CHARACTERIZATION OF GRAIN SORGHUM FOR PHYSIOLOGICAL AND YIELD TRAITS ASSOCIATED WITH DROUGHT TOLERANCE

by

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Abstract

Grain sorghum (*Sorghum bicolor* L. Moench) is the fourth most important cereal crop grown throughout the semi-arid regions of the world. It is a staple food crop in Africa and Asia, while it is an important feed crop in the United States (US). More recently it is increasingly becoming important as a potential bioenergy feedstock crop around the world. The state of Kansas is the largest producer of grain sorghum in the US and contributes 40% of the total production. Drought is one of the major environmental factors limiting sorghum production in the semi-arid regions of the US, Asia and Africa. It is estimated that global crop losses due to drought stress exceed $10 billion annually. In crop production, drought stress can be classified into pre- or post-flowering. Even though the world collections of sorghum contain over 35,000 accessions, the genetic base currently used in breeding programs is very small (about 3%). Thus, it is important to identify diverse breeding lines for crop improvement. The diversity (association) panel consisting of 300 sorghum lines from all over the world was assembled for trait evaluation and association mapping. In this research these lines were grouped into the five major races (Figure 1) and 10 intermediate races of sorghum. The objectives of the research are to: (i) quantify the performance of the diversity panel under field conditions in Kansas, (ii) identify critical physiological traits affected by drought at both pre- and post-flowering stages of sorghum development, (iii) identify the most sensitive stage to drought stress during the reproductive phase of sorghum development and, (iv) test the feasibility of using a chlorophyll fluorescence assay (CVA) as a tool for identifying stay-green lines in grain sorghum during early stages of crop development. Field experiments were conducted in 2006 and 2007 in two

locations in Kansas (Manhattan and Hays) under rainfed and irrigated conditions for the association panel. Objectives (iii) and (iv) were achieved with controlled environment experiments conducted in the greenhouse at the agronomy department, Kansas State University in 2006 and 2007. Results showed that there was large genetic variability among and within different races in the diversity panel for growth, physiological traits and yield components. Some genotypes showed yield stability across the different environments that were investigated. Drought significantly decreased seed number and harvest index across genotypes and races. In grain sorghum the period prior to flowering (panicle initiation) was the most sensitive stage to drought stress, in terms of its effect on seed-set, during reproductive development. A cell viability assay showed that there were significant differences in the loss of cell viability between leaf sample of stay green and non-stay green genotypes when leaf samples are collected in the morning and subjected to high respiratory demand. Therefore the chlorophyll fluorescence assay has potential as a tool for stay green trait screening at early stages of growth in grain sorghum.

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Acknowledgements

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CHAPTER 1 - Grain Sorghum

1.0 Introduction

1.1 Postulated Centers of Domestication

Sorghum (*Sorghum bicolor* L. Moench), a cereal grain, has its origins in Africa, is the fourth most important cereal crop after wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), and maize (*Zea mays* L.) and is now grown throughout the semiarid regions of the world. Archeological evidence suggests that hunter-gatherers consumed sorghum as early as 8000 BC (Smith and Frederiksen, 2000). Sorghum is believed to have been domesticated in Ethiopia and surrounding countries, commencing around 4000 – 3000 BC. Numerous varieties of sorghum were developed through the practice of selection, whereby selection for more than one level of a particular character within a population occurs (Doggett, 1970). Different sorghum types spread through the movement of people and trade routes into other regions of Africa, India (approx. 1500 – 1000 BC) and the Middle East (approx. 900 – 700 BC). Figure 1.1 gives the postulated movement of different genotypes around the world. By the time sorghum was transported to America during the late 1800s to early 1900s, the diversity of new sorghum types, varieties and races had developed through the movement of people, selection as well as geographic isolation and recombination of these types in different environments (Wright, 1931; Doggett, 1970). While sorghum is a staple food for millions of people in India and Africa, livestock feeding accounts for most of the sorghum use in the developed world, particularly the US and Australia.

The genus *Sorghum* is very diverse and all cultivated sorghums belong to *Sorghum bicolor* ssp. *bicolor* which is divided, based on morphology, into five races (bicolor, caudatum, guinea, durra, and kafir), along with the ten intermediate races resulting from all possible inter-racial crosses (Harlan and de Wet, 1972). The race bicolor is found nearly everywhere sorghum

is grown and is characterized by very loose, open panicles similar to wild sorghum. Caudatum race originated mostly from the region around Lake Chad to the Ethiopian border. The guinea race has its origins in West Africa and India and is grown in areas with higher rainfall. The Kafir race is primarily from southern Africa. Durra race has its origins around the edges of the Sahara and in India.

1.2 Adaptation

Sorghum is grown predominantly in low-rainfall, arid to semi-arid environments. Drought is perhaps the most important abiotic stress limiting crop productivity around the world and is certainly of great significance in the semi-arid tropics, where rainfall is generally low and its distribution is erratic. There are two forms of drought stress that have been identified in sorghum: pre-anthesis drought stress where plants experience moisture stress during panicle differentiation prior to flowering; and post-anthesis drought stress when moisture stress occurs during the grain filling stage (Rosenow and Clark, 1995). The identification of varieties and lines with naturally high levels of pre-anthesis drought tolerance and the selection of these lines for higher yields has resulted in sorghum varieties with stable and high yields (Ellis et al., 1997). Post-anthesis drought stress can result in significant yield reduction. There are genotypes that show some post-flowering drought tolerance, a characteristic often referred to as stay-green. These genotypes maintain green leaf area and hence photosynthetic capability and/or improved translocation of carbohydrates under late season moisture stress, and produce higher grain yields compared with senescent genotypes (Borrell and Douglas, 1997; Borrell et al., 1999).

The International Water Management Institute (IWMI) had predicted in 2000 that one-third of the world population would be affected by water scarcity by 2025. Findings as reported in 2006 indicate that, “already more than a third of the world population is affected by water

scarcity". This will impact food production and more emphasis on crops that are efficient in water use will be key in ensuring food security and the development of crop genotypes that can withstand moisture stress is of prime importance.

Sorghum is a native to sub-Saharan Africa, a region generally characterized by unpredictable rainfall pattern. Adaptation of sorghum to a wide range of environmental conditions in the sub-Saharan region has resulted in the evolution of extensive genetic variation for drought tolerance (Blum, 1979). Its rich and apparent genetic diversity for stress tolerance makes sorghum an excellent crop model and choice for evaluating genetic and physiological mechanisms of drought tolerance. Direct selection for drought tolerance using conventional approaches has been slow and difficult. Although a number of physiological and biochemical traits have been associated with drought tolerance, only a few of these mechanisms have been demonstrated to be causally related to expression of tolerance under field conditions (Ludlow and Muchow, 1990). It is therefore important to understand physiological traits in grain sorghum that contribute to improved drought tolerance. Some physiological traits that are associated with drought tolerance include: greater leaf photosynthetic rates, greater canopy temperature depression, improved panicle exsertion under drought stress for pre-flowering drought tolerance; increased pollen production, pollen viability, higher seed-set and larger seed number for drought stress during flowering; and traits such as increased green leaf area duration (stay-green), longer grain filling duration, increased grain filling rate and increased seed-size for post-flowering drought tolerance.

1.3 Some Key Issues on Grain Sorghum Improvement for Drought Tolerance

1. The adaptation of grain sorghum to a wide range of environmental conditions has led to the evolution and existence of extensive genetic variation for drought tolerance (Blum, 1979; Dogget, 1988).
2. The genetic base that has been used in sorghum breeding is very narrow and can be traced to few parents. There is a need to expand this by looking at other existing lines and evaluating them for traits that can be used in sorghum improvement.
3. Even though much work has been done on variety or hybrid improvement towards drought tolerance, there is still a lot that can be done. Work in the area of drought tolerance in crops is most complicated as drought is a complex trait and genetic and physiological mechanisms that control it are poorly understood.
4. A number of physiological traits have been associated with enhancement of drought tolerance but only a few have demonstrated to be related to the expression of tolerance under field conditions (Ludlow and Muchow, 1990).
5. Some reasons why breeders have not adopted physiological traits as selection criteria could include the fact that genetic control of stress tolerance is poorly understood and if understood multiple genes often control stress tolerance. Variation for stress tolerance actually exhibits a large environmental component or large genotype-by-environment interaction making direct selection for a physiological trait in a single environment difficult.

1.4 The Sorghum Association Panel

The association panel that was used in this study is a collection of about 300 representative grain sorghum genotypes collected from all over the world and will be used for sequencing and characterizing of the grain sorghum genome. The genotypes can be classified

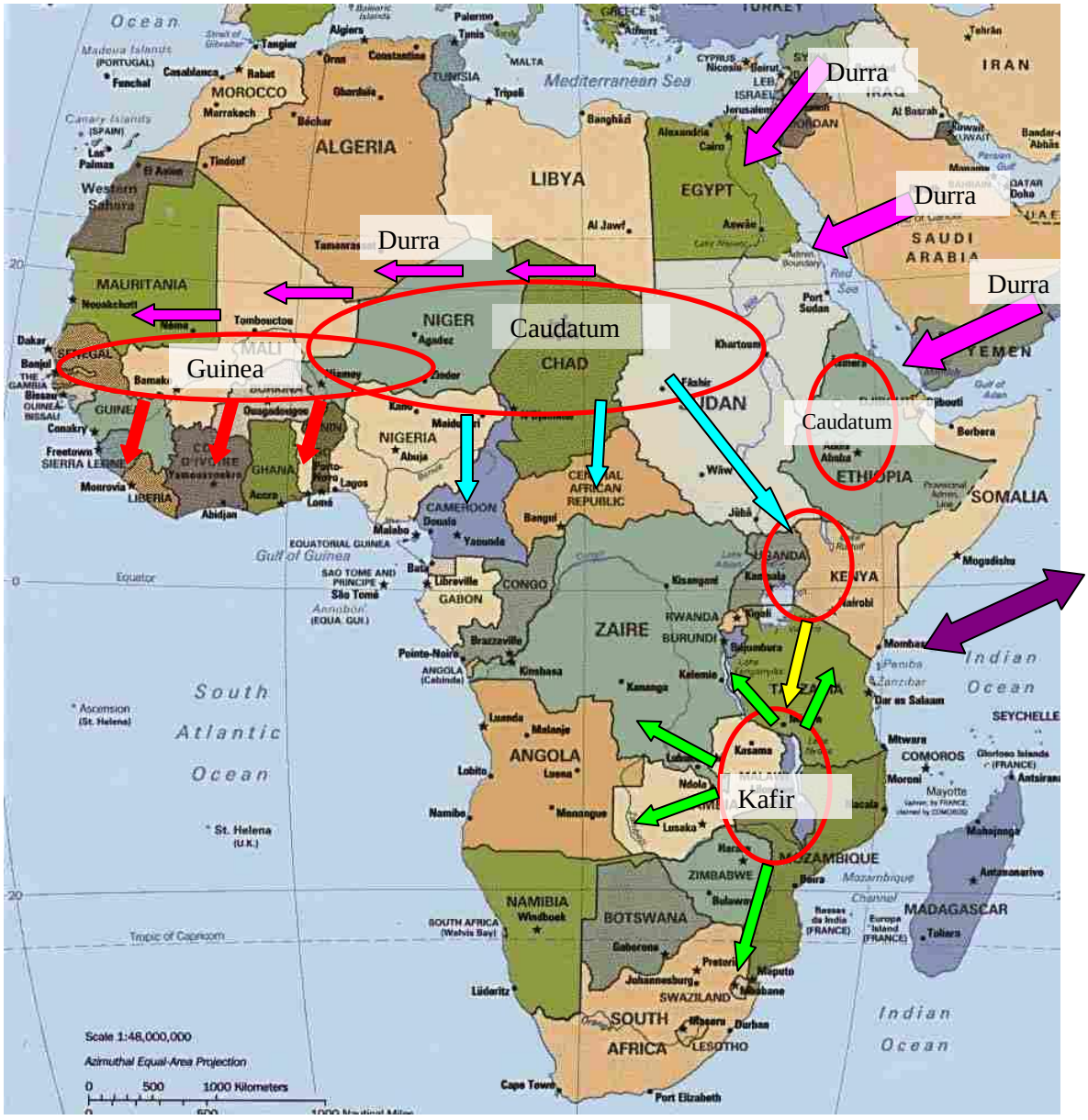
into about 23 groups based on race, intermediate race and in some cases the region where the line came from. Our hypothesis is that there is genetic variation within this association (diversity) panel for traits associated with drought tolerance. Physiological traits can be used as a basis for identifying drought tolerant genotypes from the association panel, which could be used in the breeding programs aimed towards improving drought tolerance. The purpose of this study therefore is to characterize physiological traits associated with pre- and post-flowering drought tolerance in the association panel.

1.5 Study Objectives

The objectives of the study are to (a) quantify the performance of the association panel under field conditions at Kansas; (b) identify critical physiological traits affected by drought at both pre- and post-flowering stages of crop development; (c) identify the most sensitive stage during the reproductive phase of crop development to drought stress; (d) and test the feasibility of using a chlorophyll fluorescence assay (cell viability) for identifying stay-green lines of grain sorghum during early stages of crop development (leaf 5).

1.6 Tables and Figures.

Figure 1.1: Postulated centers of origin of *Sorghum bicolor* and subsequent movement.



Postulated movement from centers of origin for different races: different colors show the movement of a particular race from its centre of origin

Postulated centers of origin for the different races

NB: The centers of origins are the regions from which a particular line is believed to have come from.

CHAPTER 2 - Sorghum Production

2.0 An Overview

2.1 Importance of Sorghum

According to the 2007 United States Grains Council (Building Global Markets for America's Grains), grain sorghum is the third most important cereal crop in the US. Due to its adaptation to a wide variety of environmental conditions, sorghum has continued to be a major crop in Kansas. The state produces about 40% of the total sorghum grown in the nation and in 2005 production was 4.95 million metric tons out of the national production of 7.72 million metric tons. Even though grain sorghum is mainly produced as grain for the livestock industry, there is an expansion of its market to ethanol production and human consumption. The fact that grain sorghum is gluten free has resulted in research aimed at including it in diets for people who have gluten intolerance or celiac disease. Even though grain sorghum in the US has gained importance as a feed crop, and now as a food and biofuel crop, its breeding has a very narrow base and hence the need to look at existing genetic material and identify traits that may be important to breeders. Table 2.1 gives a list of sorghum introductions into the US that have been used in the development of current cultivars or hybrids.

2.2 Growth and Development of Grain Sorghum

In his publication "How a Sorghum Plant Develops", Vanderlip (1993) defined nine stages that can be used in understanding the growth and development of grain sorghum. These stages are from stage 0 (emergence) to stage 9 (physiological maturity) with each stage having some distinctive characteristics. Time required to reach each stage depends both on the hybrid and the environment in which it is growing. Other factors such as soil fertility, insect or disease

damage, moisture stress, plant population, and weed competition may also affect both timing of the various stages of development and condition of the plants at each stage of development. Following is an outline of the development stages in grain sorghum based on Vanderlip's description.

2.2.1 Sorghum Seed

Sorghum has smaller seed when compared to corn (*Zea mays* L.) and soybean (*Glycine max* L. Merr.) which are the three major spring planted crops in Kansas. The seed size also varies greatly among different hybrids and genotypes. It is important to note that while there seems to be a poor relationship between seed size and field performance; when many sorghum hybrids or genotypes are compared, both extremely small and extremely large seed have lower-than-average emergence and establishment capability.

2.2.2 Stage 0: Emergence

Emergence is defined by when the plant first breaks through the soil surface and generally occurs 3 to 10 days after planting. Time to emergence depends on soil temperature, soil moisture conditions, depth of planting, and vigor of the seed. During this period, growth depends on the seed for nutrients and food reserves. Cool, wet conditions during this stage may favor disease organisms that seriously damage stands. Since depth and date of planting greatly affect emergence rate, planting should be timed so that germination and early growth occur during warm temperatures and flowering will occur before the hottest period in the plant growing season. Planting too early delays emergence and subjects the seed to longer attack of soil micro-organisms and cooler soil temperatures.

2.2.3 Stage 1: Three-leaf Stage

Leaves are counted when the leaf collar can be seen without tearing the plant apart. At this stage the growing point is still below the soil surface and therefore much of the leaf area can be removed without killing the plant. While the plant's growth rate depends largely on temperature, this stage usually will occur about 10 days after emergence (DAE) and since the plant is quite small, relatively slow growth and competition for nutrients due to poor weed control during this stage can seriously reduce yields.

2.2.4 Stage 2: Five-leaf Stage

This will be approximately 21 DAE and the plant has 5 fully expanded leaves. At this stage the plant's root system is developing rapidly and roots produced at the lower nodes may push the lower leaf off the plant. The plant enters its "grand period of growth" during this stage and dry matter accumulates at nearly a constant rate until maturity, if growing conditions are satisfactory. During this stage the growing point is still below the soil surface and therefore leaf loss will not necessarily kill the plant. Regrowth is more vigorous than at the three-leaf stage. Weed competition, nutrient and drought stress, or other problems, such as insect damage at this stage can seriously reduce yields if they are not corrected.

2.2.5 Stage 3: Growing Point Differentiation

Growing point differentiation occurs about 30 DAE. The plant's growing point changes from vegetative (leaf producing) to reproductive (head producing), the total number of leaves has been determined and potential head size will soon be determined. About one-third of the total leaf area has fully developed (7 to 10 leaves depending on maturity class) and the lower 1 to 3 leaves may have been lost. Culm or stalk growth increases rapidly following growing point

differentiation. Nutrient uptake is rapid and therefore adequate supply of nutrients and water is necessary for maximum growth. Time from planting to growing point differentiation is generally about one-third of the time from planting to physiological maturity (maximum dry weight). Sorghum plants at this stage are quite competitive and this helps maintain good weed control.

2.2.6 Stage 4: Flag Leaf Visible

Following growing point differentiation, rapid culm elongation and rapid leaf development occur simultaneously, and the flag leaf (final leaf) eventually becomes visible in the whorl. At this point, the final 3 to 4 leaves are fully expanded and about 80% of the total leaf area is present. Light interception approaches maximum, and growth and nutrient uptake continue at a rapid rate. The head is developing and the lower 2 to 5 leaves have been lost. Any reference to leaf number from now on may be from the top, counting the flag leaf as leaf number 1.

2.2.7 Stage 5: Boot Stage

At the boot stage, all leaves are fully expanded, providing maximum leaf area and light interception. The head is developed to nearly full size and is enclosed in the flag-leaf sheath. Except for the peduncle, culm elongation is essentially complete. Peduncle elongation begins at this stage resulting in the exsertion of the head from the flag-leaf sheath. Potential head size is determined during this stage. Rapid growth and nutrient uptake are continuing. Severe moisture stress or herbicide injury during stage 5 may prevent the head from exserting completely from the flag-leaf sheath.

2.2.8 Stage 6: Half-bloom Stage

Following the boot stage, the peduncle grows rapidly pushing the head through the flag leaf sheath. Half-bloom is usually defined as when one-half of the plants in a field or area are in some stage of bloom. However, because an individual sorghum head flowers from the tip

downward over 4 to 9 days, half-bloom on an individual plant is when the flowering has progressed half-way down the head. At half-bloom approximately one-half of the total dry weight of the plant has been produced. Time required from planting to half-bloom depends on the maturity of the hybrid/genotype and environmental conditions; however, it usually represents two-thirds of the time from planting to physiological maturity. During this stage, grain formation begins and hence any limitation in plant size, leaf area, or plant numbers can no longer be corrected. However, if environmental conditions are favorable, the sorghum plant can still compensate for grain number per head through an increase in seed size and seed weight. Severe moisture stress during this stage can result in "blasting" and poor head filling.

