghum has a deep and extensive root system, which effectively extract water from the rooting volume (Bremner *et al.*, 1986). If there are no physical and chemical impediments to growth, sorghum roots penetrate undifferentiated soils at 3.4cm per day (Robertson *et al.*, 1989). There are however, many instances when water is left in the lower part of the rooting volume and below the root zone. This water could contribute both the survival and to economic yield, if the root system was deeper or more extensive.

There are numerous ways by which sorghum avoids dehydration by reducing water loss. The first, but invisible response to water stress is reduction in the rate of leaf growth, and hence the rate of increase of transpiring area. The initial reduction is probably in response to chemical signals, probably hormonal, produced when the roots close to the soil surface become dehydrated (Ludlow *et al.*, 1989). This reduction occurs before there is a decline of water status, because the remaining part of the root system has access to sufficient water to satisfy the evaporative demand. This root signal may also cause partial closure of stomatas and initial leaf rolling. Both these responses assist avoidance of dehydration, because of reduced water loss (Begg, 1980). The degree of all three avoidance mechanisms intensifies when leaf water status falls. Eventually as water stress increases, leaf growth ceases, stomata close, and leaves roll tightly. Finally, under extreme condition, the transpiring area is reduced as leaves die progressively from the oldest to the youngest. Although this ultimate response assists in survival, the loss of leaves is expensive for subsequent production. Under the most extreme situations, the shoot may die. Then the subsequent growth depends on the survival of buds at the crown of the plant, which produce tillers when rain eventually comes.

The important strategy in crop plant is drought tolerance. Gaff (1980) observed that plant tolerates dehydration through turgor maintenance and desiccation tolerance, which enable them to survive with low tissue water status. The major mechanism of turgor maintenance is osmotic adjustment, that is the accumulation of solutes under condition of water deficits thereby decreasing the osmotic potential and hence increasing the turgor pressure of cells. Osmotic adjustment of shoots was observed by Hsiao *et al.* (1984) to lower leaf water potential, and to defer leaf rolling and leaf death until lower leaf water potential are reached. This together with the decrease in stomatal conductance and photosynthesis suggests that low soil water contents may be over riding any turgor maintenance by shoot.

Drought tolerant types had a greater ability of leaf cell membrane to function after stress (Blum and Ebercon 1981). Santamaria *et al.* (1986) found correlation among drought tolerance traits but not drought avoidance traits; they correlated leaf rolling positively with osmotic adjustment. Bennett and Tucker (1986) reviewed that the epicuticular wax present on the underside of the leaf and upper leaf sheath aids in moisture stress tolerance by reducing water loss. Bewazir and Idle (1989) indicated that the extent of leaf rolling in sorghum is a measure of degree of water stress. Sorghum is also well adapted to drought due to a higher root hair density per unit length and longer root depths of up to 2.0-2.3 meters (Blum, 1988). Dogget (1988) showed silica deposits in the endodermis of the root of sorghum thus enabling it to withstand higher pressure during drought stress conditions. Bewazir and Idle (1989) observed that relative conductivity and number of seminal roots were negatively correlated with percent of survival and a high relative conductivity indicates drought resistance in lines with less restricted seminal roots.

2.4.3. Osmotic adjustment in relation to drought stress in sorghum

Osmotic adjustment (OA) reduces sensitivity of turgor dependent process such as leaf expansion, stomatal conductance and leaf rolling to the declining leaf water potentials (Jones and Turner, 1980) and allows plant growth at otherwise inhibitory leaf water potentials (Cuttler *et al.*, 1980; Mayer and Boyer, 1981, Takami *et al.*, 1982). Henzell *et al.* (1976) suggested genotypic differences of sorghum leaves to adjust osmotically. Osmotic adjustment to leaf considered the main trait responsible for stomatal adjustment to leaf water deficits (Ludlow *et al.*, 1985). Osmotic adjustment involves the net accumulation of solutes in a cell in response to fall in the water potential of the cell's environment. As a consequence of this net accumulation, the osmotic potential of the cell is lowered, which in turn attracts water into the cell and tends to maintain turgor pressure. Osmotic adjustment is important in drought resistance because it allows plants to retain higher turgor at a given level of plant water deficit and subsequently support carbon assimilation and growth under stress. Al-Hamdani *et al.* (1991) observed a decrease in water potential, stomatal conductance and CO_2 assimilation at the pre-anthesis compared to the post-anthesis stage in majority of the drought tolerant genotypes. The drought resistant genotypes showed higher osmotic adjustment and sufficient decrease in leaf water potential to maintain leaf tugor (Salam, 1995). Osmotic adjustment contributes to yield of sorghum under drought by enhancing the amount of water transpired, and by moderating the potential reduction in harvest index (Tangpremsri *et al.*, 1991). It promotes leaf survival or 'stay green' by increasing both the avoidance (more root growth and greater soil water extraction) and tolerance of dehydration. However, it may actually reduce dehydration avoidance if the timing of the adjustment maintains leaf growth and increase transpiration during stress.

It has not been shown that osmotic adjustment has any particular cost over growth (McCree *et al.*, 1984), nor any yield penality in sorghum (Santamaria *et al.*, 1990). However, high level of osmotic adjustment has sometimes been found in low yielding genotypes, especially when stress occurs during grain filling (Tangpremsri *et al.*, 1991). This may occur because the poor sink strength of these genotypes allows solutes to accumulate in leaves above normal levels, or because grain filling completes with osmotic adjustment for solutes in the higher yielding genotypes. Blum (1988) found that landraces of sorghum from dry habitats had relatively greater capacity for osmotic adjustment than landraces from more humid habitats. This capacity was related to better plant growth under drought stress. The effect of osmotic adjustment on sorghum productivity under drought stress is largely ascribed to an increase in root size, root length, density and soil moisture extraction (Tangpremsri *et al.*, 1991). Santamaria *et al.* (1986) noticed a decrease in osmotic adjustment toward the end of drying cycle in early genotypes and increase in osmotic adjustment in the late genotypes. In view of this observations, Flower *et al.* (1986) concluded that under drought there is little advantage of selecting for plants with higher capacity for osmotic adjustment.

2.5. Staygreen and its influence on drought resistance in sorghum

The expression of drought tolerance is dependent on the stage of development when stress occurs. This developmental interaction complicates the characterization and study of drought tolerance. Susceptibility to drought can occur during the early vegetative seedling stage, during the period of panicle development prior to flowering and post flowering stage of grain development (Rosenow and Clark, 1995). Drought during post flowering period accelerates the senescence, affecting the assimilatory capacity needed to avoid drastic reduction in grain filling (Nooden, 1988). The yield reduction results from reduced seed as well as premature plant and leaf senescence, stalk rot and lodging of post-flowering drought susceptible cultivars. Therefore, any mechanism that postpones the onset of senescence and keep the leaves green can benefit the crop. Rosenow and Clark (1995) used the term 'staygreen' to describe the post-flowering drought resistance response. During senescence chlorophyll disintegrates and the ultimate product of catabolism seem not to be pigmented. As a plant ages, the built in process which defend the plant against auto destruction begin to decline, thereby in the senescence syndrome with visible and bio-chemically measurable symptoms. Plants with high heritable staygreen phenotypes defy or postpone such senescence process. In sorghum, staygreen genes confer resistance to post-flowering drought stress by preventing the premature death of leaves and stems, plant senescence, stalk lodging and charcoal rot disease when the plants are exposed to moisture stress during the late stage of grain development. Genetic studies of staygreen have generally indicated a complex pattern of inheritance. Both dominant and recessive expression have been reported. These studies also indicate the expression of staygreen is strongly influenced by environments (Mitchell *et* *al*., 1997). Studies by Tenkavano *et al.* (1993) indicated that staygreen was controlled by a single dominant factor with some epistatic interaction in certain genetic backgrounds. Under severe post-flowering drought conditions, the hybrid from non staygreen parents showed 20-55 percent of lodging compared to less than 10 percent lodging in hybrid with staygreen parent (Rosenow and Clark, 1995). Thus the staygreen has a major direct benefit to sorghum by reducing moisture stress and lodging associated with the pre-mature leaf and stalk death.

Gerik and Miller (1984) have described sorghum improvement based on selection for retention of greenness. They observed that the stover dry weight of hybrid between two tropically adjusted non-senescence (staygreen) sorghum was greater than the hybrid between temperate senescence type parents. Generally sorghum is an annual but staygreen types can survive for years with the generation of fresh tillers from the old plant bases and are thus good for ratooning. The annual or senescence type begins to dry during grain filling commencing with the lower leaves until finally the whole plant is dead. In non-senescence perennial lines senescence is more slow and the stem and plant base do not die.

2.6. Influence of drought resistant traits on yield and yield components of sorghum

Khizzaha and Miller (1992) correlated components of drought resistance with yield and found negative correlation between lodging and days to anthesis, panicle exertion and harvest index; and positive correlation with plant height, panicle length, green leaf retention, grain size and grain weight. Green leaf retention was negatively correlated with panicle exertion, grain yield, harvest index; while grain yield was positively correlated with height, panicle exertion, lodging, harvest index and grain weight; negatively correlated with days to anthesis and green leaf retention. He concluded that non-lodging and green leaf retention are useful indices for drought resistance.

Blum *et al.* (1989) showed a reduction in yield but not relative yield under stress, due to decrease in harvest index with increased growth duration of the genotypes. They concluded that genotypes showing traits of early heading, high leaf water potential, lower canopy temperatures and higher stomatal conductance yielded more under drought. Wenzel (1988) reported a positive correlation between characters related to growth rate (total dry matter), and leaf area, and those related to drought resistance (total and relative moisture loss, and moisture loss/unit leaf area).

CHAPTER III

3.0 MATERIAL AND METHODS

Two separate experiments were carried out (1) to study seedling emergence of sorghum under high soil surface temperature (2) to study the drought tolerance of sorghum genotypes at mid-season and post-flowering stages of crop growth. The experiments were conducted at ICRISAT Patencheru, India.

3.1 SELECTION METHODS FOR SEEDLING EMERGENCE UNDER HIGH SURFACE TEMPERATURE

3.1.1 Seed bed preparation

The trial was conducted in 30cm raised brick tanks. The brick tanks were equally divided into 9 plots of 80 x 150cm size (3 plots per replication). The soil over the brick tanks was loosened and the surface soil powdered to break all the clods to have a fine tilth. The soil type was sandy clay soil. The seedbed was properly leveled and equal amount of water was given to all plots before planting. A wooden plank with 145x67 cm with holes at 7 cm between rows and 6 cm within rows were used to make 3 cm deep holes for planting.

3.1.2 Planting

Depending upon the germination of the genotypes in the petri plates 3-6 seeds per hole were placed in the prepared seedbed. Date of planting was carried out on 13/5/1998. Dry sand soil was spread uniformly in each main block to cover the seed and fill the 3 cm deep holes. Finally equal amount of watering was given to all plots after planting and specified quantities of charcoal and heavy kaolin powder were spread uniformly according their respective treatments.

3.1.3 Treatments

Design of the experiment was split plot with 3 temperatures as main treatments and 36 genotypes as sub plots. The three main treatments were:

- High temperature ensured by charcoal powder applied at a rate of $415 gm/m^2$ = T1
- Low temperature ensured by heavy kaolin powder applied at a rate of $415 gm/m^2$ = T2
- Control temperature ensured by bare soil = T3

3.1.4 Genotypes

The sub plots were the 36 sorghum genotypes (Table 3.1). Out of these, 31 were random inbred lines of sorghum derived from the crosses of staygreen x senescence line which was developed in Purdue university, U.S.A. by Professor G. Ejeta and further evaluated at ICRISAT center. Advanced generation (F_9) materials were evaluated in these experiments. The remaining genotypes were five checks from ICRISAT.

Table 3.1 Random inbred staygreen and check lines of sorghum used in experiment 1, 1998 rainy season, ICRISAT Patencheru

1	SSD1	13	SSD51	25	SSD76
2	SSD7	14	SSD52	26	SSD82
3	SSD19	15	SSD53	27	SSD83
4	SSD22	16	SSD56	28	SSD91
5	SSD25	17	SSD59	29	SSD92
6	SSD26	18	SSD61	30	SSD93
7	SSD31	19	SSD62	31	SSD100
8	SSD32	20	SSD64	32	ICSV112 (control)
9	SSD38	21	SSD66	33	296B (control)
10	SSD44	22	SSD69	34	SB 55483 (control)
11	SSD47	23	SSD71	35	B-35 (control)
12	SSD48	24	SSD75	36	Q-104 (control)

The word **SSD** is used to indicate Sorghum Screening for Drought

3.1.5 Temperature recording

Automatic data logger 21x was programmed to log the soil temperature at 2 cm, 7 cm depths and air temperature (45 cm above ground) at an interval of 5 minutes and averaged over an hour period. Three intervals of temperature reading were taken by observing the data records. Minimum temperature reading taken 5:00-7:00, maximum temperature reading 13:00-15:00 and intermediate 22:00-24:00 hours (Table 3.2). Average maximum temperature was used for analysis of this experiment.

3.1.6 Observations recorded

3.1.6.1 Number of seedling emerged

Under optimal condition sorghum seeds germinate 5-7 days after planting. Taking this into consideration two germination counts were taken on the 5th and 9th days after planting.

3.1.6.2 Seedling vigor scoring

Seedling vigor scores were taken on a 1 to 5 scale, where 1 is indicating most vigor and 5 least vigor.

3.1.7 Statistical Analysis

The computer program Genstat 5 (1993) were used for all the statistical analysis. A separate and combine analysis of variance was carried out for each of the variables by taking into consideration the germination percentage across the three treatments and the soil surface cover treatments.

Table 3.2 **Temperature readings of the three treatments at 2 and 7 cm depth of soil, 1998 rainy season,ICRISAT Patencheru**

		Temperature reading at 2 cm depth			Temperature readings at 7 cm depth		
			Treatments			Treatments	
Date	**Time**	**Charcoal**	**Control**	**Kaolin**	**Charcoal**	**Control**	**Kaolin**
16/5/1998	5:00	27.8	26	24.7	29.9	28.4	27.1
	6:00	27.4	26.7	24.6	29.5	27.9	26.8
	7:00	27.9	26	25	29.2	27.7	26.6
	13:00	49.5	43.3	36.7	40.9	38.6	34.6
	14:00	51.6	45.2	41.6	46.2	40.8	36.2
	15:00	48	44.9	36.3	41	36.2	34.1
	22:00	30.6	29.3	26.7	33.4	31.8	29.4
	23:00	29.9	28.6	26.5	32.6	31.1	29.1
	24:00	29.7	28.4	26.5	31.9	30.5	28.5
17/5/1998	5:00	27.6	26.8	25.1	30.1	28.9	27.6
	6:00	26.9	26.2	24.6	29.6	28.5	27.2
	7:00	27.3	26.3	25.1	29.3	28.1	26.9
	13:00	52.4	45.5	39.9	39.7	38.8	34.3
	14:00	53.6	46.4	43.6	42.4	41.2	36.1
	15:00	50.5	48	38.7	41.2	40.4	35.5
	22:00	31.9	30.7	28.7	34.8	33.3	30.9
	23:00	30.9	29.8	27.6	34.1	32.5	30.3
	24:00	29.8	28.9	26.6	33.3	31.8	29.7
18/5/1998	5:00	27.3	26.6	25	30.6	29.3	27.9
	6:00	26.8	26.2	24.5	30.2	28.9	27.5
	7:00	27.5	26.4	25.4	29.7	28.5	27.3
	13:00	50.2	44.3	39.4	39.5	38.3	34.1
	14:00	52.4	46.6	42.7	42.8	40.6	35.9
	15:00	48.6	45.2	38.9	40.8	39.5	35.1
	22:00	30.8	30.1	27.6	34.2	32.8	30.8
	23:00	29.6	29	26.8	33.3	31.8	30.1
	24:00	28.8	28.3	26.2	32.5	31.1	29.5
19/5/1998	5:00	27.4	27.1	25.5	30.6	29.4	28.4
	6:00	27.1	26.8	25.3	30.1	29.1	28.1
	7:00	27.4	26.9	25.6	29.9	28.8	27.9
	13:00	50.3	44.7	38.5	36.9	35.5	32.7
	14:00	51.9	46.3	42.8	40.6	39.2	35.1
	15:00	46.3	44.7	39.1	39.3	38	34.3
	22:00	31.2	30.5	28.8	33.1	32.5	30.8
	23:00	30.6	29.9	28.3	33	31.9	30.4
	24:00	30.2	29.5	28.1	32.6	31.4	30
20/5/1998	5:00	29.2	28.5	27.8	30.7	29.9	28.9
	6:00	28.7	28.2	27.4	30.4	29.7	28.8
	7:00	28.9	28.2	27.5	30.2	29.5	28.6
	13:00	47.9	43.8	40.1	37.8	36.7	34.2
	14:00	51.9	45.1	43.6	40.4	39	36
	15:00	46.4	43.8	39.7	38.9	37.8	35.1
	22:00	31.8	31.2	29.9	34.3	33	31.5
	23:00	31.3	30.5	29.6	33.6	32.5	31.1
	24:00	30.7	30.2	29	33.1	31.9	30.8

3.2 SELECTION OF SORGHUM GENOTYPES FOR TOLERANCE TO PROLONGED MID- SEASON AND TERMINAL DROUGHT

This experiment was conducted in a rain out shelter at ICRISAT Patancheru A rain out shelter is a device that excludes rainfall during cropping season and employed to impose drought stress.