2.2.9 Stage 7: Soft-dough

Between half-bloom and soft-dough the grain fills rapidly with approximately half of its dry weight accumulated in this period. The culm weight increases slightly following half-bloom and then because grain is forming rapidly the culm loses weight. The loss in culm weight may account for as much as 10% of the grain weight. Lower leaves are still being lost with 8 to 12 functional leaves remaining during this stage. Final yield depends on the rate of dry matter accumulation in the grain (grain filling rate) and the length of time that it accumulates (grain filling duration). Dry matter accumulation rates do not vary much among hybrids/genotypes. Therefore, as long as the plant is able to mature before frost and flowering does not coincide with severe moisture stress, later maturing hybrids/genotypes yield more than early maturing genotypes.

2.2.10 Stage 8: Hard-dough

At the hard-dough stage, about three-fourths of the grain dry weight is accumulated and the culm declines to its lowest weight. Nutrient uptake is essentially complete. Additional leaves may have been lost. Severe moisture stress or a freeze before the grain matures will result in light, chaffy grain.

2.2.11 Stage 9: Physiological maturity

This is the stage during which maximum total dry weight of grain occurred. Physiological maturity can be determined by the dark spot on the opposite side of the kernel from the embryo. The time from flowering to physiological maturity varies with hybrid/genotype and environmental conditions; however, it represents about one-third of the total time from planting. Grain moisture content at physiological maturity varies with hybrid/genotype and growing conditions. It is usually between 25 and 35% moisture. After physiological maturity, the remaining functional leaves may stay green or brown rapidly and die. If temperature and moisture conditions are favorable, tillers may start to grow from several of the upper nodes and the culm or stalk weight may also increase slightly near physiological maturity.

2.3. Impact of Drought on Grain Sorghum

2.3.1 Defining Drought

Although drought has several definitions, it involves a condition where there is a deficiency of precipitation (rainfall) over an extended period of time resulting in a water shortage for some activity, group, or environmental sector. In its definition and evaluation, it should be considered relative to some long-term average condition of balance between precipitation and

evapotranspiration in a particular area, a condition often perceived as “normal”. Drought is also related to the timing and the effectiveness of precipitation. Other climatic factors such as high temperature, high wind, and low relative humidity are often associated with it in many regions of the world and can significantly increase the severity of drought. The impacts of drought on society occur as a result from the interplay between a natural event and the demand people place on water supply.

Drought can be understood differently depending on the level of operation. Figure 2.1 outlines levels at which drought may be perceived differently. The definition of drought that will be used in this report will be agricultural drought which results in soil water deficiency that will lead to plant drought stress resulting in reduced biomass and eventually reduced yields (Figure 2.1). This will be in many cases termed as drought stress in this document and will be discussed at the plant level.

For drought to affect a plant community, the rainfall deficit must lead to a soil water deficit and ultimately to a plant water deficit (Jones et al., 1981). The degree to which a precipitation deficit is translated into a soil water deficit depends on the rate of evaporation during the precipitation free period, the physical and chemical properties of the soil as well as soil management practices. The degree to which a soil water deficit influences the plant is determined by the vapor pressure deficit (VPD) and various plant characteristics that influence water uptake, the rate of transpiration, and the response of the plant to the water deficit generated.

2.3.2 Plant Response to Drought Stress

Plant response to drought stress can be classified into escape where the plant has the ability to complete its life cycle before a plant water deficit can develop, avoidance which

involves the ability of the plant to endure periods of drought stress while maintaining a high tissue water potential, and tolerance which is the ability of the plant to endure drought stress at low tissue water potential. Even though plant resistance to drought can be divided into escape, avoidance and tolerance strategies (Levitt, 1972; Turner, 1986), these strategies are not mutually exclusive and plants can combine a range of response strategies (Ludlow, 1989). Plants that escape drought often have a high plasticity in their developmental stages and are able to complete their cycle before physiological drought stress occurs. Reproduction in drought escaping plants often occurs before the onset of the stress. This is an important strategy in arid regions where native annuals may combine short life cycles with high rates of growth and gas exchange, using maximum available resources while moisture in the soil lasts (Mooney et al., 1987; Maroco et al., 2000a). Improved reproductive success may also include better partitioning of assimilates, by storing them in organs such as roots or stem and mobilizing them for fruit or seed production in cereals (Gebbing and Schnyder, 1999; Bruce et al., 2002) and some legumes (Rodrigues et al., 1995; Chaves et al., 2002).

Plants can also endure drought stress by avoiding tissue dehydration through maintaining high tissue water potential or surviving at low water potential, a strategy that is common in annuals as well as perennials. Some adaptive traits associated with this strategy involve minimizing water loss and maximizing water uptake. Water loss can be minimized through closing of stomata, reducing light absorbance through leaf rolling (Ehleringer and Cooper, 1992), having a dense trichome layer that increases reflectance (Larcher, 2000), steep leaf angle, decreased canopy leaf area through reduced growth and shedding of older leaves. Plants can maximize water uptake by adjusting the allocation pattern; increasing allocation to roots (Jackson et al., 2000), which may result in increased root depth. Shedding of older leaves can

also be viewed as a recycling system that allows the reallocation of nutrients stored in older leaves to the younger leaves or stems.

When a plant experiences stress (low humidity, high temperature, high irradiance, drought stress), there are short-term and long-term responses at the whole plant level. In the short-term, there are gene responses at the root, shoot, and leaves. At the root level, there will be osmotic adjustment while in stems there will be changes in xylem hydraulics and assimilate transport. Responses at shoot level will include root signal recognition (which also takes place in the leaves) and growth inhibition. In the leaves, responses will include stomatal closure and decrease carbon assimilation, which will in turn affect photosynthetic efficiency.

In the long-term, as the plant acclimates to drought stress, there is shoot growth inhibition, reduced transpiration area, metabolic acclimation and osmotic adjustment at the plant canopy level while at the root level there will be turgor maintenance, sustained root development, increased root-shoot ratio as well as increased absorption area.

2.4 Important plant physiological processes/traits affected by drought stress

Pre- and post-flowering drought is experienced in western and eastern Kansas. In sorghum production, stages that are susceptible to drought stress will include vegetative growth, biomass accumulation and panicle emergence at pre-flowering as well as seed set and seed numbers at flowering. Figure 2.2 outlines the impacts of pre- and post-flowering drought stress on plants giving the development stages, processes affected and the resulting negative impacts.

In many plants, physiological traits that are associated with drought tolerance when a plant is subjected to drought stress include greater cell growth, photosynthesis and biomass accumulation during pre-flowering stress, high pollen viability, seed set and seed numbers at flowering and improved stay green, photosynthesis and seed size during post flowering drought.

Other traits are (i) leaf rolling and wax content which will help in reducing leaf temperature, (ii) yield traits such as seed filling duration and seed filling rate which will increase seed size, and (iii) root traits such as increased root growth and water absorption which increases water uptake.

2.4.1 Photosynthesis

Net photosynthetic rate of leaves is a result of complex exogenous environmental factors and endogenous reactions in plants, such as CO_2 concentration (ambient and or intercellular), ambient temperature, light intensity, and the activity of phosphoenolpyruvate (PEP) carboxylase and ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) and the capacity of electron transport. Furthermore, it is indirectly associated with leaf water potential and available soil nutrients (Berry and Downton, 1982). Plants growing in environments of high irradiance are more prone to photoinhibition; a sustained decrease in the efficiency of photosynthetic energy conversion, and more so when high irradiance occurs with high temperature and drought (Mattos et al., 1997).

For leaves under high irradiance combined with depressed photosynthetic rates, the excessive excited energy must be safely dissipated otherwise the photosynthetic system will suffer photoinhibitory damage (Powles, 1982; Bilger et al., 1989; Mattos et al., 1997). High temperature influences photosynthetic function of plants by affecting the rate of chemical reactions and structural organization (Pastenes and Horton, 1996). In C_3 plants, Rubisco activity is limited by CO_2 concentration. As temperature increases, the affinity of the enzyme for CO_2 and the solubility of CO_2 decreases. Together with Rubisco deactivation as temperature increases, photosynthesis declines at leaf temperatures greater than 32°C in C_3 plants (Crafts-Brandner and Salvucci, 2000). In C_4 plants, although rubisco activation is decreased at leaf

temperatures above 32°C, the high level of CO_2 in the mesophyll chloroplasts can counteract this effect until temperature approaches 40°C.

In an attempt to optimize and preserve the functioning of the photosynthetic apparatus, plants try to adjust to changes in the prevailing irradiance levels (Franco and Lüttge, 2002). Efficient control of photochemical and non-photochemical quenching and adjustments in the partition of electron flow between assimilative and non-assimilative processes minimize the danger of photoinhibition (Kozaki and Takeba, 1996; Muraoka et al., 2000; Franco and Lüttge, 2002). An advantage of the quenching control process is that there is little or no loss of assimilated carbon.

Drought stress in plants will lead to osmotic stress which, depending on severity, may lead to abscisic acid (ABA) accumulation. In response to this, several things may happen; decrease in stomatal conductance, reduction of intercellular carbon dioxide, decreased chlorophyll content, ultra structural changes in chloroplast, alteration in electron transport, decreased activity of Rubisco and sucrose accumulation. At the plant level, drought stresses will result in reduction in growth and affect photosynthesis by reducing leaf area, enhancing stomatal closure, decreasing water status in the leaf tissues, and reducing the rate of CO_2 assimilation. Ultrastructural changes in chloroplast will also affect photosynthesis electron transport and CO_2 assimilation and hence impairment of adenosine triphosphate (ATP) synthesis and Ribulose-1,5-bisphosphate (RuBP) generation.

2.4.2 Stomatal Conductance

Stomata regulate gas exchange between plants and atmosphere, optimize photosynthetic CO_2 fixation and minimize transpirational water loss (Assmann, 1993; Schroeder et al., 2001; Zeiger, 1983). The opening of stomata is driven by the accumulation of K^+ salts and/or sucrose

(Poffenroth et al., 1992) in guard cells, which results in a decrease in water potential and subsequent water uptake. Turgor elevation from water uptake increases guard cell volume, which widens stomatal apertures. The volume increase requires an increase in surface area of the guard cell plasma membrane, and this needed area is provided by the internal membranes of guard cells (Shope et al., 2003). Guard cells possess a number of small vacuoles in the closed state of stomata (Palevitz et al., 1981). Such small vacuoles fuse with each other and generate bigger vacuoles during stomatal opening. Prior to these processes, a large number of ions move from the cytosol to the vacuole via channels and pumps in the tonoplast.

Stomatal closure is caused by the release and/or removal of osmotic turgor from guard cells under drought, darkness, elevated CO_2 or low humidity, while stomatal opening is induced by light, including blue and red light, and distinct mechanisms underlying stomatal opening in response to these different wavelengths (Zeiger, 1983). Blue light acts as a signal and red light as both a signal and an energy source. Blue light activates the plasma membrane H^+-ATPase (Briggs et al., 2002; Kinoshita et al., 2001), hyperpolarizing the membrane potential with simultaneous apoplast acidification, and drives K^+ uptake through voltage-gated K^+ channels. Red light drives photosynthesis in mesophyll and guard cell chloroplasts and decreases the intercellular CO_2 concentration (*Ci)*. Red-light-induced stomatal opening may result from a combination of guard cell response to the reduction in *Ci* and a direct response of the guard cell chloroplasts to red light (Roelfsema et al., 2005; Sharkey et al., 1987; Vavassuer et al., 2005).

Stomata respond directly to the rate of water loss from the leaves because of changes in evaporative demand rather than air humidity changes (Monteith, 1995; Maroco et al., 1997). Studies have provided evidence suggesting that stomata respond to changes in the rate of water supply through changes in xylem conductance (Salleo et al., 2000; Sperry, 2000; Nardini et al., 2001) and it has been proposed (Mott, 2002) that changes in turgor pressure in the leaf can

translate into a signal that may result in changes in the guard-cell osmotic pressure and hence stomatal aperture in response to water supply and demand.

Because the diffusion of water and CO_2 occurs through the same pathway (stomata), land plants are faced with a constant dilemma. Allowing the maximal influx of CO_2 for photosynthesis is advantageous but can dangerously lead to dehydration. Therefore, stomata must function in a way that optimizes dry matter production by balancing photosynthesis and transpiration. In order to deal with this dilemma, stomata respond to internal and external factors. Internal factors that control stomatal functioning are related to water potential of cells near the guard cells and chemicals, especially abscisic acid (ABA) and cytokinins (Blackman and Davies, 1983, 1985; Davies and Zhang, 1991). With regard to external factors, stomata respond to many environmental factors such as light (quality and intensity), CO_2 concentration, leaf temperature, soil water status, leaf-to-air water vapor pressure deficit (VPD), and pollutants such as O_3, SO_2 and nitrogen oxides (Shimazaki et al., 1986; Aphalo and Jarvis, 1991; Jones, 1992).

During the onset of drought, stomatal conductance normally declines before photosynthesis suggesting that the inhibition of photosynthesis under mild stress can be mostly explained by restriction of CO_2 diffusion (Chaves, 1991; Cornic, 2000).

2.4.3 Chlorophyll Fluorescence

Two things that can happen when radiant energy from the sun strikes a plant leaf; a part of it is transmitted through the leaf and the leaf absorbs the rest. The leaf must then dissipate or use up this absorbed energy in some way so as to avoid damage (Ritchie, 2006). This process is called energy quenching and can be divided into photochemical (where light energy is converted to chemical energy used later to drive photosynthesis), non photochemical (excess energy is dissipated as heat) and fluorescent (excess energy is given off as fluorescent emissions from chlorophyll molecules) quenching. These processes occur in competition.

When light energy enters into the chloroplast many excited electrons from chlorophyll in photosystem II (PSII) are not captured by the acceptor and therefore decay back to their ground state. During this process energy lost is given off as fluorescent light and this is what is measured as Chlorophyll *a* fluorescence. Fluorescence yield is highest when photochemistry and heat dissipation is lowest and changes in this yield reflect changes in photochemical efficiency and heat dissipation. The rate of fluorescence emission is proportional to the absorbed light flux and to the quotient of the rate constant of fluorescence (k_F) divided by the sum of the rate constants ($\sum k_i$) of all competing reactions that result in a return of the chlorophyll molecules to the ground state (Kraus and Weis, 1991). Since the sum of rate constants is constant, an increase in the efficiency of one process will result in a decrease in yield of the other two. Determining the yield of chlorophyll *a* fluorescence will therefore give an indication of the changes in the efficiency of photochemistry and heat dissipation.

In the photosynthetic apparatus, drought affects PS II more than PS I. The effect of this is free high energy electrons in the leaf which may result in photo-oxidation of chlorophyll and the loss of photosynthetic capacity. With increase in drought or heat stress, minimal fluorescence (F_o) remains fairly stable but Maximal fluorescence (F_m) declines. This will in effect result in a decline in F_v/F_m ratio and F_o/F_m will increase. F_v is the variable fluorescence. These two ratios are used in determine damage of the PSII (F_v/F_m) and also cell membrane stability (F_o/F_m). Measured variables for the photosynthetic apparatus are described in details at the appendix (page 126 -127).

2.4.4. Leaf Temperature and Canopy Temperature Depression

High temperature or heat stress is one of the major abiotic factors that affect key plant processes such as leaf photosynthesis, carbon partitioning in the leaf, allocation of carbon to

developing sinks and acquisition of assimilates among different sinks (Farar, 1988). The most obvious effect of high temperature is the subsequent overall reduction in plant size (Midmore et al., 1984; Shpiler and Blum, 1986). Other effects due to heat stress include an increase in respiration (Berry and Bjorkman, 1980), reduction in photosynthesis (Al-Khatib and Paulsen, 1984), inhibition of starch synthesis in developing kernels (Jenner, 1991), reduction in spike number per plant, kernel number per spike and kernel weight (Warrington et al., 1977) and overall acceleration of leaf senescence (Al-Khatib and Paulsen, 1984). All these morphological and physiological changes result in a reduction of yields.

Increasing leaf temperature above the optimum temperature for that particular plant results in a reduction in photosynthetic metabolism (Berry and Bjorkman, 1980). This reduction in net photosynthesis is due to increased oxygenase activity of Rubisco (Ku and Edwards, 1977) because of lower CO_2/O_2 specificity of the Rubisco enzyme (Jordan and Ogren, 1984; Brooks and Farquhar, 1985). Increased leaf temperature will also result in increased water loss and stomatal closure and hence a reduction in CO_2 availability. Under high temperature conditions, photorespiratory loss of CO_2 and carbon cycling through the glycolate pathway (Zelitch, 1992; Tolbert, 1994) may increase, which can reduce ethylene-induced effects on membrane integrity (Grodzinski, 1984) and the extent of photoinhibition (Powles, 1984). Leaf temperatures above 35°C, for example, can result in thermal uncoupling of chloroplast thylakoids, inactivation of photosystems (Terzaghi et al., 1989; Oberhuber and Edwards, 1993), and inhibition of photophosphorylation (Berry and Bjorkman, 1980; Stidham et al., 1982; Havaux et al., 1991). The activity, activation, turnover, and assembly of components of the photosystems, as well as key enzymes of photosynthetic carbon metabolism, may also be affected as the leaf temperature is increased from 30 to 45°C (Berry and Bjorkman, 1980; Brooks and Farquhar, 1985; Hubbs and Roy, 1993; Ghosh et al., 1994). The relationships between leaf temperature and regulation of

the Calvin cycle via triosphosphate/Pi exchange and the resulting partitioning of carbon to starch and sucrose within the leaf mesophyll tissue have been discussed by severa1 groups (Weis, 1981; Kobza and Edwards, 1987; Stitt and Grosse, 1988; Sage et al., 1990).

Water status and transpiration play a major role in controlling leaf temperature as stress progresses (Blum, 1988; Reynolds et al., 1994; Amani et al., 1996) and the degree of cooling reflects the rate of evapotranspiration on the surface of the plant canopy (Amani et al., 1996). Organ temperature is dependent on the rate of transpiration in relation to environmental variables (Gates, 1964). In wheat varieties, canopy temperature has been used to estimate heat stress and positive correlation have been noted between stomatal conductance and grain yield under irrigated conditions (Reynolds et al., 1994; Amani et al., 1996; Fischer et al., 1998). According to Blum (1988), as canopy architecture differs, varieties may also differ in their canopy temperature.

Canopy temperature depression (CTD), the difference between the air temperature [*T*a] and plant canopy temperature [*T*c]), has been used to estimate crop yield and to rank genotypes for tolerance to heat and drought. Canopy temperature and CTD have been recognized as indicators of overall plant water status (Ehrler, 1972; Blum et al., 1982; Jackson et al., 1981; Idso, 1982) and has been used in evaluating plant response to environmental stress (Ehrler et al., 1978; Idso, 1982; Howell et al., 1986; Jackson et al., 1981), irrigation scheduling (Hatfield, 1982; Pinter and Reginato, 1982; Evett et al., 1996; Wanjura et al., 1995a), cultivar comparison for water use (Pinter et al., 1990; Hatfield et al., 1987), and tolerance to heat (Amani et al., 1996; Reynolds et al., 1998) and drought (Blum et al., 1989; Royo et al., 2002; Rashid et al., 1999). High CTD has been used as a selection criterion to improve tolerance to drought and heat (Amani et al., 1996; Ayeneh et al., 2002; Blum, 1988; Blum et al., 1989; Pinter et al., 1990; Rashid et al., 1999; Reynolds et al., 1994, 2001; Fischer et al., 1998).

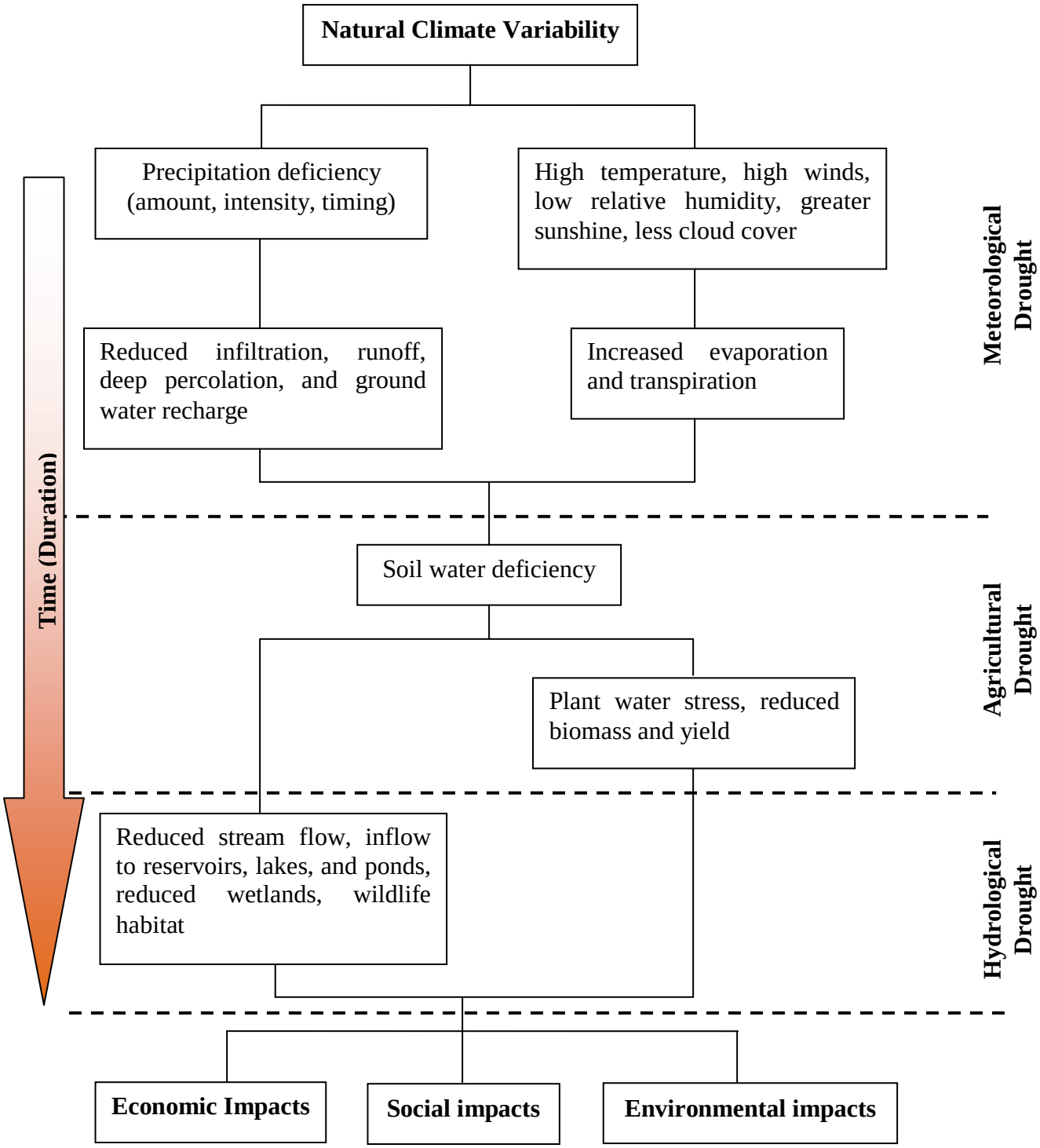
2.5 Tables and Figures

Table 2.1: Sorghum plant introductions leading to cultivar development in the United States.

Date	**Name of Introduction**	**Origin**	**Introduced by**
Pre-1800	Broomcorn	Europe	Benjamin Franklin
Forage Sorghum			
1830	Johnson grass	Turkey	Governor Means, South Carolina
1853	Chinese Amber	China via France	Unknown
1857	16 varieties of sorgo leading to Orange, Honey, Sumal, Gooseneck and White African	South Africa via France	Leonard Wray to Horace Greeley
1881	Collier	South Africa	USDA
1888	Planter	Africa via Australia	USDA
1891	McLean	Australia	USDA
1909	Sudan grass	Sudan, Africa	C.V. Piper USDA/TAES
1951	Sart	Sudan, Africa	USDA/Mississippi
Grain Sorghum			
1874	White and Brown Durra	Egypt	California
1876	White and red kafir	South Africa	T. Jones, Georgia
1879	Giant standard yellow Milo	Africa via California	B.G. Pratt, South Carolina
1890	Blackhill kafir	Africa	Unknown
1890	Shallu	India	Louisiana AES
1904	Pink kafir	Africa	USDA/Kansas
1906	Feterita	Anglo-Egyptian Sudan	USDA
1908	Hegari	Sudan	USDA/TAES

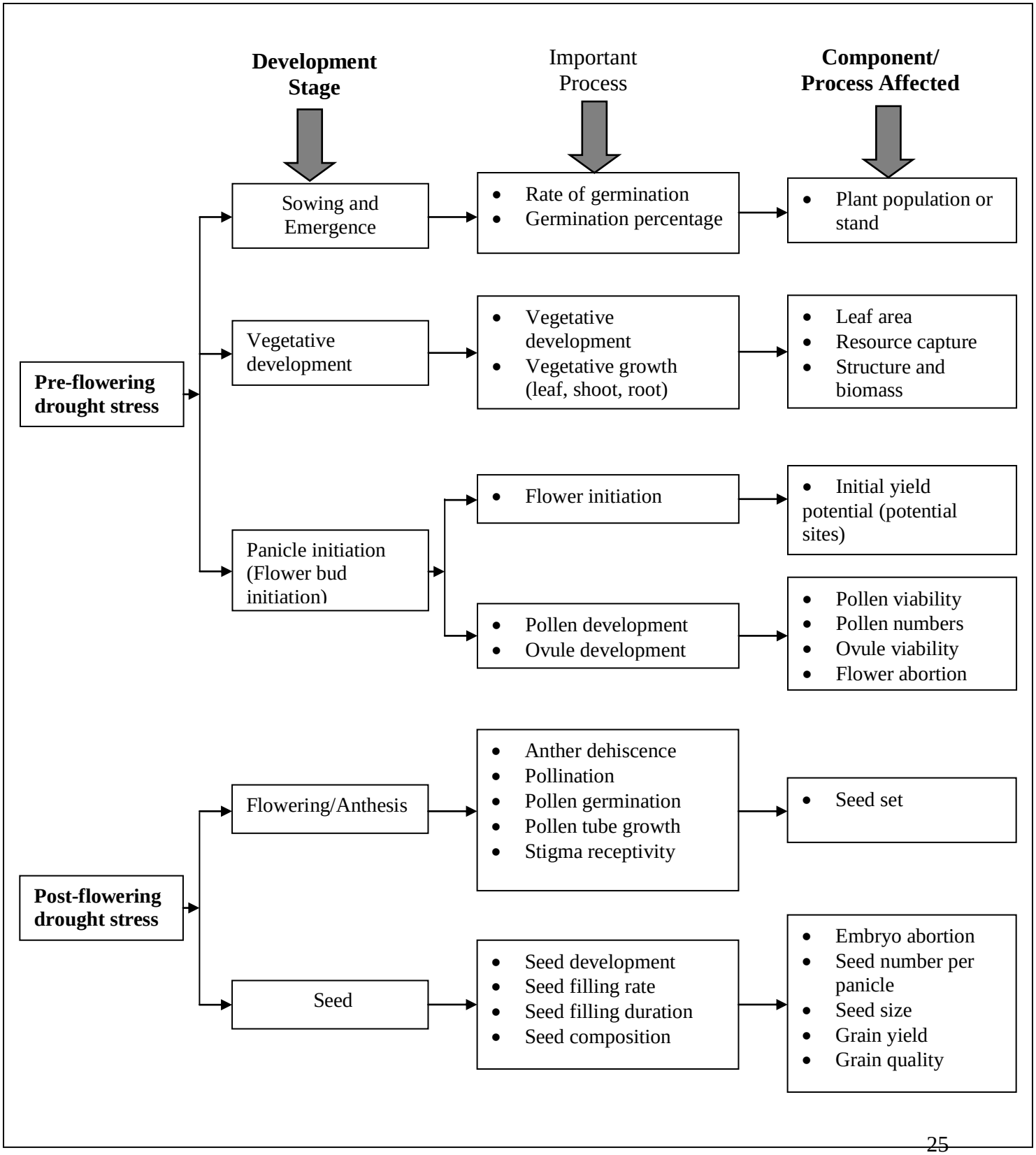
Source: History of cultivar development in the United States. From *"Memoirs of A.B. Maunder – Sorghum Breeder"*

Figure 2.1: The concept of drought at different levels.



Adapted from: National drought mitigation center; University of Nebraska.

Figure 2.2: Types of drought stress as experienced in Kansas and the resulting impact on sorghum growth development and yield.



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CHAPTER 3 - Identifying the Most Sensitive Stage to Short Episodes of Drought stress During Reproductive Phase in Grain Sorghum.

3.0 Abstract

Sorghum (*Sorghum bicolor* L. Moench) is a cereal grown throughout the semiarid regions of the world and therefore exposed to drought stress during growth and development and often in its reproductive phase. The objectives of this study were to (i) identify the most sensitive stage to drought stress during reproductive development, and (ii) quantify the impact of drought on physiological and yield traits of grain sorghum. Sorghum cultivar DK28E was grown in controlled environments. Plants were fully irrigated from sowing to boot leaf appearance and thereafter exposed to drought by withdrawing water for 11 - 15 days at different stages of crop development, and then again fully irrigated until maturity. Plants were drought stressed from panicle initiation to panicle exertion (10 days before flowering – DBF[1]), flowering to seed set (flowering – Fl), seed set to mid seed fill (15 days after flowering – DAF), mid seed fill to late seed fill (30 DAF) and late seed fill to seed maturity (45 DAF). A set of plants that were used as a control were fully irrigated. Plants that were stressed at 10 DBF (panicle initiation to panicle exertion) recorded the highest number of unfilled sites as compared to the control and plants that were stressed at 15 DAF (seed set to mid seed fill) had the lowest number of unfilled sites. Percent seed set was lowest for plants that were stressed at 10 DBF (panicle initiation to panicle exertion). A reduction in grain dry weight was significant for plants that were stressed at flowering and plants that were stressed at 30 and 45 DAF.

[1] Abbreviations: DBF – Days before flowering, DAF – Days after flowering, Fl – Flowering.

3.1 Introduction

Drought, high or cool temperatures, and high salinity are major environmental factors limiting plant growth and crop productivity. In efforts geared towards feeding the ever-increasing world population, all agricultural research advances have to contend with these adverse environmental factors. The impacts of drought stress on crop growth, development and yield depends on the severity, duration and frequency of the stress as well as the developmental stage of the crop at which it experiences the stress.

Drought stress probably ranks as the most important environmental factor limiting global crop productivity (Fischer and Turner, 1978; Boyer, 1982). In many crops, particularly cereals, the reproductive development phase is the most drought-stress-sensitive after seed germination and seedling establishment has been accomplished (Salter and Goode, 1967). In many cases, reproductive development coincides with high probability of drought where transpiration rates are high and the soil moisture level is low. Drought stresses interfer with the reproductive success of plants by affecting the development of the male gametophyte and sometimes the female gametophyte hence preventing fertilization and/or inducing premature abortion of the fertilized ovule (Moss and Downey, 1971; O'Toole and Moya, 1981; Saini and Aspinall, 1981; O'Toole and Namuco, 1983; Westgate and Boyer, 1986; Sheoran and Saini, 1996).

During seedling and vegetative growth stages, plants tends to be more tolerant to drought stress than during the reproductive stages with the most sensitive being panicle development and flowering stages in cereals. O'Toole (1982) showed that in rice, drought stress during flowering caused the highest reduction in yield when compared to other stages of development. The same has been demonstrated for corn (Claasen and Shaw, 1970). One of the reasons that can explain this sensitivity to drought stress during reproductive processes is that vegetative processes such as photosynthesis can acclimate to stress through the production of osmolytes and heat shock

proteins as well as regulation of growth. Reproductive organs and mainly pollen and stigma do not have the ability to produce these heat shock proteins or osmolytes that can be used for protection or acclimation. Sorghum grown in semi-arid to arid regions of the world is often exposed to drought stress during reproductive development and this leads to yield losses. Even though sorghum is relatively drought tolerant as compared to other crops, there is potential for improvement. An understanding of the most sensitive stages to drought stress during the reproductive phase will provide useful information that can be used in developing cultivars and strategies for addressing abiotic stress tolerance in sorghum. The objectives of this study were to (i) identify the most sensitive stage to drought stress during reproductive development; and (ii) quantify the impact of drought on phenology, physiological (chlorophyll fluorescence, chlorophyll content, leaf temperature and stomatal conductance) and yield traits (percent seed-set, seed numbers, seed-size and seed weight) of grain sorghum.

3.2 Materials and Methods

3.2.1 Crop Husbandry

This experiment was conducted in greenhouses at the Department of Agronomy, Kansas State University, in the summer of 2006. Sorghum hybrid DK28E was grown in pots (30 cm top diameter, 26 cm bottom diameter and 25 cm deep). The pots were filled with SunGro Metro Mix 300 series (Sungro Horticultural Distribution Inc., Bellevue, Washington) and 10g of Osmocote Plus, 15-9-12 (N-P_2O_5-K_2O) a controlled release fertilizer (Scotts-Sierra Horticultural Products Company, Maryville, Ohio) was applied. The pots were fully soaked with water and left for one day to drain and then three seeds were sown per pot and later thinned to two plants. Temperature in the greenhouse was kept at about 32/22°C (day/night). Red spider mites (*Tetranychus urticae*)

were controlled using Marathon 1% granular (active ingredient: Imidacloprid, 1-[(6-chloro-3-pyridinyl) methyl]-N-nitro-2-imidazolidinimine). This was applied when the plants were at two leaf stage at a rate of 2g per pot. There were three replications under fully irrigated conditions from sowing to appearance of boot leaf. Thereafter, plants were exposed to drought by stopping irrigation for about 11 - 15 days and then the plants were completed irrigated until maturity. There were five drought stress treatments: 37 days after planting (DAP) when the plants were at boot leaf until panicle emergence (10 days before flowering – DBF), 48 DAP when the plants were at panicle emergence until seed set (Flowering – Fl), 61 DAP when the plants were at seed set to mid-seed fill (15 DAF), 71 DAP when the plants were at mid-seed filling to late seed fill (30 days after flowering – DAF), late seed fill to maturity (45 DAF), and a control. The schedule of treatments is given in Table 3.1. Three plants were tagged in each replication for each treatment and data was collected from these tagged plants.

3.2.2. Data Collection

Data on phenology (time to boot leaf emergence, flowering and physiological maturity) was noted on tagged plants. Physiological traits for which data was collected during each drought stress treatment included leaf temperature which was measured using an infrared temperature gun (OS534 handheld infrared thermometer, Omega Engineering, Inc., Stamford, Connecticut, USA), stomatal conductance using a leaf porometer (SC-1 Leaf porometer, Decagon Devices, Inc. Pullman, WA, USA), chlorophyll *a* fluorescence (using a chlorophyll fluorometer, OS 30, Opti-Science, Hudson, NH, USA), and chlorophyll content (SPAD, Model 502, Spectrum Technologies, Plainfield, IL, USA). Measurements were taken from the top most fully expanded leaf. Chlorophyll *a* fluorescence measurements were taken on leaf spots that had

been darkened for about 30 minutes using clips and the variable fluorescence was determined. At maturity plant height was measured from tagged plants and the plants were harvested and oven dried at 60°C, dry weights of leaf and stem was collected. The panicles were oven dried at 40°C then the unfilled reproductive sites. Thereafter, the panicles were hand threshed to obtain the seed numbers (filled sites), seed weights and seed-size. Hand threshing was used to ensure the there was no loss of seeds.

3.2.3. Data Analysis

The experiment design was a randomized complete block design with three replications. Data was analyzed using PROC GLM in SAS (SAS 2003) with treatment and replications as the class variables and the response variables were the traits on which data was collected. Means and standard errors were computed for all samples taken for each treatment and the respective LSDs were calculated. P-values were determined for each trait and significance levels were determined based on these values. Based on the means, the percent change in each trait as compared to the control was determined. Results are provided for those traits or components that were statistically significant.

3.3. Results

3.3.1 Phenology

The treatments did not have any effects on time to boot leaf, panicle exertion dates and time to flowering as plants were subjected to stress when vegetative growth and development was almost complete.

3.3.2 Physiological Traits

There was no significant difference in chlorophyll fluorescence values among the treatments but chlorophyll content and leaf temperature were highly significant ($P<0.0001$) as well as stomatal conductance (Table 3.2 and Figures 3.1 and 3.2). It should be noted that data for chlorophyll content did not include plants stressed at 45 DAF (Figure 3.2 A) while leaf temperature and stomatal conductance did not include plants stressed at 30 DAF and 45 DAF (Figure 3.2 B&C).

3.3.3 Yield Traits

From Figure 3.3 and Table 3.3, filled sites were significantly reduced for plants that were stressed at the time of flowering (20%), 30 DAF (26%) and highest reduction was 28% on plants that were stressed at 45 DAF. Plants that were stressed at 10 DAF recorded the highest number of unfilled sites (140) as compared to the control and plants that were stressed at 15 days after flowering had the fewest number of unfilled sites (48) (Figure 3.3 and Table 3.3).

Percent seed set was lowest, 65% - a reduction of 10% as compared to the controls, for plants that were stressed at 10 DBF (Figure 3.3 and Table 3.3). The other treatments (Flowering, 15, 30 and 45 DAF) did not show much difference in percent seed set (71, 76, 70 and 72% respectively) (Figure 3.4A. A reduction in grain dry weight was observed and was significant for plants that were stressed at flowering, a reduction of 17%, plants that were stressed at 30 and 45 DAF – reductions of 21% and 20%, respectively (Table 3.3 and Figure 3.4B).