3.2.1 Soil type and field preparation

The soil type in the rain out shelter is red clay soil. The preceding crop was pearl millet. After discing and harrowing, ridges and furrows were prepared with a distance of 0.60 m between ridges two weeks before planting. Fertilizer was applied at the rate of 40N, 20P and 0K kg ha^{-1}. Nitrogen was given in two split doses. The field was then divided into plots of 1.20 x 4 m (24 plots per replication for 24 lines of sorghum).

3.2.2 Planting and crop management

3.2.2.1 Planting

The crop was planted on July 1st during the rainy season of 1998 by a machine calibrated planter at a seed rate of 12 kg ha^{-1}.

3.2.2.2 Design

The design of the experiment was split plot with two main treatments, non-irrigated (stress) and irrigated (control) and 24 genotypes as a sub plots.

3.2.2.3 Main treatments

For the control treatment drip irrigation was installed. Plots in the control treatment received irrigation every 10 days, till the plants reach physiological maturity. Plants in the non-irrigated were imposed to stress after the plants were fully established.

3.2.2.4 Genotypes (sub treatments)

There were 22 random inbred lines (RILs) of a staygreen variety x susceptible variety cross which were developed by Purdue University USA and further evaluated at ICRISAT Patencheru. Advanced generation (F_9) were evaluated in this experiment. Two checks, ICSV 112 (a high yielding line with wide adaptability) and B 35 (a stay green source) varieties were used as control. The genotypes involved here were the same as in experiment one; however, reduced in number so as to accommodate in the area available in the rain out shelter (Table 3.3). The plot size of the experiment was 1.20x4.0 m.

Table 3.3 Random inbred staygreen and check lines of sorghum used in experiment 2, 1998 rainy season, ICRISAT Patencheru

1	SSD1	13	SSD64
2	SSD19	14	SSD66
3	SSD31	15	SSD69
4	SSD32	16	SSD71
5	SSD38	17	SSD75
6	SSD47	18	SSD76
7	SSD48	19	SSD82
8	SSD51	20	SSD83
9	SSD52	21	SSD92
10	SSD53	22	SSD100
11	SSD59	23	ICSV112 (control)
12	SSD61	24	B-35 (control)

3.2.2.5 **Irrigation**

One day after planting the field was given an initial 40mm of furrow irrigation in the stress and control plots to ensure full germination. The crops were then allowed to receive rainfall for one month before the shelter starts its function. Starting from 5/7/1998-28/7/1998 both the stress and control plots receive 193.8mm of rainfall. On 28 July the rain out shelter starts its work and rainfall was excluded from the experiment. The plots in the control received drip irrigation on the 48^{th}, 58^{th}, 68^{th}, 85^{th} and 95^{th} days after planting. In each irrigation day 2.6 mm of water was applied per dripper and 16 drippers were lined in the two rows plot which supplies a total amount of 41.6 mm of water per plot in one day. The total amount of irrigation given was therefore 208 mm. Supplying irrigation stopped when the majority of the genotypes reach physiological maturity. However, plants in the stress treatments complete their life cycle with the residual moisture.

3.2.2.6 **Interculture**

Mechanical cultivation was done 20 days after sowing. Thinning was done 15 days after sowing (leaving 20 plants per row) as well as two weeding practices.

3.2.2.7 Insect and disease control

Sorghum aphid (*Rhopalsiphum maids*) and corn earworm (*Helicoverpa armigera*) were mainly observed insects. Chemicals were applied to control them.

3.2.2.7 **Harvesting**

The grains were ready to be harvest after the physiological maturity was attained. Both the stress and control treatment plants were harvested on 15/10/1998.

3.2.3 Observations recorded

The following observations were gathered to study the effect of drought on the sorghum lines:

3.2.3.1 Plant stand count

Number of plants per plot was counted in both irrigated and stress plots.

3.2.3.2 Days to 50% flowering

Fifty percent flowering dates for each of the line was recorded in both control and stress plots. The dates on which 50% of the spiklets in the 50% of the plants within the plot started shedding pollen was recorded.

3.2.3.3 Plant height

The height of the plants were measured from the base of the stem to the tip of the panicle. The measurements were taken on five randomly selected plants and averaged to represent the plant height of the genotype.

3.2.3.4 Peduncle exertion

The length of the nod between the flag leaf and the base of the panicle were measured using a scaled ruler on five randomly selected plants in each plot at harvesting and later averaged to represent the peduncle exertion of that particular genotype.

3.2.3.5 Physiological maturity

The maturity date of the plants in the field was determined by taking into consideration the black layer formation of the grain in the middle of the panicle. The panicle grains were checked at three days interval and the date at which the majority of plants within a plot showed the black layer at helium were taken as the date of physiological maturity.

3.2.3.6 Senescence or staygreen score

Expression of staygreen or senescence is evaluated only under post-flowering drought and was estimated visually on a scale of 1 to 5, where 1 is indicating no apparent senescence (staygreen) and 5 indicating complete plant death (senescence). These scores were recorded 65, 72, 80, and 89 days after planting in the stressed treatment and 75, 82, 89 and 93 days after planting in the irrigated. The visual observation of senescence or staygreen is done on whole plot.

3.2.3.7 Head weight

Mature heads from five randomly selected plants were cut about 5cm below the lowest node of each panicle. The five plants were individually weighed and later averaged.

3.2.3.8 Total grain yield per plot

All the panicles from the two-row plot were harvested and threshed separately after complete drying. Finally total grain weight in all the replications on a plot basis were recorded.

3.2.3.9 **100 seed weight**

Weights of 100 randomly selected grains were recorded for each plot.

3.2.3.9 Statistical analysis and quantifying drought tolerance

Analysis of varience was carried out for each parameters and correlated among the drought related traits using computer program Genstat 5 (1993). Prolonged pre-flowering and post-flowering drought was estimated in this experiment using the following five criteria:

1. The productivity of each line under stress condition was estimated using the average yield measured in the trial.
2. The 'yield stability' of lines performance under stress was quantified as grain yield under post-flowering drought expressed as proportion of grain yield under full irrigation for each line.
3. Seed weight stability and head weight were quantified similarly as seed and head weight under post-flowering drought expressed as proportion of seed and head weight under full irrigation.
4. Resistances to pre mature senescence quantified using the average staygreen scores.
5. Peduncle exertion, plant height, days to 50% flowering and physiological maturity were also used in quantifying for prolonged mid-season and terminal drought which was expressed as a proportion under full irrigation.

CHAPTER IV

4.0 RESULTS

The results of the two experiments are indicated below separately.

4.1 RESULTS SELECTION METHODS FOR SEEDLING EMERGENCE UNDER HIGH SURFACE TEMPERATURE

The result of this experiment is quantified based on the soil temperature readings of the three treatments and results on germination percent.

4.1.1 **Soil temperature readings**

The analysis for maximum temperature reading of the three treatments indicates significant difference in soil temperature at 2cm depth (Table 4.1). By placing charcoal as a soil cover, temperature was increased by 6-8 ^{0}C compared to the control and 4-6 ^{0}C decrease when the soil cover was modified by kaolin. The mean maximum temperature was 52.2 ^{0}C in charcoal and mean maximum 38.8 ^{0}C in kaolin compared to the total grand mean of temperature which is 45.1 ^{0}C (Table 4.3 and Figure 1).

Significant difference was also observed on the days of experimentation. The experiment was conducted during the hot season of 1998 in the month of May which is appropriate to carry such experiment. May 17, 1998 shows a maximum temperature readings in all the three treatments (Table 4.2).

Table 4.1 Analysis of varience for maximum temperature readings over the three treatments, 1998 rainy season, ICRISAT Patencheru.