3.3.4 Correlations

There was a positive significant (P-values: plant height – 0.0178, stem and leaf dry weight – 0.0014) correlation between dry grain weight per panicle and plant height as well as

stem and leaves dry weight – Figure 3.5 A & B. But this correlation was higher for stem and leaves dry weight (r = 0.888) as compared to plant height (r = 0.505). Shorter plants recorded lower grain weights as compared to taller plants even though this variation in plant height was not significant when comparing the different treatments. Plants that had higher stem and leaves dry weight recorded higher grain weight than those with lower stem and leaves dry weight (Figure 3.5A&B). Even though light adapted chlorophyll fluorescence was statistically significant across the treatments it did not seem to have a significant correlation (P-values: Dark adapted F_v/F_m – 0.5403 and Light adapted F_v/F_m – 0.6898) to grain weight (r = 0.056) as shown in Figure 3.6A. On the other hand there was a positive correlation between dark adapted chlorophyll fluorescence and grain yield (r = 0.404) (Figure 3.6 B).

3.4 Discussion

3.4.1 Phenology and Physiological Traits

There were no significant differences in the time of flowering or plant height. Chlorophyll fluorescence did not change significantly but there were significant differences in leaf temperature, stomatal conductance and chlorophyll content. Plants stressed at 10 DBF and at flowering showed decreased temperature which corresponded to an increase in stomatal conductance. This could have been caused by the plants increasing stomatal opening in an attempt to cool the leaves resulting in more water lost through transpiration. A reduction in stomatal opening during water stress reduces the amount of water that the plant is using to cool the leaves and will result in increased leaf temperature. This may lead to a reduction in yields as the amount of carbon dioxide going into the plant will be reduced. A decline in chlorophyll content in stressed plants could be attributed to the inability of the plants to take up adequate

nutrients from the soil due to limited soil moisture and therefore a depletion of the available photosynthates in the leaves, mainly nitrogen, which led to the decline in chlorophyll content. This could also be attributed to the degradation of chlorophyll and pigment-binding thylakoid proteins in senescing leaves (Thomas 1982, 1987; Davies et al., 1990; Thomas et al., 1999)

3.4.2 Panicle Initiation

This study has shown that there was higher number of unfilled sites on plants that were drought stressed during this period (Figure 3.3 and Table 3.3). Panicle initiation is characterized by the appearance of protrusions that look like raised bumps on the surface of the plant's growing point about 30 to 35 days after emergence. It is the stage in reproductive development when the maximum number of seed per plant is set and therefore the most critical period for grain production, because seed number per plant accounts for 70% of sorghum's final grain yield (Gerik et al., 2003). Drought stress during this period causes serious yield reductions in many cereals and dicot crops (Wells and Dubetz, 1966; Salter and Goode, 1967; Dubetz and Bole, 1973; O'Toole and Moya, 1981; Mahalakshmi et al., 1987; Craufurd et al., 1993; Turner, 1993; Westgate and Peterson, 1993). This also affected seed set and a reduction of 10% was noted in the experiment (Table 3.3 and Figure 3.4A). According to Saini (1997) two peaks of sensitivity are encountered within this period: the first, which appears to be common to most cereals, is centered on the period from meiosis to tetrad break-up in anthers. This has been demonstrated in wheat and rice (Bingham, 1966; Saini and Aspinall, 1981; Namuco and O'Toole, 1986; Dembinska et al., 1992; Sheoran and Saini, 1996) and probably is the same in barley, oats and maize (Salter and Goode, 1967; Downey, 1969; Moss and Downey, 1971). The other centers on the female tissue, a period that corresponds to meiosis in the megaspore mother cell and the subsequent degeneration of three redundant megaspores in the tetrad (Bennett et al., 1973).

Abortion of the developing female structure may occur at this time as the plant experiences shortage in water and other nutrients with results being structures that could have contained seeds will be empty and hence the high numbers of unfilled sites.

3.4.3 Anthesis and Seed set

This study demonstrated that there was a 20% reduction in filled sites which resulted in 17% reduction in grain weight when compared to the control plants (Table 3.3). This concurs with Saini (1997) in that it coincides with the second peak of sensitivity which occurs during anthesis and initial stages of grain development, and is conspicuous in rice, maize and some dicots (Claassen and Shaw, 1970; Hsiao, 1982; O'Toole and Namuco, 1983; Schoper et al., 1986; Westgate and Boyer, 1986; Ekanayake et al., 1989; Ekanayake et al., 1990; Turner, 1993; Westgate and Peterson, 1993). A reduction in filled sites was a consequence of fewer pollen grains and poor pollen viability (Prasad et al., 1999) which resulted in poor fertilization and hence no seeds.

3.4.4 Seed Filling and Maturity

Results from this study have further showed a reduction in grain weight for plants that were stressed at 15 and 30 DAF (Figure 3.4B and Table 3.3). Kernel size and weight depend on the plant's ability to accumulate dry matter during the seed filling stage and therefore weather, soil fertility and available soil water influence final size and weight of kernels. Eighty-five percent of the dry matter produced by the plant during this stage goes directly to grain and therefore only fifteen percent of final grain weight originates from dry matter produced during early vegetative growth stages. Ahmadi et al. (2001) demonstrated that drought stress caused premature grain desiccation resulting in a marked decline in grain sucrose and reduced grain

weight in wheat. Therefore, even though the potential seed numbers are set at an early stage, stress during the seed filling stage will result to the plant putting in available reserves to some of the seeds and others will be aborted. From seed filling through to maturity, the plant depends on the translocation of photosynthates and carbohydrate reserves from the leaves and stem to the grains. Stress during any of these stages will results in seeds that are not fully filled and hence shriveled, light, chaffy grain. This was demonstrated in the experiment as there was significant difference in grain weight for plants that were stressed at 30 DAF and 45 DAF when compared to the controls (Figure 3.4B and Table 3.3).

3.4.5 Correlations

Results from this study showed a positive correlation between dark adapted chlorophyll fluorescence and grain weight (Figure 3.6B). Zrust et al. (1994) showed that a decreasing value of F_v (variable chlorophyll fluorescence) was an indication of diminishing plant photosynthetic activity. This decline will result in a decline in the amount of photosynthates available for the plant and therefore a reduction in grain weight due to inadequate reserves that can be mobilized during the grain filling and maturity stages.

3.5 Conclusions

We conclude that grain sorghum the most sensitive to drought stress during panicle initiation – before flowering. Stress at pre-flowering and flowering period will result in poor seed set and hence lower seed numbers and therefore lower yields. Stress during post-flowering stage will affect filling rate and duration and result in a significant reduction in grain weight because of small seed size.

3.6 Tables and Figures

Table 3.1:Schedule of drought stress treatments

Treatment	Date: Started - End	No. of days	Days after planting*	Development Stage
Control	Fully irrigated			
1	Jul. 23 – Aug. 2	11	37	Panicle initiation – panicle exertion
2	Aug. 3 - 15	13	48	Flowering to seed set
3	Aug. 16 - 25	10	61	Seed set to mid seed fill
4	Aug. 26 – Sept. 12	17	71	Mid seed fill to late seed fill
5	Sept. 13 – Sept. 26	15	88	Late seed fill to maturity

* Date of planting: June 16, 2006. Duration of treatment: 13 days of drought on average

Table 3.2: Data on physiological traits – chlorophyll fluorescence, chlorophyll content and leaf temperature.

	Chlorophyll fluorescence			Chlorophyll content	Leaf temperature (°C)	Stomatal conductance (mmol/m^2/s)
Treatment	**F_o**	**F_m**	**F_v/F_m**			
Control	184.2±2.48	542.6±9.43	0.657±0.007	62.03±0.67	39.8±0.46	62.61±6.45
10 DBF	182.1±2.48	560.4±9.43	0.673±0.007	60.94±0.67	34.2±0.46	64.00±6.45
Flowering - Fl	179.4±2.48	566.6±9.43	0.682±0.007	58.12±0.67	32.2±0.46	80.36±9.13
15 DAF	184.9±2.48	565.2±9.43	0.672±0.007	58.49±0.67	32.0±0.46	30.68±9.13
30 DAF	175.1±4.02	531.0±13.33	0.669±0.009	62.06±0.95	.	.
45 DAF	169.2±4.02	537.8±13.33	0.685±0.009	.	.	.
P-Value	NS	NS	NS	***	***	**
LSD @ 0.05	16.905	56.068	0.0396	3.201	2.064	37.436

****, ** significant at <0.0001 and <0.01 respectively; NS – not significant.

NB: Data on leaf temperature and stomatal conductance for treatment 4 and 5 (30 DAF and 45 DAF) and data on chlorophyll content for treatment 5 (45 DAF) is missing.

Figure 3.1: Effects of drought stress on Chlorophyll fluorescence: Chlorophyll fluorescence ratio (F_v/F_m), Minimal fluorescence (F_o) and maximum fluorescence (F_m).

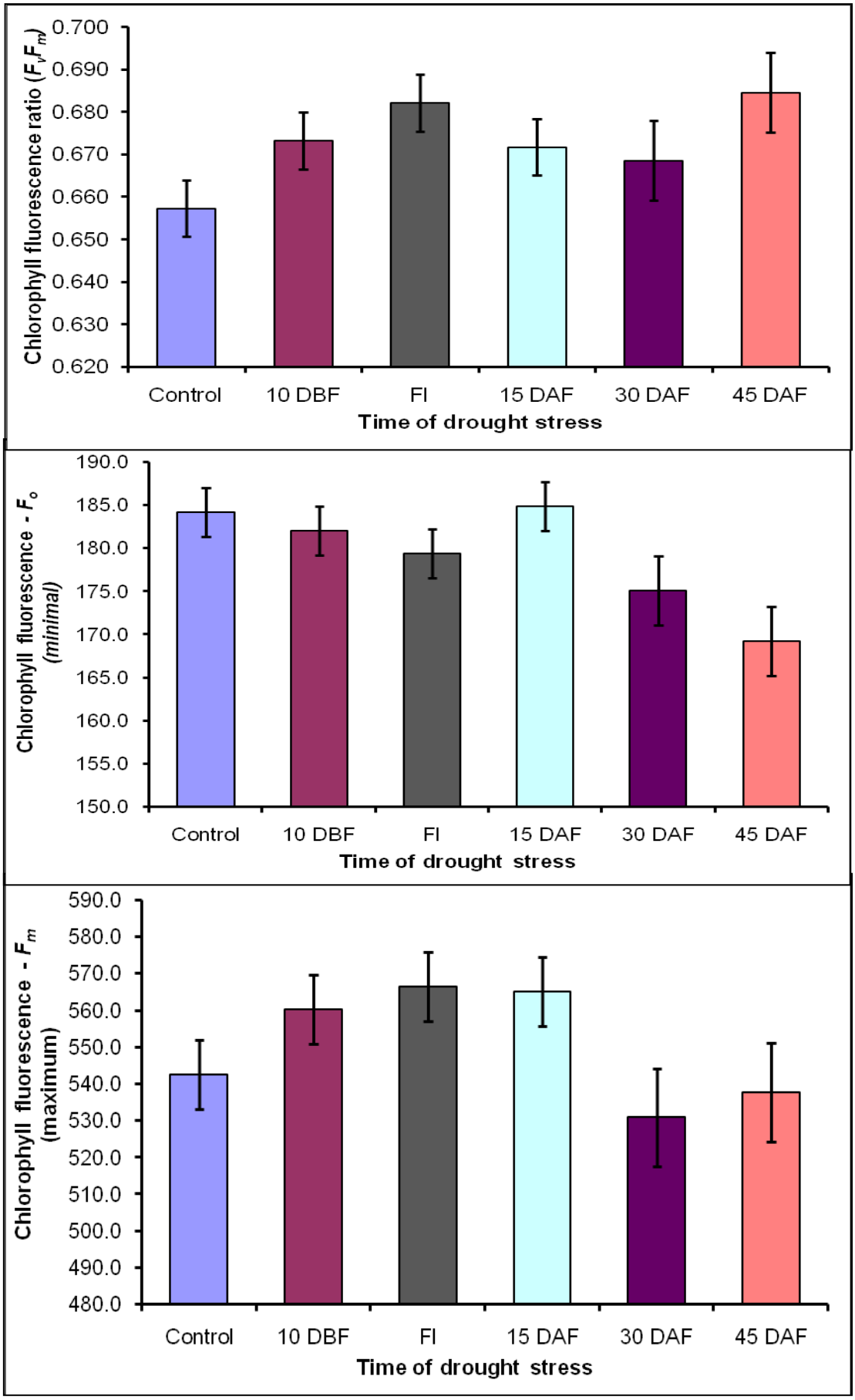


Figure 3.2: Effects of drought stress on Chlorophyll content, leaf temperature (°C) and stomatal conductance (mmol/m^2s).

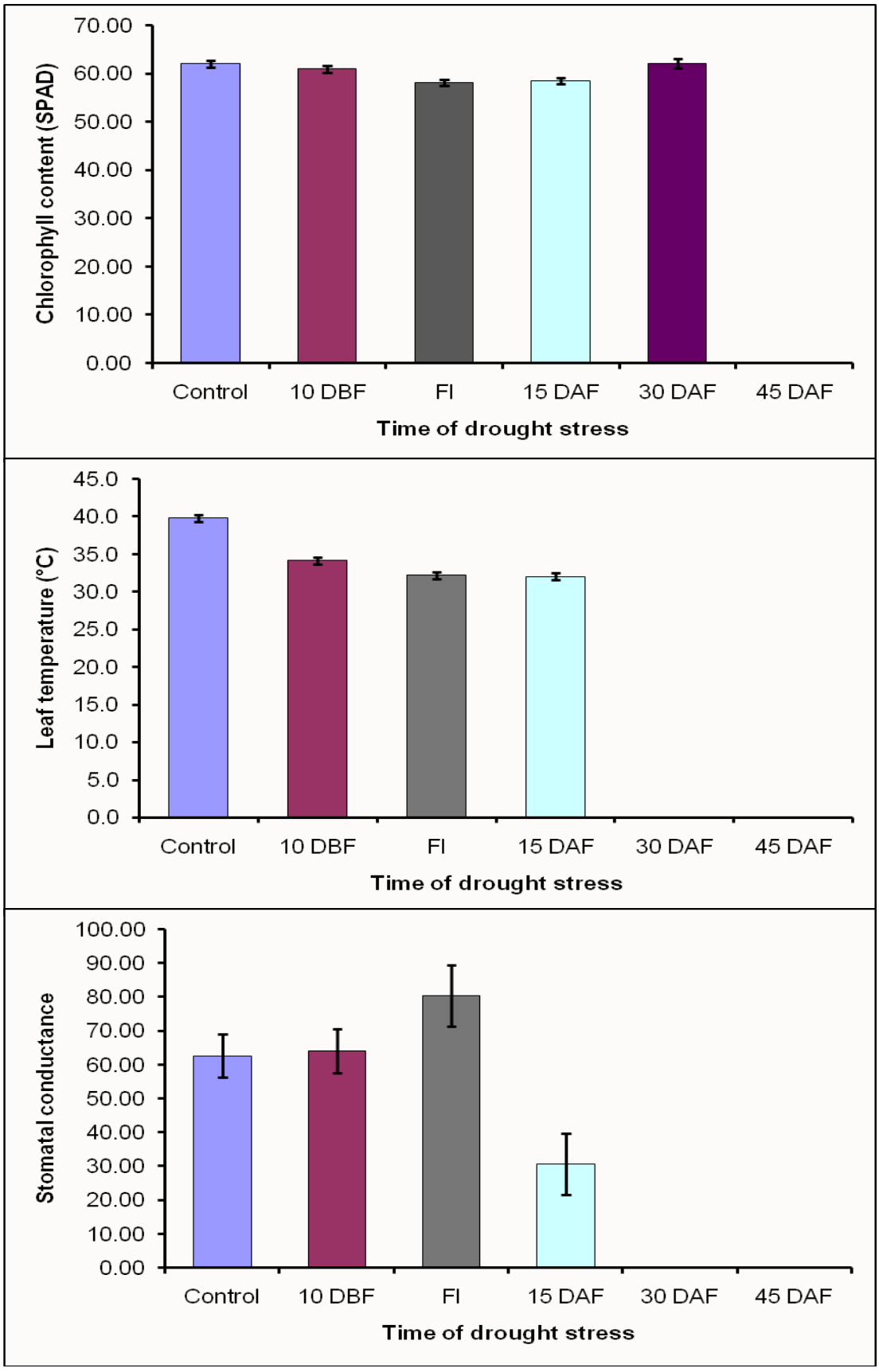


Table 3.3: Effects of Drought stress during reproductive phase. These are computed means plus or minus the standard error. LSD is at 0.05 and p-values are at a significance of 0.05.

Treat	Filled sites	%Δ	Unfilled sites	%Δ	%Seed set	%Δ	Grain weight	%Δ
Control	425.78±32.6		96.78±13.8		80.6±2.9		16.98±0.8	
10 DBF	386.22±32.6	-9.29	139.67±13.8	+44.32	72.5±2.9	-10.04	14.75±0.9	-13.12
Fl	338.89±32.6	-20.41	68.22±13.8	-29.51	82.9±2.9	+2.85	14.13±0.8	-16.75
15 DAF	365.00±34.6	-14.27	48.13±14.7	-50.27	83.5±3.0	+3.40	14.43±0.9	-15.04
30 DAF	314.33±32.6	-26.17	78.67±13.8	-18.71	81.0±2.9	+0.50	13.33±0.8	-21.47
45 DAF	309.75±37.0	-31.49	65.63±14.7	-32.19	83.3±3.3	+3.35	13.71±0.9	-19.23
LSD @ 0.05	96.0		39.4		8.6		2.3	
P-Value	*		**		*		*	

**, * Significantly significant at P ≤ 0.005 and 0.05 respectively.

Figure 3.3: Effects of drought stress on filled and unfilled reproductive sites per panicle for plants that were fully irrigated (control) and those that were stressed at 10 DBF, Flowering, 15, 30, and 45 DAF.