Source	d.f	m.s	v.r	F pr.
Replication	2	7.53	19.09	ns
Date	4	7.12	18.06	***
Date error	8	0.39	0.04	
Treatment	2	340.87	38.79	***
DxT	8	1.57	0.18	ns
Error	20	8.78		

*** $P<0.001$ SE = 0.765 Treatment CV% = 6.6

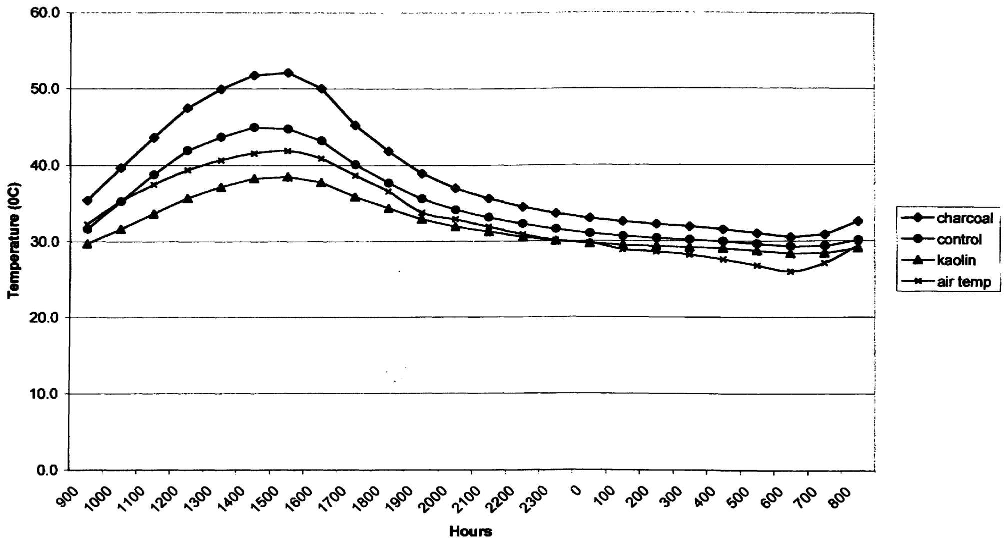
Table 4.2 Average daily maximum temperature reading of the five days (^{0}C) 1998 rainy season, ICRISAT Patencheru.

	Treatments (soil covers)		
Days	Control	Charcoal	Kaolin
16/5/98	43.9	49.7	38.7
17/5/98	46.0	52.2	41.4
18/5/98	44.8	50.4	40.8
19/5/98	44.6	49.5	40.7
20/5/98	44.3	48.7	41.2

Table 4.3 Average temperature reading at 2cm soil depth for the two soil treatments, control and air over 24 hours during May 16-20/1998, ICRISAT Patencheru

	Treatments (soil covers)			
Time	**charcoal**	**control**	**Kaolin**	**Air temp.**
900	35.4	31.7	30.1	32.3
1000	39.6	35.1	31.9	35.5
1100	43.5	38.4	33.9	37.7
1200	47.3	41.5	36.0	39.4
1300	49.8	43.1	37.5	40.7
1400	52.1	44.5	38.8	41.6
1500	52.3	44.4	39.0	41.9
1600	50.4	42.6	38.3	40.9
1700	45.6	39.3	36.4	38.7
1800	42.2	37.1	34.9	36.6
1900	39.3	35.4	33.4	33.8
2000	37.2	34.1	32.4	32.9
2100	35.8	33.2	31.7	31.9
2200	34.6	32.4	31.0	30.9
2300	33.8	31.7	30.5	30.1
0	33.1	31.2	30.0	29.8
100	32.6	30.9	29.8	28.9
200	32.3	30.7	29.7	28.6
300	32.0	30.6	29.5	28.2
400	31.6	30.4	29.4	27.6
500	31.1	30.1	29.1	26.8
600	30.7	29.8	28.8	26
700	30.9	29.8	28.8	27.1
800	32.4	30.5	29.4	29.4

Fig.1 Average temperature readings for the two soil treatments, control and air temperature, 1998 rainy season, ICRISAT, Patencheru



Temperature reading at 7cm depth of soil surface failed to show significant difference among the treatments.

4.1.2 **Seedling germination percentage**

Temperature is a main factor in determining the rate of germination. As a result of increasing temperature above the normal, significant phenotypic variation was observed for seed germination (Table 4.4). The experiment indicates that high soil surface temperature seems to delay or prevent rate of seed emergence of various lines of sorghum (figure 2 and figure 3).

Table 4.4 Analysis of varience for germination percentage of sorghum genotypes in the three treatments, 1998 rainy season, ICRISAT Patencheru

Source	d.f	m.s	v.r	F pr.
Replication	2	4554.4	24.94	Ns
Treatment	2	57426.0	314.44	**
Genotype	35	817.1	4.47	***
TrxG	70	202.9	1.11	Ns
Error	214	182.6		

** $P<0.01$ and *** $P<0.001$ SE = 4.5 Genotype CV% = 26.9

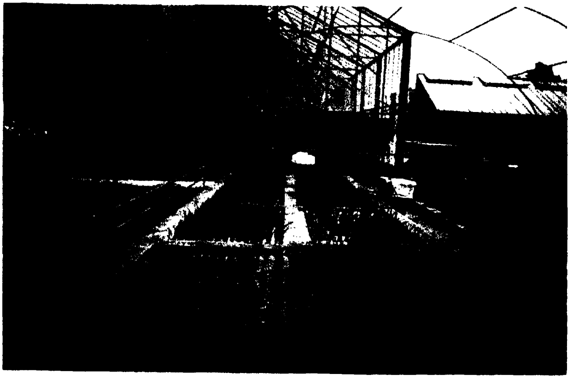


Fig.2 The effect of high soil surface temperature on sorghum genotypes germination percentage. In the charcoal treatment (right) few seeds has emerged as compared with the control treatment. May 16-21/1998, ICRISAT, Patencheru.

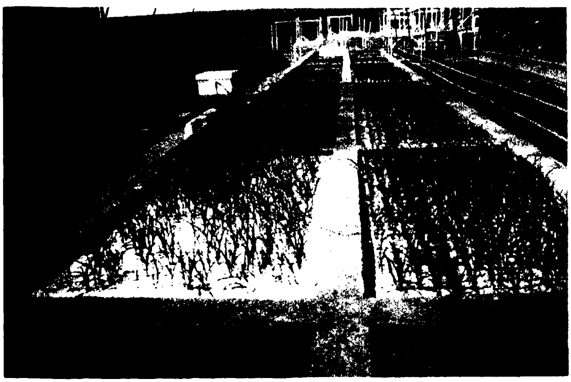


Fig.3 Comparison of germination percentage among sorghum genotypes on kaolin, charcoal and control treatments. In the kaolin high germination with good seedling vigour is observed, while in the charcoal treatment failure of seed emergence can be seen. May 16-21/1998, ICRISAT, Patencheru

The majority of the genotypes show partial or complete failure of germination but few genotypes germinate successfully in the charcoal treatment. Significant effect on the average germination rate was observed with a decrease from 61.8% in kaolin to 51.6% in control and further decrease to 18.0% in the high surface temperature charcoal soil cover treatment (Table 4.5).

Significant difference was also observed among the genotypes within their respective treatments. In control treatment the genotypes ICSV 112 (73.1%) and SSD 47 (71.9%) showed maximum germination percentage and SSD 25 (32%), SSD 91 (30.9%) and 296 B (13%) were recorded for their minimum emergence. In the high surface temperature treatment, SSD 66 and ICSV 112 showed the best germination percentage with 44.7% and 41.8% respectively where as SSD 64, SB5583 and 296 B showed poor germination with 6.3%, 4.4% and 2.2% respectively. In kaolin, SSD 48 (90.1%) and B 35 (81%) were among the best genotypes for their germination percentage.

Treatment by genotype interaction failed to show significant differences. This indicated that the genotypes are stable across all the three treatments (Charcoal, Kaolin and Control).

In general, ICSV 112 showed better and consistent germination performance across all the treatments. Based on the evaluation of least significant difference of means between genotypes, SSD 66 and ICSV 112 were much better in their ability to emerge under high surface temperature treatment (Table 4.5).

Table 4.5 Germination percentage of sorghum genotypes in their decending order for the three treatments, 1998 rainy season, ICRISAT Patencheru

CONTROL		CHARCOAL		KAOLIN	
Genotype	**Ger %**	**Genotype**	**Ger %**	**Genotype**	**Ger %**
ICSV 112	73.1	SSD 66	44.7	SSD 48	90.1
SSD 47	71.9	ICSV 112	41.8	B 35	81.0
SSD 100	69.8	SSD 76	32.0	SSD 19	77.3
SSD 32	68.6	SSD 32	30.2	SSD 69	74.7
SSD 82	68.0	SSD 47	27.4	ICSV 112	74.5
SSD 71	67.2	SSD 48	26.9	SSD 82	72.7
SSD 48	66.0	SSD 69	25.3	SSD 66	71.7
SSD 69	64.0	SSD 100	24.5	SSD 64	70.9
SSD 1	61.8	SSD 22	24.4	SSD 92	70.8
SSD 31	60.9	SSD 19	22.7	SSD 76	70.7
SSD 92	59.5	SSD 51	22.6	SSD 1	69.1
SSD 19	57.3	SSD 71	21.9	SSD 59	67.3
SSD 64	57.3	SSD 82	21.3	SSD 83	66.7
SSD 38	57.0	SSD 92	20.9	SSD 47	65.9
B 35	56.6	SSD 31	20.0	SSD 31	65.8
SSD 53	55.1	B 35	19.6	SSD 53	63.3
SSD 59	52.8	SSD 56	19.1	SSD 93	62.7
SSD 61	52.1	SSD 52	19.1	SSD 32	62.3
SSD 51	51.2	Q 104	16.2	SSD 22	61.1
SSD 22	50.0	SSD 61	15.1	SB 55483	61.1
SSD 75	49.4	SSD 93	14.6	SSD 44	59.4
SSD 93	48.0	SSD 26	12.6	SSD 51	58.3
SSD 66	47.1	SSD 83	12.5	SSD 26	58.1
SSD 52	45.8	SSD 38	12.1	SSD 25	57.8
SSD 56	45.5	SSD 91	11.0	SSD 100	56.8
SB 55483	43.3	SSD 59	10.7	SSD 52	56.6
SSD 62	43.1	SSD 25	10.2	SSD 7	56.4
SSD 44	42.2	SSD 62	10.1	SSD 71	54.2
SSD 76	42.0	SSD 44	9.9	SSD 62	52.8
SSD 7	40.9	SSD 1	9.2	SSD 38	52.7
Q 104	40.1	SSD 53	9.2	Q 104	52.1
SSD 83	39.6	SSD 7	8.9	SSD 75	49.4
SSD 26	33.3	SSD 75	7.2	SSD 91	47.2
SSD 25	32.0	SSD 64	6.3	SSD 56	43.5
SSD 91	30.9	SB 55483	4.4	SSD 61	36.0
296 B	13.0	296 B	2.2	296 B	35.2
AVERAGE	**51.6**		**18.0**		**61.8**

genotypes L.S.D =10.9 genotype x treatment L.S.D =23.0

4.2 RESULTS ON SELECTION OF SORGHUM GENOTYPES FOR TOLERANCE TO PROLONGED MID- SEASON AND TERMINAL DROUGHT

Results of observed data among the stressed and irrigated treatments on days to 50% flowering, plant height, peduncle exertion, days to physiological maturity, scores on staygreen/senescence, head weight and grain yields are separately given below.

4.2.1 Days to 50% flowering

The two treatments (Stress and Irrigated) did not differ significantly from each other for days to 50% flowering (Table 4.6). The mean flowering date for both the Irrigated and Stressed were 64 and 65 days after planting.

Stress however, had significant effect due to genotypes for days to 50% flowering and the lines differed significantly from each other (Table 4.6). In the stressed treatment flowering occurred earliest in line SSD 48 (51 days after planting) followed by SSD 51(53 days after planting) and latest in line SSD 38 (74 days after planting) followed by SSD 69 (71 days after planting). In the irrigated treatment earliest line was SSD 48 (53 days after planting) and SSD 51(53 days after planting) and latest in line SSD 38 (73 days after planting) (Table 4.7).

Table 4.6 Combine analysis for days to 50% flowering 1998 rainy season, in Rain Out Shelter, ICRISAT Patencheru.

Source of variation	d.f	m.s	v.r	F pro
Replication	2	10.21	5.29	ns
Treatment	1	7.11	3.76	ns
Genotype	23	195.30	103.08	***
TxG	23	4.96	2.62	***
Total error	94	1.89		

*** P<0.001, SE = 0.56 Genotype CV% = 2.1

4.2.2 Plant height

Water stress had showed significant effect and reduction on plant height when compared with the irrigated treatment (Table 4.14). The mean heights were 136cm and 101cm for the irrigated and stressed treatments respectively. The lines differed significantly in their heights (Table 4.8). In the stress treatment genotype, ICSV 112 (150cm) showed highest while line SSD 32 (71cm) lowest in height. In the irrigated treatment ICSV 112 (195cm) recorded the highest and line SSD 32 (100cm) the lowest (Table 4.7).

Table 4.7 Means of 8 variables measured in sorghum genotypes in stress and irrigate treatments1998 Rainy season, ICRISAT Patencheru

		Irrigated Treatment						
GENO	**TGW ($t\ ha^{-1}$)**	**100 GW (g)**	**PLHT (cm)**	**PHM (days)**	**PEX (cm)**	**DFL (days)**	**HW (g)**	**SG (1-5)**
SSD 1	2.96	2.47	138.33	102	13.00	66	59	3
SSD 19	2.16	2.32	105.00	97	8.67	65	43	1
SSD 31	3.30	2.19	135.00	101	19.27	64	51	1
SSD 32	2.53	1.94	100.00	99	14.27	64	43	4
SSD 38	2.50	1.70	138.33	102	12.00	73	52	2
SSD 47	3.76	2.25	138.33	99	18.07	57	54	2
SSD 48	3.33	2.13	115.00	92	25.00	53	42	3
SSD 51	3.43	3.21	133.33	91	19.87	53	49	1
SSD 52	3.13	2.28	153.33	102	23.00	67	53	2
SSD 53	3.66	2.17	125.00	92	19.87	59	52	3
SSD 59	2.76	2.07	133.33	103	14.00	71	49	2
SSD 61	4.20	2.11	140.00	100	14.33	61	69	2
SSD 64	3.20	2.35	130.00	99	14.27	64	58	2
SSD 66	3.60	2.45	170.00	101	26.27	67	70	2
SSD 69	3.36	1.75	138.33	104	10.33	70	54	2
SSD 71	3.43	2.20	123.33	101	16.27	60	64	2
SSD 75	4.30	2.55	163.33	98	22.27	65	52	1
SSD 76	3.66	2.64	155.00	100	14.80	64	63	2
SSD 82	3.86	2.72	121.67	97	24.07	57	59	2
SSD 83	2.60	2.70	135.00	100	12.13	67	51	3
SSD 92	2.20	1.75	133.33	98	8.40	68	52	1
SSD 100	2.63	1.82	128.33	101	5.60	69	55	4
ICSV 112	4.43	2.42	195.00	102	10.60	69	86	3
B-35	2.16	2.08	128.33	103	20.87	68	55	2
Mean	**3.21**	**2.26**	**136.53**	**99**	**16.13**	**64**	**56**	**2**
SE	**0.31**	**0.11**	**3.79**	**1.53**	**1.51**	**0.58**	**4.49**	**0.38**
LSD	**0.90**	**0.34**	**10.79**	**4.37**	**4.31**	**1.67**	**12.80**	**1.10**
CV (%)	**17.10**	**9.20**	**4.80**	**2.70**	**16.30**	**1.60**	**14.00**	**31.70**

GENO= Genotype; TGW= Total Grain Weight; 100 GW= 100 Grain Weight; PLHT= Plant Height; PHM= Physiological Maturity; PEX= Peduncle exertion; DFL= Days to Flowering; HW= Head Weight; SG= Stay Green score on 1 to 5 scale where 1= staygreen and 5 = senescence