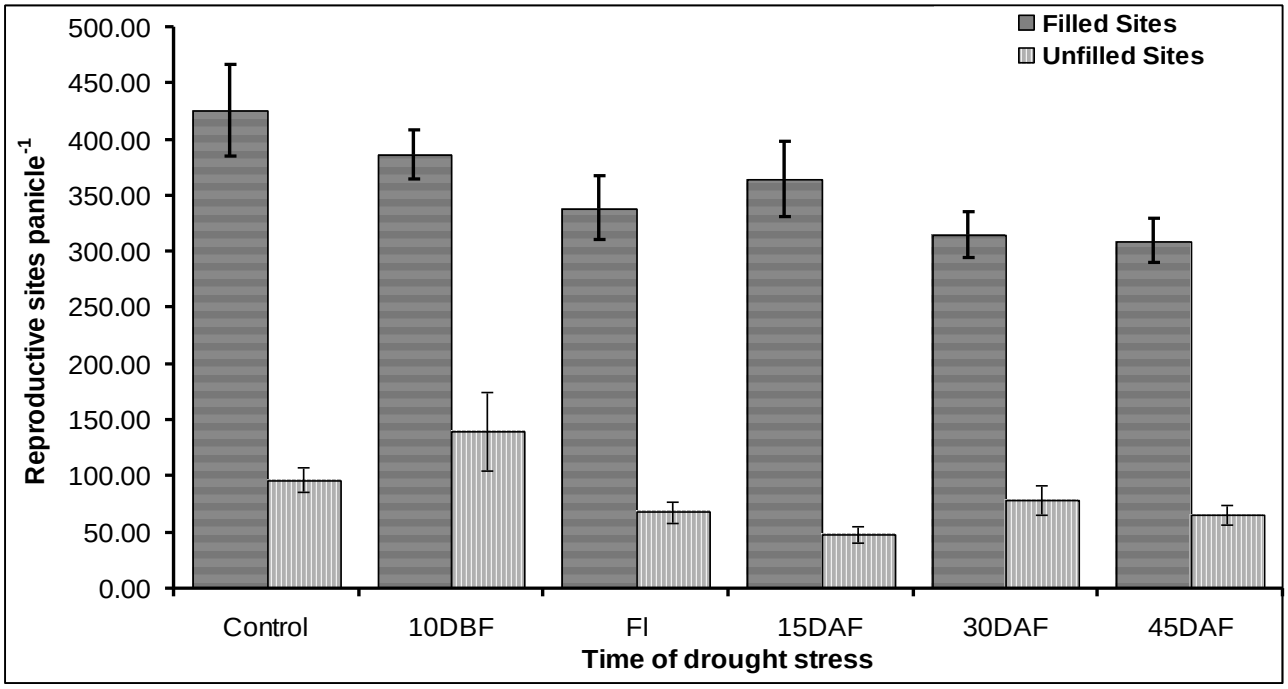


Figure 3.4: Effects of drought stress on seed set (%) and grain weight (g) per panicle for plants that were fully irrigated (control) and those that were stressed at 10 DBF, Flowering, 15, 30, and 45 DAF**.**

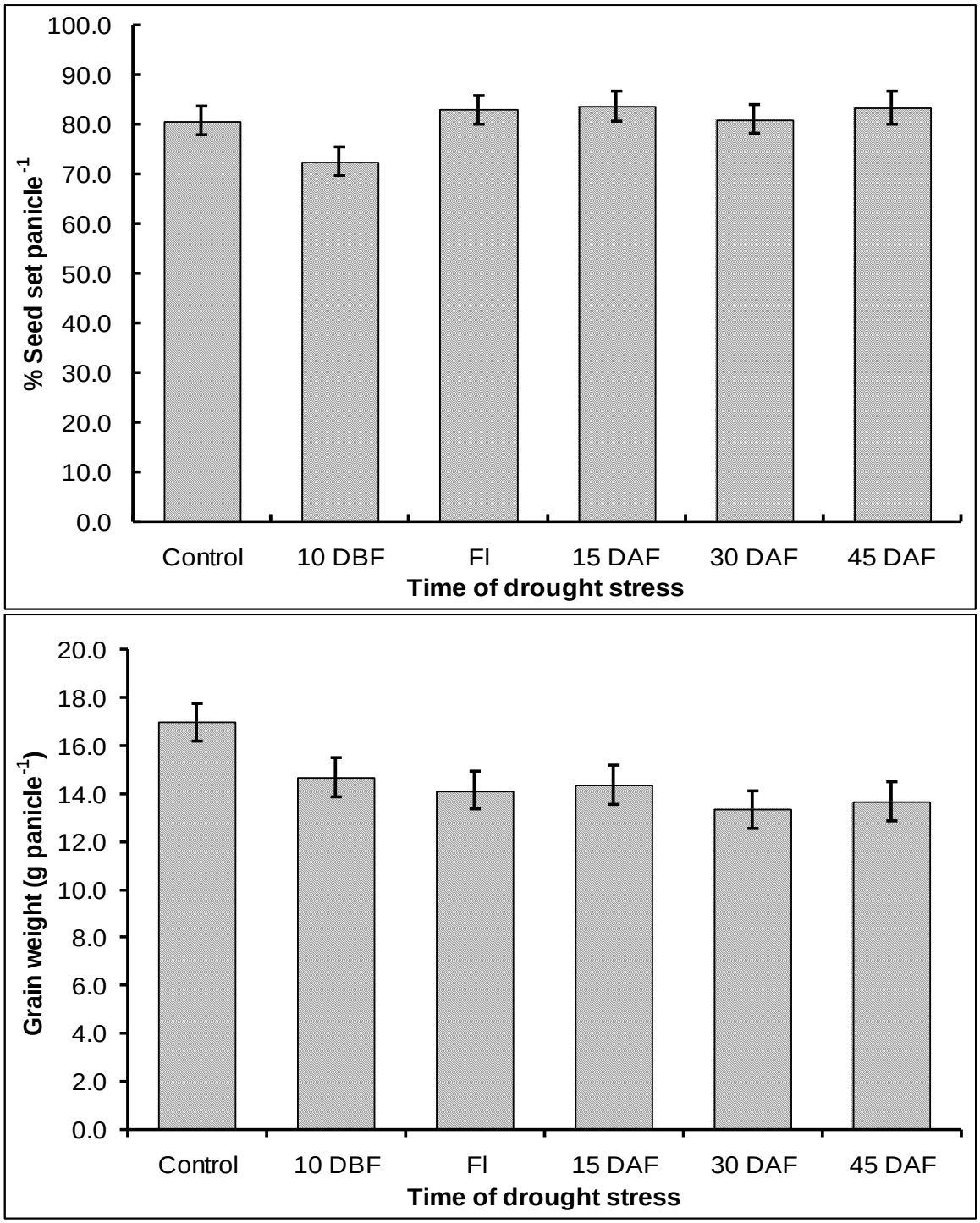
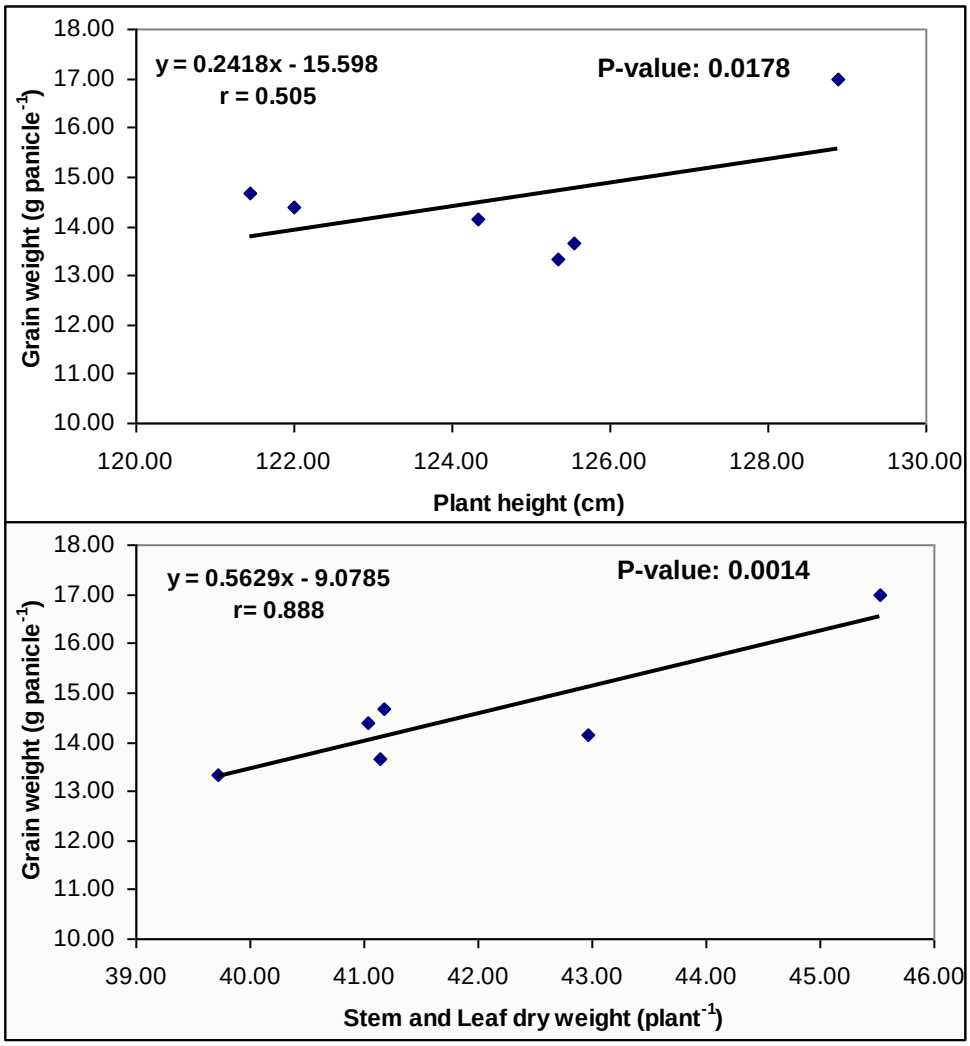


Figure 3.5: Correlation between grain weight (g/panicle), plant height (cm) and stem and leaves dry weight (g).

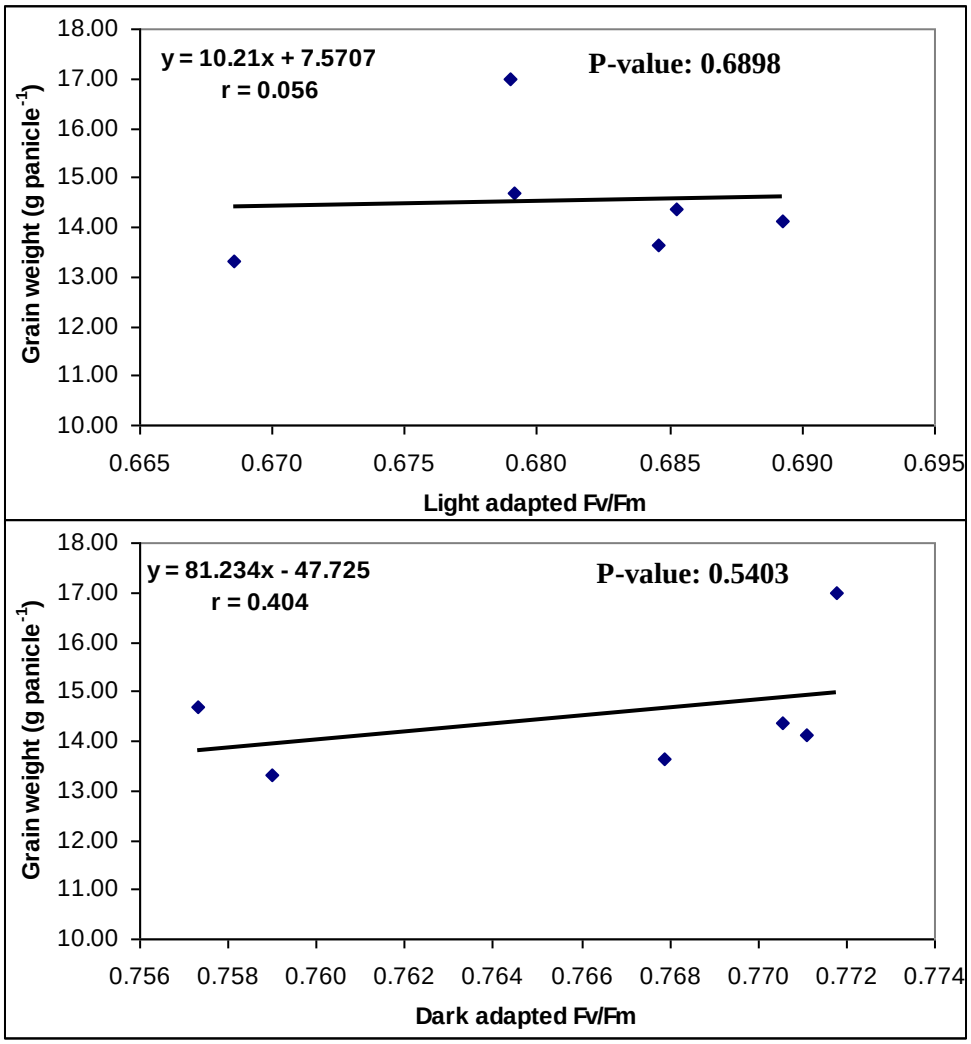


Correlation equations:

Plant height: Grain weight = 0.2418 * Plant height – 15.598, r = 0.505;

Stem and Leaves dry weight: Grain weight = 0.5629 * Stem and Leaf weight – 9.0785, r = 0.888

Figure 3.6: Correlation between Chlorophyll fluorescence and grain weight.



Correlation equation:-

Light adapted F_v/F_m: Grain weight = 10.21 * (Light adapted F_v/F_m) + 7.5707, r = 0.056

Dark adapted F_v/F_m: Grain weight = 81.23 * (Dark adapted F_v/F_m) – 47.725, r = 0.404

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CHAPTER 4 - Chlorophyll Fluorescence Assay as a Tool for Screening the Stay Green Trait in Sorghum

4.0 Feasibility of Using Chlorophyll Fluorescence Assay as a Tool for Screening the Stay Green Trait in Sorghum

4.1 Abstract

Chlorophyll fluorescence has been used as a screening tool for environmental stress tolerance in plant and to quantify the effect of environmental stress such as photoinhibition, chilling, freezing, heat stress, and nutrient deficiency on photosynthesis. The stay green trait in sorghum helps the plant maintain its chlorophyll for a longer period of time during maturity. Therefore it lengthens the seed filling duration as there is a constant supply of resources from the leaves resulting in higher yields. The objectives of this study were to test the feasibility of a cell viability assay based on chlorophyll fluorescence to estimate stay green in sorghum and determine whether stay green lines use their carbohydrates more efficiently than non stay green lines. Experiments were conducted in a greenhouse environment using ten lines with known contrasting stay green scores. The plants were fully irrigated and kept free of stress. At leaf 5, leaf samples were punched from the leaves and their initial chlorophyll fluorescence measured. Leaf punches were then subjected to high respiratory demand at 41^{o}C in an incubator and cell viability readings (chlorophyll fluorescence) were taken every 30 minutes for 7 hours. Leaf samples were also collected early in the morning and frozen in liquid nitrogen and then analysed for total carbohydrates in the stem, leaves and midrib. Results indicated that stay green genotypes lost their viability faster than non-stay green types as indicated by loss of chlorophyll fluorescence. The stay green genotypes also had lower glucose content in the leaves when compared to non-stay green ones. This suggests that the cell viability assay can be used as a

potential tool to identify stay green genotypes under green house conditions at early stages of crop development.

4.2 Introduction

Although cereal crops such as sorghum (*Sorghum bicolor* L. Moench) generally tolerate relatively higher temperatures, injury occurs when temperatures are too high, exceeding optimum temperature. High temperatures affect crop yield by altering radiation interception and use, carbohydrate partitioning, and yield attributes. Effects of heat stress include the denaturation of enzymes, alteration of membrane fluidity, unfolding of nucleic acids, and inhibition of electron transport (Quinn and Williams, 1985; Sayed et al., 1986, 1989a, b; McKersie and Leshem, 1994). High temperatures also enhance respiration to a rate exceeding that of photosynthesis causing depletion of carbohydrate reserves (Teiz and Zeiger, 1991). Bunce (2005) demonstrated that increases in temperature are known to increase plant tissue respiration, as exemplified by a study of soybean (*Glycine max*) leaves which showed that respiration increased by a factor of 2.5 between 18°C and 26°C average night temperatures.

Grain sorghum, like most plants, accumulates photosynthate in the source leaves during the daylight hours when photosynthesis is taking place and later mobilizes these reserves at night to the growing points or sinks of the plant (Warner and Burke, 1993). The stay green trait in sorghum helps the plant maintain its green pigment for a longer period of time during maturity and therefore lengthens the seed filling duration as there is a constant supply of resources from the leaves.

This study was designed to test the hypothesis that stay green lines have a different pattern of carbohydrate use than non-stay green lines. This difference would predispose the stay green genotype leaf tissue to succumb to high respiratory demand more rapidly than the non-stay green genotype source tissues that contained more photosynthates. When leaf samples are

collected in the morning and exposed to high respiratory demand, they loose their cell viability faster than non-stay green ones. The fluorescence yield gives an indication of the cell viability. Cultivars that loose viability faster may be indicative of stay-green trait.

The cell viability assay used in this study was developed by Burke et al. (2007). Initially, 2,3,5-triphenyltetrazolium chloride (TTC) reduction had been used as a viability assay for over 50 years (Bennett, 1949) and represents a simple means of assessing viability when dealing with large numbers of samples. Steponkus (1971) concluded that the TTC procedure gives a reasonably accurate estimate of viability for leaf discs, stem sections, and tissue cultures. Unfortunately, this procedure provides only a point-in-time measurement of cell viability (Burke 2007). If determining changes in the rate of tissue death is needed, then additional samples are required for each time measurements are desired. In an effort to avoid significant increases in the number of tissue samples needed to determine the rate of tissue death, a novel stress test was developed where repeated chlorophyll fluorescence yield (CFY) measurements of individual tissue samples provide provide a relative measure of the rate of tissue death during the dark incubation at elevated temperatures (Burke, 2007). Results from this procedure indicated that the CFY measurements were an excellent surrogate for the TTC reduction determinations. The objective of the study was to test the feasibility of cell viability assay based on chlorophyll fluorescence to determine stay green trait in sorghum genotypes at leaf 5-7 stage.

4.3 Materials and Methods

4.3.1 Crop husbandry

This experiment was conducted at the Department of Agronomy greenhouses at Kansas State University in the summer of 2006. Ten sorghum cultivars listed below were grown in controlled environment conditions (Experiment 1).

1. 00MN7645 – stay green (medium)
2. TX7078 – non stay green
3. TX2737 – non stay green
4. SC35 – stay green (high)
5. B35 – stay green (high)
6. SC599 – stay green (high)
7. QL41 – stay green (high)
8. TX3042 – non stay green
9. TX3042 x TX2737 – non stay green
10. TX3042 x 00MN7645 – stay green (medium)

The plants were grown on pots 30 cm top diameter, 26 cm bottom diameter and 25 cm deep. The pots were filled with SunGro Metro Mix 300 series (SunGro Horticultural Distribution Inc. Bellevue WA) and 10g of Osmocote Plus - 15-9-12 (N-P_2O_5-K_2O), a controlled release fertilizer (Scotts-Sierra Horticultural Products Company, Maryville, Ohio), was applied in each pot. All pots were soaked with water and then left standing for one day to allow for drainage. Seeds were then sown at three seeds per pot and later after germination thinned to two plants. Temperature in the greenhouse was kept at about 32/22°C (day/night) and humidity at 29%. Spider mites were controlled using Marathon 1% granular. Plants were fully irrigated and kept free from any stress.

In a second experiment (Experiment 2), cultivars TX7078, SC599, TX3042 and B35 were grown in two growth chambers at optimum temperature (32/22°C – day/night) and were fully irrigated till leaf 5. Other crop management practices were similar to those in experiment 1.

4.3.2 Data Collection

4.3.2.1 Experiment 1

At leaf 5, three leaf punches from the topmost fully extended leaf were collected from each cultivar at 6:30 AM and immersed in distilled water and carried to the laboratory for further analysis. In the laboratory, the leaf punches were placed on a moist filter paper placed on a glass

plate and then wrapped with transparent plastic glad–wrap. Initial chlorophyll fluorescence was measured using a fluorometer (OS 30P, OptiScience, Hudson, NH, US) and the trays were kept in an incubator at high temperature (42ºC) to expose the leaf punches to high respiratory demand. Chlorophyll fluorescence measurements taken included basal fluorescence (F_o) which is the fluorescence when primary quinone electron acceptors of PSII (Q_A) are maximally oxidized (PSII centers are open), maximum fluorescence (F_v); the level of fluorescence when Q_A is maximally reduced (PSII centers are closed), and the fluorescence ratio (F_v/F_m) which is the PSII operating efficiency. A detailed outline of these measurements is given on page 126-127 as an appendix. Measurements were taken every 30 minutes for a period of 7 hours.

4.3.2.2 Experiment 2

Tissue samples were taken at 8:30 AM from the fifth leaf (leaf blade and midrib) and stem. These samples were immediately frozen in liquid nitrogen and stored at -80°C. The leaf, midrib and stem samples were then taken out, thawed and a subsample of 2 grams was taken for further analysis. Total sugars were extracted from each subsample using 70% aqueous ethyl alcohol in a pestle and mortar. The extract was then centrifuged and a 2 ml aliquot was dried and resuspended in 2 ml of distilled water. A 0.1 ml aliquot of this solution was diluted with 0.9 ml of distilled water and then 3 ml of Dinitro-salicyclic acid (DNS) was added. This mixture was heated in a boiling water bath for 15 minutes and 1 ml of potassium tartrate solution added. The solution was allowed to cool and then readings were taken at 540 nm wavelength using a fluorescence spectrophotometer (FP-6200 Fluorescence Spectrometer, JASCO Inc. Easton, MD, U.S.A.). A blank containing distilled water mixed with DNS and Potassium tartrate solution was used to set a standard for the readings. The amount of glucose was calculated using the slope of a graph developed with glucose standards.

4.3.3 Data Analysis

The experiment was a randomized complete block design with each pot taken as a replication. There were four replications for each cultivar. All data were analyzed using PROC GLM procedures in Statistical Analysis System (SAS, 2003) software. The standard error and LSD values were calculated to compare variability and test for significance. Data analysis procedures were similar for both experiment 1 and 2.

4.4. Results

4.4.1 Cell Viability

There was significant decline in chlorophyll fluorescence ratio (F_v/F_m) under high respiratory demand (41°C) with time for all the genotypes (Table 4.1 and Figure 4.1). At 0.0 hours (initial fluorescence reading) there were no significant differences among genotypes with values ranging from 0.754 for B35 to 0.780 for Tx3042. At 6.0 hours chlorophyll fluorescence readings had declined and the lowest was 0.356 for SC599 (initial reading was 0.755) and the highest was 0.712 for Tx2737 (initial reading was 0.768). B35 and TX3042 readings were 0.550 and 0.704 respectively after 6 hours of high respiratory demand (Table: 4.1). The variation in chlorophyll fluorescence ratio (F_v/F_m) between genotypes increased significantly overtime with increased exposure to high respiratory demand (Table: 4.1). At 0.5 to 1 hour significant difference was at $P< 0.05$, at 1.5 – 2.5 hours this increased to $P< 0.001$, and at 3.0 – 6.5 hours chlorophyll fluorescence for the genotypes was significantly different at $P< 0.0001$.

The highest reduction in F_v/F_m was observed for SC599. Other genotypes that recorded large reductions in F_v/F_m ratio were QL41, B35 and TX3042x00MN7645. The other genotypes grouped themselves together as a group that did not record a high reduction in F_v/F_m (Figure 4.1 A). These results indicate that the separation of genotypes into two groups was noticeable after 2.0 hours of exposure to high respiratory demand. Minimal chlorophyll fluorescence (F_o)

remained fairly stable for all the lines (Figure 4.1 B). There was a slight increase between 0.0 – 1.5 hours for most of the genotypes and afterwards (2.0 – 6.5 hours) this stabilized and there was no further increase.

Minimum chlorophyll fluorescence for genotypes TX2737, SC35, B35 and 00MN7645 remained fairly stable even in the initial hours of high respiratory demand as opposed to the other genotypes (Figure 4.1 B). Maximal chlorophyll fluorescence (F_m) decreased with time (Figure 4.1 C) for all the genotypes. The highest decline was observed in SC599, QL41, and TX3042 x 00MN7645.

Chlorophyll fluorescence reduction was greatest in genotypes SC599, QL41 and B35 which recorded a reduction of 54.7%, 40.8% and 27.1% respectively (Figure 4.2 and Table 4.2). TX2737, TX3042, TX7078, SC35, TX3042 x TX2737 and 00MN7645 recorded the lowest reductions in chlorophyll fluorescence ratio Fv/Fm; 7.9%, 8.2%, 9.8%, 11.2%, 11.2% and 12.2% respectively. TX3042x00MN7645 was average with a reduction of 21.6%.

4.4.2 Carbohydrate Analysis

Stem, midrib and leaf blade samples taken in the morning were analysed for glucose content to determine if there were any differential levels of carbohydrates between the genotypes. Results from this analysis showed significant differences in glucose content in the leaf blade samples between the stay green (SC599 and B35) and non-stay green (TX3042 and TX7078) genotypes (Table 4.3 and Figure 4.3). Amount of glucose ranged from 1.19 – 1.30 mg ml^{-1} in the stems samples, 1.20 – 1.30 mg ml^{-1} in the midrib samples and 1.16 – 1.29 mg ml^{-1} in the leaf blade samples (Table 4.3). B35 had the highest amount of glucose in the midrib as compared to the other genotypes (Figure 4.3). TX3042 and TX7078 both are non-stay green and they had higher glucose amounts in the leaf blades than the stay green genotypes (B35 and

SC599). SC599 had the lowest amounts of glucose in the leaf blades when compared to all the other genotypes – 1.20 mg ml^{-1} (Figure 4.3 and Table 4.3).

4.5. Discussion

4.5.1 Cell Viability

Throughout the day as much as one-half of the carbon assimilated by photosynthesis is stored in the chloroplast as starch. At night, this transitory starch is degraded and the products of this degradation exported to the cytosol where they are converted to sucrose and exported from the leaf (Geiger and Batey, 1967). Increases in temperature are known to increase plant tissue respiration. A study of soybean (*Glycine max*) leaves demonstrated that respiration increased by a factor of 2.5 between 18°C and 26°C average night temperatures (Bunce, 2005). The research described in this study evaluated the ability of source leaf tissues harvested at sunrise from stay green and non-stay green sorghum genotypes to withstand prolonged respiratory demands before experiencing complete tissue death.

Of the 10 genotypes that were used in this experiment, SC599, B35 and QL41 are known stay green lines while TX7078, TX3042 and TX2737 are known senescing (non-stay green) lines. The results indicated that there was a clear separation based on chlorophyll fluorescence ratio F_v/F_m in the lines that are known stay green and those that are not. With increasing levels of stress, the increases in non-photochemical quenching can be insufficient to maintain the PSII electron acceptors partially oxidized and this will result in photo-damage to PSII unless alternative electron acceptors, such as oxygen, are used (Ort and Baker, 2002). Studies by Smillie et al (1979) and Havaux (1993) demonstrated that high temperature stress will lead to the inactivation of PSII and thylakoid disorganization and a sharp rise in F_o is a function of temperature that indicates the critical temperature for PSII inactivation. Both the rise in F_o and a

decrease in F_v/F_m have been used to determine differences in the response of potato cultivars (Havaux, 1995) and species of birch (Ranney and Peet, 1994) to high temperatures.

From the results in this experiment it can be concluded that sorghum lines that are stay green will lose their cell viability faster under high temperatures, which result in high respiration demand, than lines that are not stay green.

4.5.2 Carbohydrate Contents

Results from this experiment showed that leaves from non-stay green genotypes (TX3042 and TX7078) had higher amounts of glucose in the morning than stay green genotypes (SC599 and B35), an indication that the stay green lines transport carbohydrates from the leaves and utilize them more efficiently leaving its reserves low at the end of the night. Stay green lines are also known to have more carbohydrates in the stem as reserves that are later translocated and used during the grain filling stage. This is, therefore, one of the reasons why leaf punches from stay green lines lost their viability faster when exposed to high respiratory rates because stay green lines are known to mobilize a lot of the carbohydrates synthesized in the leaves and therefore carbohydrate reserves in the leaves may be lower as compared to non stay green lines in the morning.

Glucose content in the stem samples was not significantly different but in the midribs B35 had higher quantities that the rest.

4.6 Conclusion

This preliminary study showed that stay green genotypes had lower glucose levels in their leaves in the morning and hence an indication of higher mobilization of carbohydrates. Therefore, the stay green lines lose their cell viability faster than non stay green lines when subjected to high respiratory demand. This can be detected by measuring chlorophyll fluorescence yield from leaf punches taken in the morning and kept at 41°C for 3 – 7 hours. It is

therefore feasible to screen for stay green lines in sorghum using a chlorophyll fluorescence assay at an early growth stage (leaf 5-6).

4.7 Tables and Figures

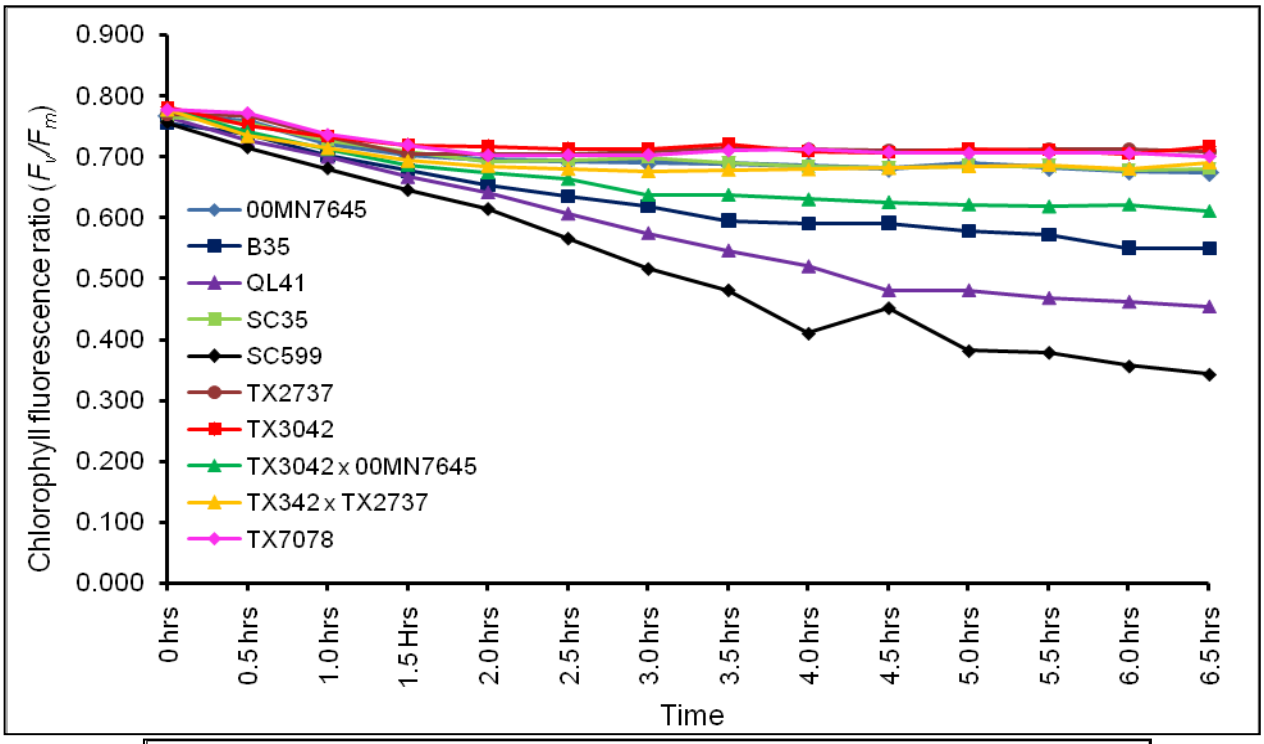
Table 4.1: Effects of incubation temperature (41°C) on chlorophyll fluorescence ratio (F_v/F_m) ratio of grain sorghum leaf punches at leaf 5-7 stage in growth. The values given below include the means, Standard Error (±SE) and LSDs at 0.05 significance level. Significance level is determined using P-values from ANOVA tables.

	Chlorophyll fluorescence ratio (Fv/Fm) change with time (hours)													
Genotype	0.0	0.5	1.0	1.5	2.0	2.5	3 .0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
00MN7645	0.767	0.756	0.721	0.702	0.694	0.692	0.689	0.688	0.684	0.680	0.688	0.682	0.676	0.673
B35	0.754	0.736	0.702	0.676	0.652	0.635	0.618	0.595	0.590	0.591	0.578	0.572	0.550	0.550
QL41	0.764	0.727	0.699	0.666	0.641	0.606	0.574	0.545	0.519	0.480	0.480	0.467	0.461	0.453
SC35	0.765	0.754	0.727	0.708	0.693	0.695	0.699	0.690	0.683	0.681	0.685	0.684	0.678	0.679
SC599	0.755	0.714	0.680	0.644	0.613	0.565	0.515	0.480	0.410	0.451	0.381	0.378	0.356	0.343
TX2737	0.768	0.766	0.732	0.704	0.704	0.705	0.709	0.715	0.712	0.710	0.710	0.712	0.712	0.708
TX3042	0.780	0.751	0.733	0.719	0.717	0.713	0.712	0.720	0.709	0.707	0.712	0.710	0.704	0.716
TX3042 x 00MN7645	0.777	0.741	0.712	0.686	0.673	0.663	0.636	0.637	0.629	0.624	0.620	0.617	0.621	0.610
TX342 x TX2737	0.777	0.733	0.714	0.693	0.684	0.679	0.675	0.678	0.679	0.681	0.684	0.687	0.680	0.690
TX7078	0.777	0.771	0.736	0.719	0.702	0.703	0.703	0.710	0.713	0.707	0.706	0.706	0.706	0.701
Significance Level	NS	*	*	**	**	**	***	***	***	***	***	***	***	***
SE	0.007	0.011	0.010	0.011	0.016	0.023	0.029	0.034	0.038	0.044	0.045	0.046	0.047	0.050
LSD	0.020	0.031	0.028	0.032	0.05	0.065	0.083	0.097	0.108	0.126	0.127	0.130	0.133	0.143

Significance level: NS – Not Significant, *, **, *** - Significant at $P < 0.05$, $P < 0.001$,

$P < 0.0001$ respectively.

Figure 4.1: Variation among sorghum lines in cell viability characteristics based on changes in (A) chlorophyll fluorescence ratio (F_v/F_m), (B) minimal fluorescence (F_o), and (C) maximal fluorescence (F_m) of grain sorghum leaf punches at leaf 5 – 7 stage.



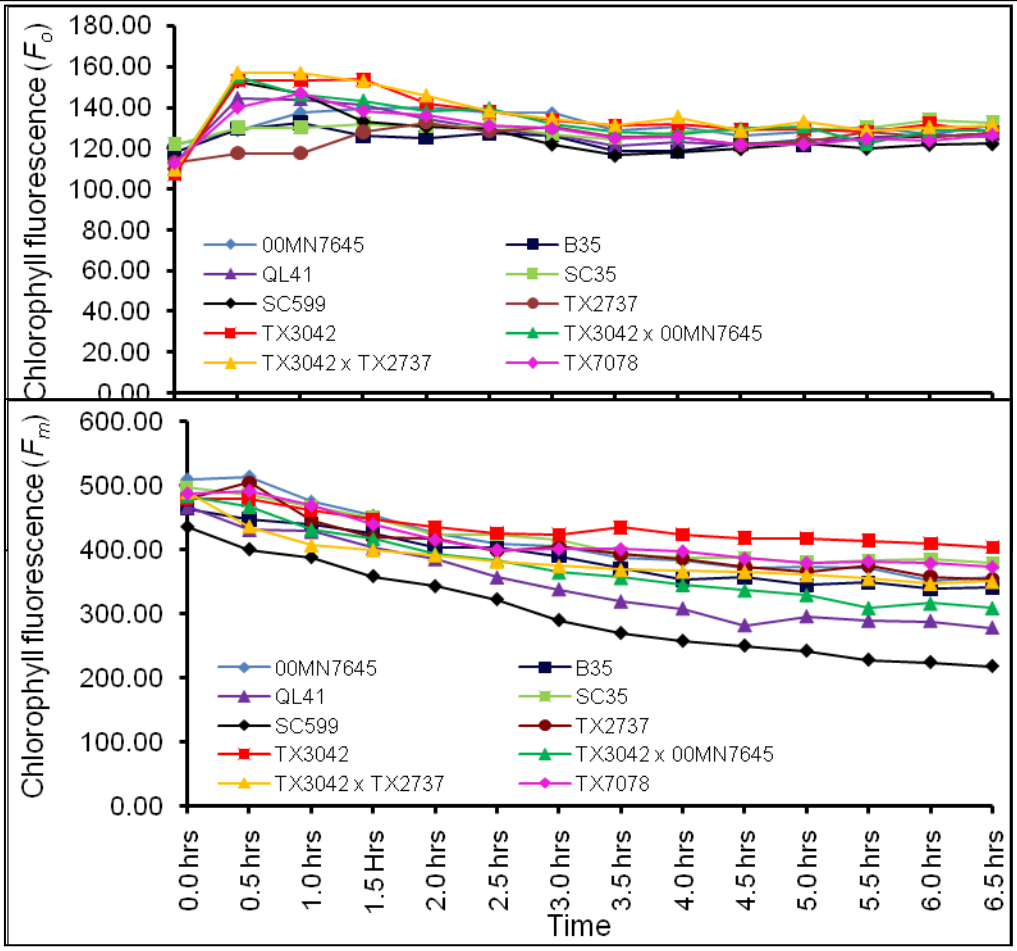


Figure 4.2: Percent maximum and average change in chlorophyll fluorescence for the 10 genotypes as an indicator of loss in cell viability.

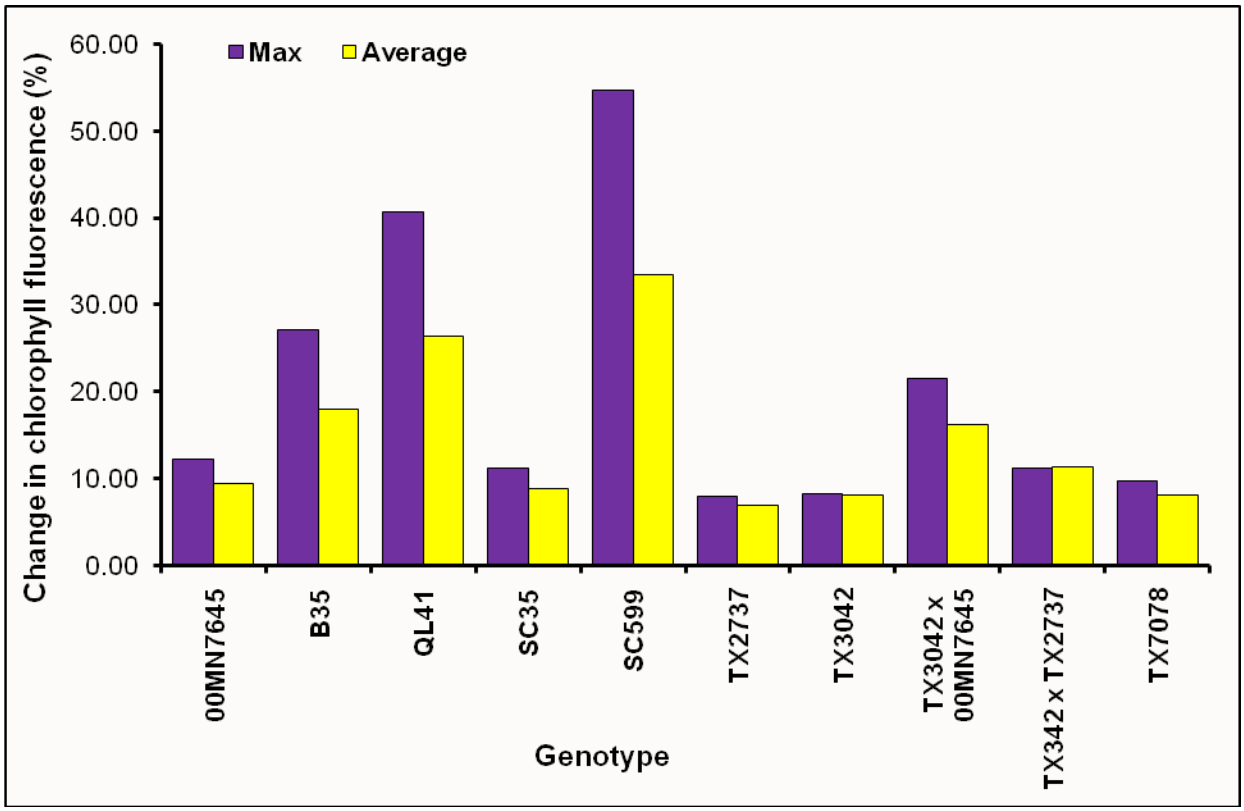


Table 4.2: Percent change in chlorophyll fluorescence – F_v/F_m ratio as compared to the initial (0.0 hrs). All values give magnitude of decline in chlorophyll fluorescence readings.