Table 4.7 Continued

	Stress Treatment							
GENO	**TGW ($t\ ha^{-1}$)**	**100 GW (g)**	**PLHT (cm)**	**PHM (days)**	**PEX (cm)**	**DFL (days)**	**HW (g)**	**SG (1-5)**
SSD 1	1.70	1.76	105.00	95	14.67	66	29.07	3
SSD 19	2.30	2.24	81.67	93	4.27	64	31.67	1
SSD 31	1.70	1.47	103.33	97	8.93	64	23.80	3
SSD 32	0.80	1.28	71.67	92	2.80	64	21.17	5
SSD 38	1.93	1.84	106.67	98	6.07	74	25.60	2
SSD 47	1.16	1.69	120.00	96	12.93	56	36.17	5
SSD 48	1.10	1.60	101.67	88	16.73	51	28.80	5
SSD 51	2.00	1.79	115.00	88	14.20	53	32.87	4
SSD 52	1.00	1.54	90.00	99	6.50	69	23.27	3
SSD 53	1.40	1.46	91.67	92	12.13	59	25.50	5
SSD 59	2.50	2.10	105.00	102	10.00	70	26.53	2
SSD 61	2.83	1.84	106.67	95	9.00	61	31.10	3
SSD 64	1.00	1.35	86.67	96	4.60	65	27.63	4
SSD 66	1.83	1.83	100.00	102	8.33	71	18.87	2
SSD 69	1.50	1.45	101.67	98	3.20	71	27.27	3
SSD 71	1.73	1.40	93.33	94	9.53	60	25.87	3
SSD 75	2.66	1.82	103.33	96	9.53	69	22.27	3
SSD 76	1.96	2.04	116.67	100	6.20	65	24.13	2
SSD 82	1.26	1.72	98.33	92	15.60	57	34.07	5
SSD 83	1.36	1.62	95.00	99	4.40	69	24.53	2
SSD 92	1.16	1.49	106.67	95	4.87	63	33.70	2
SSD 100	1.33	1.54	90.00	99	2.80	71	26.50	3
ICSV 112	2.20	2.04	150.00	100	0.80	70	35.70	3
B-35	1.73	1.55	95.00	102	11.40	70	23.20	2
Mean	**1.67**	**1.69**	**101.46**	**96**	**8.31**	**65**	**27.47**	**3**
SE	**0.23**	**0.08**	**4.86**	**1.04**	**1.51**	**0.92**	**3.03**	**0.36**
LSD	**0.67**	**0.24**	**13.84**	**2.96**	**4.32**	**2.60**	**8.63**	**1.03**
CV (%)	**24.60**	**8.80**	**8.30**	**1.90**	**31.70**	**2.50**	**19.10**	**20.70**

GENO= Genotype; TGW= Total Grain Weight; 100 GW= 100 Grain Weight; PLHT= Plant Height; PHM= Physiological Maturity; PEX= Peduncle exertion; DFL= Days to Flowering; HW= Head Weight; SG= Stay Green score on 1-5 scales where 1= staygreen and 5 = senescence

Table 4.8 Combine analysis for plant height, 1998 rainy season, in Rain Out Shelter, ICRISAT Patencheru.

Source of variation	d.f	m.s	v.r	F pro
Replication	2	60.59	0.62	ns
Treatment	1	44275.17	455.90	***
Genotype	23	1629.34	16.78	***
TxG	23	286.04	2.95	***
Total error	94	97.12		

***$P<0.001$ SE = 4.02 Genotype CV% = 8.3

4.2.3 Peduncle exertion

Comparing the two treatments moisture stress greatly affected the length of peduncle exertion (Fig 4). The stressed treatment showed 49% reduction in exertion when compared with irrigated (Table 4.14). The lines also showed significant difference from each other (Table 4.9). In the irrigated treatment, line SSD 66 (26.27cm) showed the highest length and line SSD 100 (5.6cm) the shortest peduncle exertion. In the stressed treatment, SSD 48 (16.73cm) recorded the highest and genotype ICSV 112 (0.80 cm) the shortest peduncle exertion. In general the drought-escape genotypes (SSD 47, SSD 48 and SSD 51) showed better peduncle exertion than the others in stressed treatment (Table 4.7).

Table 4.9 Combine analysis for peduncle exertion1998 rainy season, in Rain Out Shelter, ICRISAT Patencheru.

Source of variation	d.f	m.s	v.r	F pro
Replication	2	32.50	4.73	ns
Treatment	1	2201.95	320.16	***
Genotype	23	130.41	18.88	***
TxG	23	27.11	3.93	***
Total error	94	6.87		

***P<0.001 SE = 1.07 Genotype CV% =21.5

4.2.4 Days to physiological maturity

The stress and irrigate treatments differed significantly from each other in the time of physiological maturity. The lines also differed from each other and stress had significant effect on days to maturity (Table 4.10). The lines, SSD 48 and SSD 51 that matured in 88 were earliest while the lines SSD 59, SSD 66 and B 35 (102 days after planting) were the last to mature in the stressed treatment. The mean maturity was 96 days in the stress and 100 days in the wet treatment. In the wet treatment maturity was earliest in line SSD 51 that took 91days while it occurred latest in the line SSD 69 that matured in 104 days. In general early flowered genotypes were recorded earlier physiological maturity and escaped the moisture stress (Fig 5b).

Table 4.10 Combine analysis for days to physiological maturity, 1998 rainy season, in Rain Out Shelter, ICRISAT Patencheru.

Source of variation	d.f	m.s	v.r	F pro
Replication	2	13.08	2.57	ns
Treatment	1	351.56	68.97	***
Genotype	23	71.96	14.12	***
TxG	23	7.40	1.45	ns
Total error	94	5.09		

***P<0.001 SE = 0.92 Genotype CV% = 2.3

4.2.5 Staygreen scores

The treatments differed significantly for the staygreen trait. The lines also showed a significant difference from each other (Table 4.11). In general the lines could be grouped in to 3, depending on the senescence and greeness (Table 4.7). Lines with 1 and 2 score could be grouped as staygreen (group 1), lines with score 3 moderate staygreen (group2) and with score 4 and 5 senescence lines (group3). Staygreen lines retained high number of green leaf and showed green leaf area duration than the senescence lines. In the stressed treatment the line SSD 19 with score 1 showed the highest staygreen duration followed by SSD 38, SSD 59, SSD 66, SSD 76, SSD 83, SSD 92 and B-35 each with staygreen score

2 while highly senescence was recorded by the lines, SSD 32, SSD 47, SSD 48, SSD 53 and SSD 82 each with score 5 (Table 4.7 and Fig 5). In the irrigated treatment the lines SSD 19, SSD 31, SSD 51, SSD 75 and SSD 92 showed better staygreeness each with score 1 while SSD 32 and SSD 100 express senescence both with score 4. In general the early drought escapers showed high senescence with lower yield while staygreen genotypes give better yield.

Table 4.11 Combine analysis for staygreen 1998 rainy season, in Rain Out Shelter, ICRISAT Patencheru.

Source of variation	d.f	m.s	v.r	F pro
Replication	2	0.64	1.57	ns
Treatment	1	38.02	92.35	***
Genotype	23	3.91	9.51	***
TxG	23	1.89	4.61	***
Total error	94	0.41		

*** $P<0.001$, SE = 0.26 Genotype CV% = 24.3

4.2.6 Head weight

The performance of the treatments varied significantly both in the stress and irrigated with respect to head weight (Table 4.12). Moisture stress greatly affected the mean head weight and size of the panicle when compared with irrigated treatment (Table 4.14 and Fig 4). In the stressed treatment line SSD 47 (36g) showed the highest head weight followed by ICSV 112 (35.7g) while the line SSD 66 (19g) recorded the lowest. In the irrigated ICSV 112 (86g) showed the highest head weight followed by SSD 66 (70g) where as head weight was least in line SSD 48 (42g). The mean head weight per plant was 28g in the stress and 56g in the irrigated treatment (Table 4.7).

Table 4.12 Combine analysis for Head weight, 1998 rainy season, in Rain Out Shelter, ICRISAT Patancheru.

Source of variation	d.f	m.s	v.r	F pro
Replication	2	259.21	5.22	ns
Treatment	1	27722.25	557.99	***
Genotype	23	205.97	4.15	***
TxG	23	146.90	2.96	***
Total error	94	49.68		

*** $P<0.001$, SE = 2.87 Genotype CV% = 16.9

Fig.4 Effect of stress on sorghum genotypes on panicle size and peduncle exertion when compared with the irrigated treatment at ICRISAT Patencheru, 1998 rainy season

4a. SSD 76 irrigated

4b. SSD 76 stressed

4c. ICSV 112 irrigated

4d. ICSV 112 stressed

Fig.5 Comparison of sorghum genotypes for drought escape, staygreen and senescence traits under stress condition at ICRISAT Patencheru, 1998 rainy season

5a. SSD 51 irrigated

5b. SSD 51 stressed (Drought escape)

5c. SSD 19 stressed (Staygreen)

5d. SSD 32 stressed (Senescence)

Grain weight

Moisture stress caused a significant reduction in the mean grain yield of the lines when compared to the irrigated treatment (Table 4.14). Lines differed significantly from each other with respect to grain yield (Table 4.13). The overall means of the irrigated and stressed treatments were 3.2 tha^{-1} and 1.67 tha^{-1} respectively. In the stressed the highest grain weight was recorded in lines SSD 61 (2.8 tha^{-1}) and SSD 75 (2.6 tha^{-1}) while the lowest was recorded in SSD 32 (0.8 tha^{-1}) followed by SSD 64 (1.0 tha^{-1}). ICSV 112 (4.43 tha^{-1}) and SSD 75 (4.3 tha^{-1}) were the highest in the irrigated and lowest in SSD 19 and B-35 each with 2.16 tha^{-1}. The moderate staygreen and staygreen lines give better yield in the stressed treatment (Table 4.7).