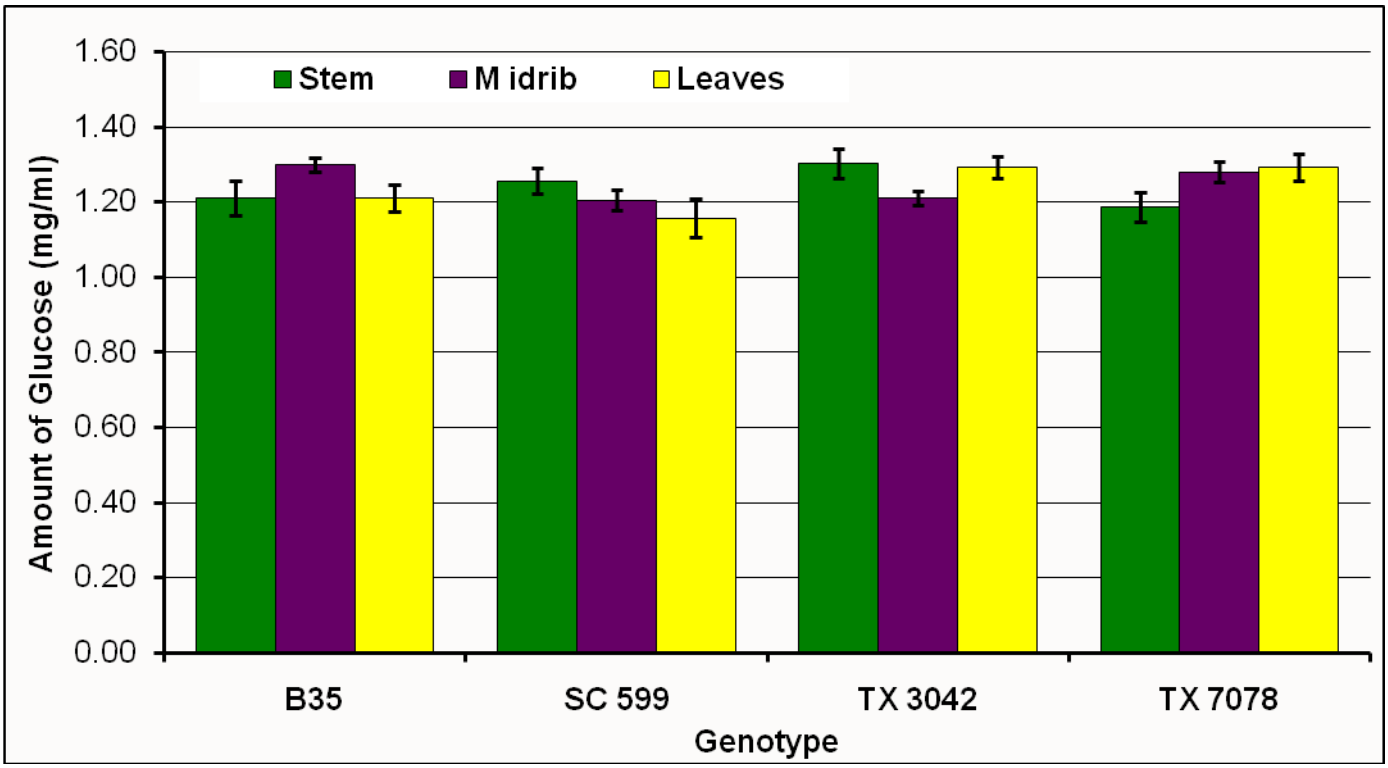
	00MN7645	**B35**	**QL41**	**SC35**	**SC599**	**TX2737**	**TX3042**	**TX3042x 00MN7645**	**TX3042x TX2737**	**TX7078**
0.0 hrs										
0.5 hrs	1.37	2.41	4.93	1.35	5.45	0.26	3.74	4.67	5.62	0.71
1.0 hrs	6.00	6.90	8.53	4.95	10.00	4.71	6.05	8.43	8.17	5.26
1.5 hrs	8.52	10.34	12.89	7.39	14.70	8.33	7.80	11.73	10.85	7.36
2.0 hrs	9.45	13.50	16.18	9.44	18.80	8.35	8.12	13.38	11.95	9.57
2.5 hrs	9.74	15.80	20.74	9.15	25.20	8.24	8.61	14.73	12.59	9.51
3.0 hrs	10.13	18.01	24.92	8.59	31.77	7.70	8.68	18.14	13.08	9.47
3.5 hrs	10.32	21.15	28.67	9.79	36.41	6.96	7.71	18.12	12.74	8.59
4.0 hrs	10.82	21.72	32.08	10.64	45.79	7.35	9.15	19.08	12.68	8.16
4.5 hrs	11.30	21.70	37.27	10.94	40.27	7.57	9.40	19.68	12.42	8.91
5.0 hrs	10.28	23.36	37.22	10.46	49.56	7.66	8.74	20.20	12.01	9.14
5.5 hrs	11.11	24.20	38.90	10.51	49.93	7.35	9.04	20.60	11.65	9.10
6.0 hrs	11.89	27.12	39.71	11.36	52.89	7.40	9.70	20.15	12.53	9.14
6.5 hrs	12.19	27.14	40.75	11.16	54.66	7.90	8.18	21.59	11.22	9.79
Mean	9.47	17.95	26.37	8.90	33.49	6.91	8.07	16.19	11.35	8.05

Table 4.3: Summary of glucose amounts in leaf, midrib and stem samples taken from four cultivars (SC599, TX7028, TX3042 and B35).

	Glucose amount (mg ml^{-1})		
Genotype	**Stem**	**Midrib**	**Leaves**
B35	1.21±0.05^{A}	1.30±0.02^{A}	1.21±0.04^{AB}
SC599	1.26±0.04^{A}	1.20±0.03^{C}	1.16±0.05^{B}
TX3042	1.30±0.04^{A}	1.21±0.02^{BC}	1.29±0.03^{A}
TX7078	1.19±0.04^{A}	1.28±0.03^{AB}	1.29±0.04^{A}
P-Value	NS	***	**
LSD @ α = 0.05	0.118	0.074	0.118

***, ** Statistically significant at P≤ 0.05 and 0.1 respectively

Figure 4.3: Comparison between the four cultivars for glucose amounts in the stem, midrib and leaves.



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CHAPTER 5 - Characterization of Diverse Sorghum Genotypes for Traits Related to Drought Tolerance.

5.0 Abstract

Grain sorghum (*Sorghum bicolor* L. Moench) has its origins in Africa, is the fourth most important cereal crop after wheat, rice, and maize, and is now grown throughout the semiarid tropical and semiarid temperate regions of the world. From the time the domestication of sorghum commenced, around 4,000 – 3,000 BC, numerous varieties have been developed through farmer selection. These improved sorghum types spread through the movement of people and trade routes into other regions of Africa, India (approx. 1500 – 1000 BC) and the Middle East (approx. 900 – 700 BC). The genus *Sorghum* is very diverse and all cultivated sorghums belong to *Sorghum bicolor* ssp. *bicolor* which is divided, based on morphology, into five races (bicolor, caudatum, guinea, durra, and kafir), along with the ten intermediate races resulting from inter-racial crosses (Harlan and de Wet, 1972). Although the US National Plant Germplasm System (NPGS) maintains a large collection of accessions, the genetic base used in sorghum breeding programs is still small. An association panel of 300 sorghum genotypes, which is believed to be representative of sorghum globally, has been developed for genetic studies in sorghum. The purpose of this study was to characterize the association panel for physiological traits associated with pre- and post-flowering drought tolerance. The objectives were to (i) quantify the performance of the association panel under field conditions in Kansas, (ii) characterize the sorghum association panel for phenological, physiological and yield traits that might be associated with pre-flowering and post-flowering drought tolerance, and (iii) identify drought tolerant lines with higher yield potential that may be used in the sorghum breeding program. Results from the study indicated that there is a wide genotypic, phenotypic

and yield variability within the diversity panel. The race caudatum has a higher potential for use in the sorghum breeding programs due to its higher yields and genotypic stability.

5.1 Introduction

The world collection of sorghum, which is maintained at ICRISAT in Hyderabad, India, contains over 35,000 accessions. Most of these are available through the US Plant Germplasm System (NPGS). Many of those maintained by the NPGS are from tropical, short-day regions of the world, too tall, too late flowering (photoperiod sensitive), or not adapted to temperate-zone environments and therefore just a small portion of the total genetic diversity within the species is available in a usable form for sorghum improvement programs and development of hybrids in the US. These collections have been the primary source of new exotic lines for the sorghum conversion program. The Sorghum Conversion Program was established in 1963 with an objective of converting many of the tropical accessions to temperate adaptation (Quinby, 1974; Rosenow and Dahlberg, 2000; Stephens et al., 1967). Recessive dwarfing and photoperiod insensitive genes from a four-dwarf temperate zone variety were moved into the genomes of exotic lines and over 840 converted and partially converted lines were developed thereby providing new, diverse germplasm that now provides an important source of the germplasm used in sorghum improvement programs throughout the world. Many lines with superior pre- and/or post-flowering drought tolerance have been identified and converted to dwarf and photoperiod insensitive (Jordan et al., 1979; Rosenow, 1980; Rosenow and Clark, 1981). Excellent sources of staygreen have also been identified in conversion program (Rosenow et al., 2000).

The association panel used in this study is a collection of about 300 representative grain sorghum genotypes from all over the world and has been used for studying and sequencing of the

sorghum genome. The genotypes in this study can be put into five races and 11 intermediate races based on the classification of Harlan and de Wet (1972) - Tables 5.1 and Appendix 2.

Basic races described in Appendix 2, are:

1. Bicolor
2. Caudatum
3. Durra
4. Guinea
5. Kafir

Intermediate races;

1. Caudatum-bicolor
2. Durra-bicolor
3. Durra-caudatum
4. Durra/durra-bicolor
5. Kafir-bicolor
6. Kafir-caudatum
7. Kafir-durra
8. Guinea-bicolor
9. Guinea-caudatum
10. Guinea-durra
11. Guinea-kafir

We hypothesize that there is genetic variation within the association panel for drought tolerance traits. Physiological traits can be used as a basis for identifying drought tolerant genotypes from the association panel, which could be used in the breeding programs aimed

towards drought tolerance in grain sorghum. The purpose of this study therefore is to characterize the association panel for physiological traits associated with pre- and post-flowering drought tolerance. The objectives of the study were (i) to characterize the performance of the association panel under field conditions in Kansas, (ii) to characterize the sorghum association panel for phenological, physiological and yield traits that might be associated with pre-flowering and post-flowering drought tolerance, and (iii) to identify drought tolerant lines with higher yield potential that may be used in the sorghum breeding program.

The data generated from this experiment will also help determine drought tolerant lines from the association panel and give a better understanding of physiological traits associated with drought tolerance in sorghum. In addition, the data will help determine the best physiological traits that could be used for identification of drought tolerant lines.

5.2 Materials and Methods

5.2.1 Location and Environmental Conditions

In the summer of 2006, 300 genotypes from the association panel were grown under rain-fed conditions at the Ashland Bottoms farm near Manhattan; Kansas (Unit 7: Rain-fed plots - 39°06′54.2″N - 96°38′10.0″W, Altitude: 323 m) and at the Kansas State University Agricultural Research Centre – Hays (38°51′11.6″N - 99°20′10.6″W, 613 m). The experiment was repeated again in 2007 in both locations with an additional unit that was fully irrigated (Unit 1: Irrigated plots - 39°08′35.3″N - 96°37′39.2″W, Altitude: 308 m) at the Ashland Bottoms farm (Manhattan).

5.2.2 Crop Husbandry: Genotypes and Agronomic Practices

In 2006 and 2007, the plots were chisel plowed in the fall and field cultivated in the spring in Manhattan and Hays. Fertilizer application was 90 kg ha^{-1} N in both locations and Bicep was used for weed control at a rate of 4.5 liters ha^{-1}. Hand weeding was performed once for all the plots. The genotypes were planted in 30-foot single rows with two replications. A breakdown of the genotypes into races, intermediate races and groups is given in Table 5.1 and a list of the genotypes used in this study is given in Supplementary Table 1.

5.2.3 Data Collection

A single plant was tagged during early vegetative development in each replication for each genotype. Data on physiological traits (chlorophyll fluorescence, leaf temperatures, SPAD meter reading and stomatal conductance) were measured four times (at 15 d intervals) starting from booting through maturity on the tagged plants for each line. Measurements were taken on the tagged plants from the top most fully expanded leaf or the flag leaf. Leaf temperature measurements were taken on a clear sunny day and were in most cases completed on the same day for each unit. Dark adapted chlorophyll fluorescence measurements were taken from regions on the leaves that had been dark adapted using clips. The clips were placed on the leaf and closed to prevent any light from entering into the clipped spot and the clips were left there for at least 30 minutes. Readings were then taken by inserting the flourometer tip, opening the clip shutter and then giving a flash of light from the flourometer that activated the reaction centers.

At maturity, the single tagged plants were harvested, the above ground biomass (stem and leaves) was oven dried at 60°C for seven days and then weighed to determine vegetative dry weights. Harvested panicles from the tagged plants were oven dried at 40°C for three days,

threshed and seeds were weighed and counted. Data from these tagged plants were used to calculate the ratio of grain produced to the total above ground biomass (harvest index).

In addition, a 2 m section of each plot was marked and the number of plants was counted. Thereafter, the panicles from these 2-m rows were harvested, oven dried at 40°C for three days, and then threshed and the grains weighed and used to compute yield.

5.2.4 Data Analysis

Data analysis was done using a combination of programs (PROC GLM, PROC REG) in SAS. Means, SE and LSDs were determined for all the observed traits and ANOVA were used to determine significance based on P-value. PROC GLM was used to determine (i) genotype means (within environment) as fitted values (labeled G*E) for analysis with Genotype, Environment and Genotype*Environment effects, (ii) environment means were computed as fitted values (labeled EINDEX) for analysis with only environment effects. PROC REG was used to compute individual regressions for genotype performance (within environment), G*E, on environmental index EINDEX. Using PROC REG, correlations were also done for yield and physiological traits. Yield ranking was determined based on genotype yield means. Genotypic stability was computed based on mean regression coefficient ($b_i = 1$) and mean yield.

Statistical models used in data analysis include;

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$$

Where μ is the general mean, $\boldsymbol{\alpha_i}$ is the genotype/Race effect, $\boldsymbol{\beta_j}$ is the environment effect, $\boldsymbol{(\alpha\beta)_{ij}}$ is the interaction effect and $\boldsymbol{\varepsilon_{ijk}}$ is the experimental error.

The genotype/race, environment, genotype-environment and race-environment interactions for all traits were evaluated using:

$$Y_{ij} = \mu + b_i \xi_j + \delta_j + \varepsilon_{ij}$$

Where; $\mathbf{Y_{ij}}$ is the mean for the genotype *i* at environment *j;* $\boldsymbol{\mu}$ is the general mean for genotype *i*, $\mathbf{b_i}$ is the Regression coefficient for the ith genotype at a given environment index, which measures the response of a given genotype to varying environments, ξ_j is the environment index (effect), which is defined as the mean deviation for all genotypes at a given location from the overall mean; $\boldsymbol{\delta}_j$ is the deviation from regression for the i^{th} genotype at the j^{th} environment and $\boldsymbol{\varepsilon}_{ij}$ is the experimental error. This linear regression model was used in the analysis of genotypic stability.

5.3 Results

5.3.1 Environmental Conditions: Rainfall and Temperature

In Manhattan (Ashland), total rainfall amount for 2006 was 468 mm and 652 mm in 2007 (Data for Manhattan Regional Airport, Source: NOAA - National Climatic Data Center) while Hays (KSU Agricultural Research Station) recorded 380 mm in 2006 and 578 mm in 2007 (Source: Data from KSU Weather Library) – Table 5.2 and Figure 5.1. This made 2006 a dry year when compared to 2007 and crops suffered some moisture stress. For the two years, Manhattan also had higher rainfall as compared to Hays. In Manhattan (Ashland), the average temperature was about 21.2°C in 2006 and 22.4°C in 2007 (Data for Manhattan Regional

Airport. Source: NOAA - National Climatic Data Center) while in Hays it was 22.7°C in 2006 and 28.4°C in 2007. (Source: Data from KSU Weather Library)(Table 5.2 and Figure 5.2). In both years and locations, temperatures peaked in August.

5.3.2 Genotype Performance

5.3.2.1 Phenology

Flowering time based on days after planting varied for the genotypes studied. Flowering time ranged from 49 – 72 days in the rainfed unit and 59 – 88 in the irrigated unit in 2007. Mean values were 59, 72 and 65 days after planting for the rainfed, irrigated and overall/combined data. The difference in means for the rainfed and the irrigated could be attributed to soil temperatures at the time of planting. The irrigated plot was planted earlier and accumulation of growing degree days may have been slower in the initial stages since conditions were cooler. Variation was highly significant when analysed at the genotype as well as the race level (Table 5.3). A complete set of this data is provided in Supplementary Table 2 in the Appendix.

Flowering for all the genotypes (July 14 – August 23) occurred at a time when temperatures were favorable and therefore seed numbers were not affected during the 2007 growing season (Figure 5.3A). Moisture levels were also favorable during this period and therefore there was no moisture stress on the plants, a condition that was favorable for flowering and seed set (Figure 5.3B).

5.3.2.2 Physiological and Yield traits

Analysis at the genotype level for the various genotypes in the different environments show that there was significant variation in plant height, all the yield traits (grain dry weight and numbers per panicle, harvest index and yield) and leaf temperature but there was no significant

difference in most of the physiological traits (chlorophyll content, chlorophyll fluorescence and stomatal conductance (Table 5.4 and 5.5).