Table 4.13 Combine analysis for grain yield 1998 rainy season, in Rain Out Shelter, ICRISAT Patencheru.

Source of variation	d.f	m.s	v.r	F pro
Replication	2	0.72	2.37	ns
Treatment	1	85.25	279.08	***
Genotype	23	1.46	4.79	***
TxG	23	0.79	2.61	***
Total error	94	0.30		

***P<0.001 SE = 0.22 Genotype CV% = 22.6

Table 4.14 Means of grain yield, grain weight, head weight and plant height measured in the genotypes grown under moisture stressed and irrigated conditions. 1998 rainy season, Rain Out Shelter, ICRISAT Patencheru.

	Stressed	Irrigated	% of reduction
Grain yield (tha^{-1})	1.67	3.21	48
Seed weight (gm/100 seed)	1.69	2.26	25
Head weight (gm/panicle)	27.47	56.00	51
Plant height (cm)	101.5	136.5	26
Peduncle exertion (cm)	8.3	16.3	49

4.2.7 100 seed weight

Moisture stress had a significant effect on seed weight of the lines under evaluation and the lines differed significantly from each other (Table 4.15). In the irrigated treatment the lines SSD 51 (3.21g) recorded the highest weight while the line, SSD 38 (1.7g) showed the lowest. In the stressed treatment the line, SSD 19 (2.4g) showed the highest weight and the line SSD 32 (1.28g) the lowest. In general, staygreen lines recorded better seed weight in the moisture stress treatment (Table 4.7).

Table 4.15 Combine analysis for hundred grain weight, 1998 rainy season, in Rain Out Shelter, ICRISAT Patencheru.

Source of variation	d.f	m.s	v.r	F pro
Replication	2	0.15	4.92	ns
Treatment	1	11.94	373.99	***
Genotype	23	0.37	11.64	***
TxG	23	0.19	6.14	***
Total error	94	0.032		

***P<0.001 SE = 0.07 Genotype CV% = 9.1

4.2.9 Correlation among the drought related and morphological traits

Total grain yield was positively correlated with seed weight, plant height and staygreen in the stressed treatments and no correlation between peduncle exertion and head weight. In the irrigated treatment total grain yield showed negative correlation with days to 50% flowering and positive association with seed weight, head weight, peduncle exertion and plant height. However, it showed no correlation with physiological maturity and staygreen (Table 4.16)

Green leaf retention (staygreen) showed positive association with days to 50% flowering, 100 seed weight, total grain yield and physiological

Table 4.16 **Correlation matrix for traits under the two treatments**

Stressed treatment

	DFL	GW	HW	PEX	PHM	PLHT	SG(*)	TGW
DFL	1.00							
GW	0.144	1.00						
HW	-0.483	0.270	1.00					
PEX	-0.647	0.021	0.167	1.00				
PHM	0.835	0.280	-0.377	-0.456	1.00			
PLHT	0.025	0.470	0.514	0.060	0.199	1.00		
SG(*)	-0.661	-0.488	0.229	0.442	-0.626	-0.059	1.00	
TGW	0.220	0.735	0.046	0.020	0.222	0.389	-0.507	1.00

Irrigated treatment

	DFL	GW	HW	PEX	PHM	PLHT	SG(*)	TGW
DFL	1.00							
GW	-0.496	1.00						
HW	0.174	0.164	1.00					
PEX	-0.524	0.412	-0.043	1.00				
PHM	0.793	-0.403	0.380	-0.340	1.00			
PLHT	0.326	0.238	0.750	0.104	0.348	1.00		
SG(*)	0.076	-0.233	0.085	-0.200	0.081	-0.126	1.00	
TGW	-0.402	0.409	0.586	0.405	-0.162	0.577	-0.071	1.00

TGW= Total Grain Weight; GW= 100 Grain Weight; PLHT= Plant Height; PHM= Physiological Maturity; PEX= Peduncle exertion; DFL= Days to Flowering; HW= Head Weight; SG= Stay Green

(*) Note that the negative correlation for the staygreen trait in **table 4.16** means positive association and vice versa. Because in the 1-5 scaling the best scores for stay green was given 1 or 2 and least for senescence with score 5.

maturity under the stressed treatment. However, staygreen was negatively correlated with peduncle exertion and no correlation with head weight and plant height (Table 4.16).

Physiological maturity showed strong positive association with days to 50% flowering in both stressed and irrigated treatments; and positively associated with staygreen and negative correlation with head weight and peduncle exertion in the stressed treatment (Table 4.16).

CHAPTER V

5.0 DISCUSSION

5.1 SELECTION METHODS FOR SEEDLING EMERGENCE UNDER HIGH SURFACE TEMPERATURE

Adequate germination is the base for vigrous seedling establishment. In the semi-arid tropics a hot, dry seedbed environment during sowing and crop establishment is very likely with soil surface temperature greater than 50^0C. Specially after the initial planting rain, the subsequent rain could be delayed and result in drying the soil surface very rapidly. Seeds therefore can fail to germinate due to this abiotic problem.

Changing the soil cover by charcoal powder, temperature can be increased above the normal. All the genotypes under study showed a great decrease in germinability at high surface temperature treatment. The current investigation agrees with the ICRISAT 1980 findings on seed germination under high surface temperature. Seeds planted in charcoal treatment where soil temperature reaches above 50^0C showed a complete or partial failure of germination compared to the control and kaolin treatments. The percentage of germination largely determines how long a seed will take to emerge in a particular soil environment and therefore, the duration of its exposure to high temperature. It was also noticed that all the seeds in the poorly germinated genotypes when it was dug out inside the soil to 4cm depth, the seeds were germinated but when they reach the high surface temperature zone they fail to emerge out from the soil. It was therefore confirmed and agrees with Wilson's

(1982) demonstration that the delayed and poor germination were associated with high surface temperature. The plumule of the susceptible genotypes bent laterally after reaching the high temperature cover while the tolerant genotypes emerged successfully.

Emergence of seeds also associated with the low moisture levels and high evaporation that resulted from the increased soil temperature. In the field, seeds usually experience high temperature for a few hours each day rather than 12 hours. As it was examined by Garcia-Huidobro *et al.* (1985), seeds were most sensitive to short term temperature at 45^0C or 50^0C when they were absorbing water. The adverse effects of high temperature were much less severe when seeds were allowed to imbibe water for eight hours at control temperature before exposure to the high surface temperature. Germination would be more successful when seeds are sown in early evening, after which the soil temperature remains relatively low for at least 18 hours (Garcia-Huidobro *et al.*, 1985).

One problem in this experiment was that germination percentage could be affected not only by high surface temperature but also with the viability of the seed lots. For instance genotype 296 B and SSD 91 show very low germination rate across all the treatments (Table 4.5). This could be explained by the fact that these two genotypes possibility have low viability percentage from the very beginning compared to other genotypes. Seeds with low viability will normally be more affected by adverse conditions than seeds of high quality.

This trial therefore indicates that the two genotypes, SSD 66 and ICSV 112 specifically can be taken as tolerant to high temperature germination and recommended for high soil surface temperature areas. However, the results need to be confirmed further.

5.2 SELECTION OF SORGHUM GENOTYPES FOR TOLERANCE TO PRO-LONGED MID-SEASON AND TERMINAL DROUGHT

Drought is a serious agronomic problem that contribute a great deal to crop yield loss. This problem could be alleviated by developing crops that are well adapted to dry land environment. Sorghum is considered a drought tolerant plant adapted to harsh climatic conditions of the semi-arid tropics through the process of evolution. Different cultivars show different morphological and physiological modification to overcome the various environmental stresses encountered during the crop growth. Drought escape and staygreen are such mechanisms of drought tolerance in sorghum. Sorghum cultivars can escape drought by making the flowering time shorter and by maturing earlier. Staygreen is a delay in leaf and plant death resistance mechanism in sorghum that prevents the detrimental effects of reduced soil moisture during post-flowering growth

5.2.1 Days to 50 percent flowering

The genotypes differed significantly from each other in their flowering dates. However, they did not vary significantly between the irrigated and stress treatments. The flowering on an average over all the lines differed only in one day which is not significant. The probable reason for the uniformity across the treatments in the flowering dates could be absence of moisture stress until up to flowering due to the rains and irrigation received at the time of crop establishment stage.

5.2.2 Plant height

Water stress had greatly affected the plant height. The genotypes show a clear difference from each other. The stressed treatment showed 26% reduction in plant height when compared with the irrigated (Table 4.14).

Plant height showed significant positive correlation with head weight, grain yield and seed weight as it has reported by Bittinger *et al* (1981). This was expected because both head weight and seed weight are major components of yield and yield has been frequently shown to be strongly and positively correlated with plant height.

5.2.3 Physiological maturity

The genotypes differed significantly from each other in the dates to maturity. Due to moisture stress, the mean maturity of the genotypes were earlier in the stressed treatment when compared with the irrigated. Within the groups, the staygreen genotypes had longer duration to post flowering (GS3). The result was in contrast with those obtained by Blum (1985) who reported that early maturity i.e., short duration of GS3 may be a potential benefit in situation where growth is achieved solely on stored water. Among the senescence genotypes the duration of maturity of SSD 51 was shorter but recorded good yield. The probable reason may be escape of the stress due to fast grain filling.

Physiological maturity showed positive significant correlation with days to 50 percent flowering in both stressed and irrigated treatments (Table 4.16). This indicates that those late flowering genotypes were late to mature. However, physiological maturity was negatively associated with head weight and peduncle exertion that could be explained the early and drought escape genotypes like SSD 51 had better head weight and taller peduncle exertion under moisture stress.

5.2.4 Grain weight

The means of grain yield and seed weight in the irrigated and moisture stressed treatments indicated significant differences in the reduction of grain weights. The stressed treatment resulted in 48% reduction in grain yield and 25% decrease in seed weight relative to the irrigated treatment (Table 4.14). These reductions in grain yield and seed weight indicate severity of post-flowering terminal drought.

The grain weight was significantly more in the staygreen genotypes compared to the senesced ones across both the treatments indicating a higher genetic potential as well as high resistance to prolonged mid-season and terminal moisture stress in the staygreen genotypes. Grain yield of sorghum is a function of carbohydrate that is stored in the grain. This productivity ultimately depends on leaf area development and maintenance along the distribution of assimilates between grain and stover. A higher senescence rate in the senescence genotypes will cause a rapid decrease in number and leaf area of functional leaves that cause significant yield reduction. The results were in conformation with Begg (1980) reports that water stress had a great effect on leaf area and photosynthetic rate per unit area. Among the staygreen lines, the moderately staygreen lines recorded the highest grain yield while the highest stay green lines tend to increase greeness of stem and leaf that could be good source of animal feed. Thus it seems that for grain purpose the moderate staygreen genotypes could be better suited.

Grain yield indicated significant positive association with seed weight, plant height and staygreen; and no association was observed with days to 50% flowering, head weight and physiological maturity in the stressed treatment. While in the irrigated treatment, grain yield was negatively correlated with days to 50% flowering and positively associated with seed weight, head weight, peduncle exertion and plant height; and no correlation with physiological maturity and staygreen (Table 4.16). Thus, genotypes with high seed weight, head weight, taller in height and peduncle exertion tends to have high yield. The reason for the absence of correlation between grain yield with staygreen in the irrigated treatment could be the availability of moisture to keep green all the genotypes and scored similar yield performance.

5.2.5 Staygreen

Leaf senescence is a factor that impaired chlorplast function and partial stomatal closure which resulted in decreased photosynthesis. This failure in photosynthesis activities followed by a rapid translocation of stored assimilates to the developing grain increased the rate of senescence of the leaves. Higher yield was observed in the moderately staygreen and staygreen genotypes when compared with the senesced lines. This result was in conformation with the studies of Gerik and Miller (1984). Genotype SSD 51, the senesced line was an exception which gives good yield under moisture stress (Fig 5b). The possible reason may be the early initiation of grain filling helps to escape the moisture stress where then the senescence occurs as a normal process in the life cycle of the crop.

Staygreen showed significant positive correlation with days to 50 percent flowering, seed weight, physiological maturity and grain yield under moisture stress. It was negatively correlated with peduncle exertion and no correlation with head weight and plant height. The probable reason for the poor yield in the senescence genotypes could be that the leaf senescence was hastened by the moisture stress which reduces the grain filling, resulted in low mean grain weight while the staygreen genotypes that able to cope with the stress gave better yield.

CHAPTER VI

6.0 SUMMARY

High surface temperature is one of the causes for poor germination in the semi-arid tropics. Each plant has a minimum and maximum temperature at which no seed germinate, and an optimum temperature at which germination will be highest. Soil temperature has a direct effect on both germination and subsequent plumule extension, thereby resulting in poor seedling emergence. In the semi-arid tropics, air temperature exceeds 40^0C and soil surface temperature may reach up to 50^0C. Genotype differences in emergence were most evident even at 45^0C. The current experiment (experiment one) was therefore focused in investigating and screening sorghum genotypes that response to high surface temperature at 2 and 7cm soil depth with soil cover treatments of charcoal, kaolin and control. Such experiment is important in areas where moisture is a limiting factor and experienced high surface temperature at the time of planting and seedling emergence. The experiment was standardized to screen genotypes for emergence ability through the adopting of soil cover treatments. The sorghum genotypes have shown significant genotypic variability in seedling emergence across the treatments. The results also indicated that high surface temperature were associated with late and poor emergence. In the charcoal treatment where the temperature reached 52^0C at 2cm depth, emergence was failed in few genotypes in one or two replications. It was also noticed non-significant genotype x treatment interaction. This indicated that the genotypes were stable in all the treatments. Among the 36 sorghum genotypes under study, ICSV 112 and SSD 66 score relatively higher germination percentage in the high surface temperature

charcoal treatment. With further confirmation and studies these two genotypes can be recommended for areas where high soil surface temperature is commonly seen at the time of planting.

Moisture stress is one of the greatest factor in reducing yield in the arid and semi-arid tropics. Because, the period of drought stress under variable environments is unpredictable, generalization on the effects of stress on grain yield is difficult.

Eritrea is one of those countries which located in semi-arid tropics frequently experienced moisture stress at the time of flowering and post-flowering terminal. The rainfall situation is short and highly variable from season to season, erratic and uneven distribution which is associated with high rate of evapotranspiration. The current experiment, aimed at the selection of sorghum genotypes to terminal drought is highly applicable and can be used for sorghum improvement program in Eritrea.

Sorghum is considered as a drought tolerant crop that has good adaptation to versatile adverse environments. Stress on sorghum can occur at any stage of its growth. Stresses during mid-season and terminal stages of crop growth have more severe effects on grain yield. The reduction in yield under initial mid-season stress is small that the plant can recover when rainfall re-starts. However, if the stress extends to the prolonged mid-season and the post-flowering terminal stages, yield reduction is more severe because the opportunity to recover is gradually lost. There are three general strategies for plant to survive in drought environments: escape, avoidance, or tolerant.

The current experiment, experiment two can provide important source of information for sorghum growing areas that are highly affected by moisture stress at post-flowering stage of growth. It is possible to select sorghum genotypes that are tolerant to post-flowering terminal stress by imposing water stress at flowering stage and quantifying the yield losses or reduction as a proportion to irrigated (control) treatments. The genotypes under study showed wide variation to each other for all the traits considered except for days to 50% flowering. The result of the experiment in general indicated that the non-senescence (staygreen) in sorghum genotypes was positively correlated with yield and yield components. However, the genotypes (SSD 19, SSD 38, SSD 66, SSD 92 and B-35) with high staygreen showed reduced grain yield when compared to the moderate staygreened genotypes (SSD 61, SSD 75 and ICSV 112). This suggests that selection of sorghum genotypes for high staygreen may be at the cost of grain yield which other wise can give high forage yield.

Besides the staygreen, the result also indicated that terminal moisture stress could be alleviated by selection of sorghum genotypes that matched to the expected period of available moisture. In this experiment SSD 51 was such genotype that escapes the terminal drought and gives good yield by matching its duration with the available moisture and matures earlier. From this experiment it can be concluded that the moderate staygreen and early maturing genotypes can give reasonable yield under mid season and terminal moisture stress areas.

CHPTER VII

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