Analysis at the race and/or group level showed that all the yield and physiological traits were highly significant at $P < 0.0001$ (Table 5.6 and Figure 5.4A-H). The guinea race had the tallest genotypes on average and the breeding lines from the US, caudatums, durras and kafirs were short on average as compared to the mean height for all the genotypes (Table 5.6 and Figure 5.1A). The bicolors were medium in height. In all the yield traits, the bicolors had the lowest values. The breeding lines from the US had high grain weight per panicles and the caudatums recorded high yields. A comparison of the yield traits combined with the physiological traits showed that the US breeding lines had high chlorophyll content, high grain dry weight, and grain numbers per panicle as well as high harvest index. The caudatums had slightly lower values for chlorophyll fluorescence.

Table 5.4 shows interactions at the genotype, race, environment, genotype*environment and race*environment level. Environment effects were highly significant for all traits at $P<0.0001$. Genotype effect was not significant for chlorophyll content (SPAD), chlorophyll fluorescence ratio (F_v/F_m) and stomatal conductance.

Figures 5.5 – 5.7 show the general trend, based on mean values, for the physiological traits monitored over time. Leaf temperature did not change much over the growing season (Figure 5.5) both at the genotype and race level. It is only the breeding lines that had a significant drop in temperature from early August to early September and then increased in the remaining days in September. The kafirs also showed a similar trend but with a decline in August. Chlorophyll content declined in the early days of the reproductive phase (July) and then increased in August to reach a plateau that was maintained till late September (Figure 5.6). This change could be due to an increased demand for photosynthates for the new sink (seed) which is

rapidly developing and once the seed size has been reached then the chlophyll content was maintained at an almost steady level. Chlorophyll fluorescence ratio (F_v/F_m) increased throughout the reproductive phase at both genotype and race level (Figure 5.7).

5.3.2.3 Yield Rankings

The genotype with the highest mean yield over the two years and for the four environments (Ashland 2006 rainfed, Ashland and Hays 2007 rainfed, and Ashland 2007 irrigated) was SC1019 (Caudatum) recording 5,935 kgha^{-1}. In 2006, a year which had a period of moisture stress, this genotype yielded only 39.67 kgha^{-1} which was below the overall average (Table 5.7). This genotype performed well only in 2007 when there was adequate moisture; 6,376 kgha^{-1}, 9,065 kgha^{-1} and 8,260 kgha^{-1} in Hays, Ashland rainfed and Ashland irrigated respectively. Generally, the caudatums were high yielding when compared to the other races taking up 57% of the 30 top yielding genotypes (Table 5.7). The kafirs took up 27% and the others were durra, guinea, a genotype from Central America and eight genotypes that could not yet be placed within any race due to limited information. Among the US breeding lines that were used as checks during the study, BTx378 was the highest yielding with 4,747 kgha^{-1}. Table 5.8 shows genotypes that were highest yielding in 2006, a dry year, in Manhattan under rainfed conditions and also their performance in 2007 in Hays (rainfed conditions) and Manhattan (rainfed and irrigated). SC420 (kafir) recorded the highest yield (3,357 kgha^{-1}) in Manhattan 2006 but did not perform as well under irrigated conditions in 2007. The caudatums took up 43% of these, the kafirs and guineas 14% each, durras 11% and the rest were a one genotype from East and South Africa (4%), one from West Africa (4%) and three that were not placed anywhere (11%).

Table 5.9 shows ten among the 30 best yielding genotypes that performed well over the two years and in the three environments where yield was produced and yielded over 2,000 kgha^{-1}

in 2006. The caudatums had the best performance with five genotypes (SC720, SC424, SC391, SC51 and SC373). The others were two Kafirs (SC1211 and SC1074), one genotype from West Africa (Malisor 84-7) and two genotypes that were not placed in any race (SC332 and Segaolane).

5.3.3 Genotypic Stability

Figure 5.8 gives genotypic stability for the 289 genotypes whose yield was analysed. Based on a selection level of mean yield +1SD and mean regression coefficient ±1SD a total of thirty one (31) genotypes were selected and characterized as genotypically stable within the four environments where yields were obtained (Table 5.10). Mean yields for these genotypes ranged from 4,022 $kgha^{-1}$ to 5,387 $kgha^{-1}$ (overall mean yield was 3,004 kg/ha) and regression coefficient ranging from 0.4467 – 1.8505 (limits were 0.376 – 1.816). A breakdown of the 31 stable genotypes showed races ranked as caudatums 41.9%, US breeding lines – 25.8%, guinea – 6.5%, kafir – 6.5%, durras – 3.2% and 16% was taken up by the genotypes whose races were not established. Based on mean yield and a regression coefficient closest to 1, out of the thirty one (31) stable genotypes, the best were SC51 (caudatum) with mean yield of 4,241 $kgha^{-1}$, regression coefficient - 1.1103, SC1211 (kafir) with mean yield of 4,329 $kgha^{-1}$, regression coefficient - 1.0721, Tx2741 (US breeding line) with mean yield of 4,506 $kgha^{-1}$, regression coefficient - 0.9391 and SC720 (caudatum) with mean yield of 4,716 $kgha^{-1}$, regression coefficient -1.1978 (Table 5.10).

5.3.4 Correlations

Correlation analysis performed on physiological (leaf temperature, chlorophyll content and chlorophyll fluorescence) and yield (grain weight and grain number for single panicle, harvest index and grain yield per hectare) traits at the genotype and race level is given in Table 5.11 and Figures 5.7 – 5.14. Leaf temperature had a positive correlation to all the yield traits at

genotype and race level except for durra and bicolor (grain yield) and significant in grain weight and grain numbers (except for guinea), not significant for harvest index except at genotype level, breeding lines and the caudatums and significant in grain yield except for durra and bicolor.

Chlorophyll content showed a positive correlations with yield traits except for bicolor (grain yield and harvest index) and breeding lines and durra (grain yield). The correlation was significant between chlorophyll content and grain weight for the breeding lines, guineas and kafirs, not significant in grain numbers except for guinea, significant in harvest index all races except guinea and kafir, and significant in grain yield for only the breeding lines, kafir and bicolor (Table 5.11).

Chlorophyll fluorescence ratio F_v/F_m showed a negative correlation at the genotype level and in all the races except for caudatum which had a positive correlation at r = 0.333, 0.3094, 0.3378 and 0.354 for grain weight, grain number, harvest index and grain yield respectively. This is the only race that behaved differently when chlorophyll fluorescence ratio (F_v/F_m) was correlated with all the yield traits. In grain yield the correlation was negative in the kafirs and guineas. Correlation was significant for grain numbers per panicle in all races except for bicolor. It was also significant for the caudatums in all the yield traits (Table 5.11).

5.3.4.1 Grain Weight and Grain Number per Panicle

Correlations between leaf temperature and grain weight per panicle were highest in kafir (r = 0.3924, P<0.01) and lowest in the US breeding lines (r = 0.1077, P< 0.05) and it was not significant for guinea (Table 5.11, Figure 5.13A and 5.12A). For grain weight per panicle and chlorophyll fluorescence, caudatum had the highest correlation (r = 0.333; P<0.01) while bicolor had the lowest (r = 0.1122; NS) (Table 5.11, Figure 5.11C and 5.14C). Chlorophyll content correlations were low (r < 0.30) for all the yield traits (Table 5.11and Figure 5.9 – 5.14).

For grain number per panicle and leaf temperature, bicolor recorded the highest correlations (r = 0.3933; P<0.01), kafir (r = 0.3890; P<0.01) and caudatum (r = 0.3812; P<0.01) while guinea was the lowest (r = 0.0374; NS), with chlorophyll content guinea recording the highest correlation (r = 0.2968; P<0.01) and the US breeding lines the lowest (r = 0.2274; P<0.001) (Table 5.11). In correlations between chlorophyll fluorescence ratio F_v/F_m and grain numbers, the US breeding lines had the highest correlation (r = 0.4491; P<0.01), durra (r = 0.3686; P<0.001), guinea (r = 0.3658; P<0.01), and kafir (r = 0.3040; P<0.01) while bicolor was the lowest (r = 0.2012; NS) (Table 5.11). The correlation between grain numbers per panicle and chlorophyll content for caudatum was positive and significant (r = 0.3094; P<0.01) (Table 5.11).

5.3.4.2 Harvest Index

Results showed that correlation between leaf temperature and harvest index were highest in the caudatums (r = 0.4562; P<0.001) and lowest for the durras (r = 0.0954; NS) (Table 5.11). While correlation between harvest index and chlorophyll content was highest in the caudatums (r = 0.33; P<0.01) and guinea (r = 0.3233; P<0.01) while bicolor was the lowest (r = 0.0101; NS) for chlorophyll content (Table 5.11). Chlorophyll fluorescence ratio Fv/Fm correlations with harvest index were highest in the US breeding lines (r = 0.4042; P<0.01), guinea (r = 0.3396; P<0.01), and lowest in bicolor (r = 0.0980; NS) (Table 5.11). For caudatum there was a positive correlation (r = 0.3378; P<0.01) between harvest index and chlorophyll fluorescence (Table 5.11).

5.3.4.3 Grain Yield

Grain yield and leaf temperature correlations were highest in the kafirs (r = 0.6184; P<0.001), caudatum (r = 0.4484; P<0.001), guinea (r = 0.4205; P<0.01) and lowest in the durras (r = 0.0616; NS) (Table 5.11). Grain yield and chlorophyll content correlations were highest for bicolor (r = 0.6177; P<0.01) and kafir (r = 0.4405; P<0.01) while the US breeding lines had the

lowest (r = 0.0900; P<0.05) (Table 5.11). For chlorophyll fluorescence ratio F_v/F_m and grain yield correlations, durra and caudatum had the highest (r = 0.3585 and 0.3540 respectively; P<0.01) and kafir had the lowest (r = 0.0889; NS) (Table 5.11).

5.4 Traits Related to Drought Tolerance

5.4.1 Leaf temperature

Results indicated that there were some genotypes that maintained fairly high temperature under stress free conditions (irrigated). Based on a selection criteria of genotypes with mean leaf temperature plus 1.5 standard deviations and above average grain yield (over 3,827 $kgha^{-1}$), 29 genotypes were selected (Figure 5.15 and Table 5.12). Out of the 29 genotypes selected 15 were caudatums (52.7%), 17% were kafirs or kafir related (3 kafirs, 1 kafir-caudatum, 1 kafir-durra) 14% were durras or durra related (1 durra, 3 durra-bicolors) and 2 were bicolors (7%) (Table 5.12).

5.4.2 Seed Numbers and Harvest Index

Seed numbers per panicle were low for all the races in Manhattan and Hays in 2006 (Figure 5.16) which was a comparatively dry year. Reduction in seed numbers was at an average of 55.3% when 2006 was compared to 2007 (Table 5.13). Greatest reductions was in Hays for the collection of lines from West Africa (90%) and the minimum was also for the same lines in Manhattan (27%) (Table 5.13). The US breeding lines recorded high seed numbers in 2007 and were consistent in Manhattan and Hays for the irrigated and rainfed conditions. The caudatums had also high and consistent seed numbers in 2007 in the two locations. The durras had higher seed numbers in the rainfed conditions as compared to the irrigated. Overall, kafirs had the

lowest seed numbers. In 2006 harvest index was low for all the races when compared to 2007 (Figure 5.17). There was a reduction of 46.4% in harvest index (Table 5.13) the greatest reduction of 74.3% was in Hays for the West African lines. The bicolors had the lowest reduction in harvest index (4.8%, Hays).

5.5 Discussion

There was difference in moisture amounts in the soil as indicated by the amount of rainfall received in 2006 and 2007. Year 2007 was better with respect to moisture availability (Table 5.2 and Figures 5.1 and 5.2). This resulted in differences in the performance of the lines used in this study both at the genotype and race level for the two years (2006 and 2007). Variability for most of the traits measured was manifested at the genotype and race level in both years for the different environments. The study showed that there is variability within the 300 genotypes as well as the 5 races. In 2007 flowering took place at a period with adequate moisture and favorable temperatures, a condition that was prevailing even two weeks before flowering. This favored the initiation and development of the reproductive processes and grain numbers were not negatively affected. Flowering started on July 14 and went on till August 23 giving a wide variability at the genotype level and indication that there is potential for grouping the various genotypes/races into different maturity groups.

The US breeding lines that were used as checks in the diversity panel had high grain weight per panicle and this is because these are genotypes that have already undergone some improvement through breeding. The caudatums proved to be superior to the other genotypes in terms of grain yield in the different environments. They performed better in 2006, a year with significant moisture stress. The caudatums are described by Mann (Mann et. al., 1983) as high yielding in the description of the sorghum races (Appendix 2) and hence a reason as to why they

have been used as a source of germplasm for breeding programs in sorghum. The kafirs also showed some potential for high yields in 2006 (a dry year) (Table 5.8). The bicolors were the lowest in yields and this concurs with the characteristics given for this particular race as described by Mann et al. (1983) – Appendix 2.

Eberhart et al. (1966) used a modified linear regression model to characterize genotypic stability (equation 2). The joint-regression model has been widely used by plant breeders to analyze genotype-by-environment interaction (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Williams et al., 1992). The standard method for fitting the model dates back to Yates and Cochran (1938) and was further developed by Finlay and Wilkinson (1963) and Eberhart and Russell (1966). Based on this model, it was possible to rank the 31 genotypes that showed genotypic stability and the caudatums were more stable when compared to the other races.

Plants regulate their leaf temperature through the opening and closing the stomates. When air temperature is high, the stomates will open more and hence more water is pulled up from the soil and helps cool the leaves. In days with normal air temperature and under fully irrigated conditions, plants that maintain a high leaf temperature may be an indication of low stomatal conductance which results in elevated leaf temperature. Low stomatal conductance will also mean that less water is taken out of the soil and therefore these plants will have water available for a longer period in their growing cycle. Sinclair (Sinclair et. al., 2005) demonstrated increased yields in sorghum mainly in dry, low yielding years which was associated with self imposed limitations on maximum transpiration rates through stomatal closure. This phenomenon has also been shown in occur in soybean by Sinclair (Sinclair et. al., 2007). The results in this experiment showed some plants that maintained elevated leaf temperature (due to reduced/regulated stomatal conductance or self imposed limitations on maximum transpiration

rates) and no reduction in yields. These could be genotypes that will do well under water limited conditions since they are conservative in extraction of water from the soil.

Seed numbers and harvest index were both affected by drought stress. It should be noted that even though environmental conditions were favorable at the time of flowering stress occurring 10-15 days before flowering will reduce seed numbers this could be a scenario in 2006. Seed numbers may be reduced if drought stress occurs immediately after seed set as a result of embryo abortion. As indicated in the results, 2006 was a dry year and this resulted in a reduction of seed numbers and harvest index for almost all the races.

5.6 Conclusion

From this study it can be concluded that there is genetic variability within the diversity panel in phenology, physiological traits such as leaf temperature, chlorophyll content and chlorophyll fluorescence ratio (F_v/F_m) as well as in yield components such as grain weight per panicle, grain number per panicle, harvest index and grain yield. The caudatums are high yielding and have more genotypic stability and therefore have the potential to be used in breeding programs as a source of genetic material. The kafirs showed some potential for yield improvement and hence a race that needs to be evaluated more for further exploitation in breeding programs. Seed numbers per panicle and harvest index were negatively affected by environment. Leaf temperature could be investigated more to establish whether it can help in understanding drought tolerance in sorghum. Lines within each race were identified using physiological and yield traits for potential tolerance to drought stress.

5.7 Tables and Figures

Table 5.1: Races/intermediate races and groups used in the study.

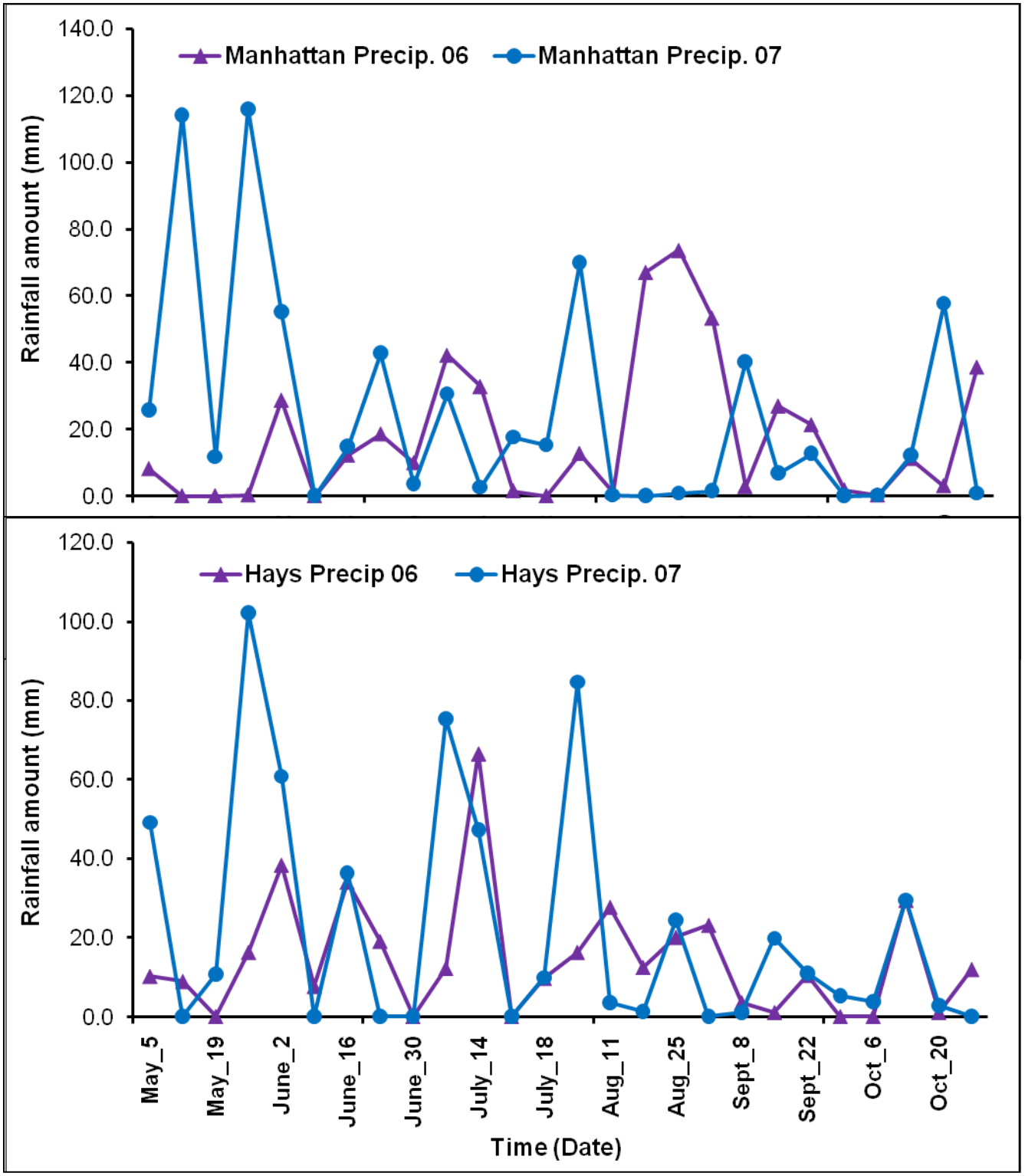
Race/Group	Number	Intermediate race/Country of origin	Number
Bicolor	16		
Caudatum	69	Caudatum-bicolor	7
Durra	25	Durra-bicolor	19
		Durra-caudatum	5
		Durra/durra-bicolor	1
Guinea	15	Guinea-bicolor	3
		Guinea-caudatum	11
		Guinea-durra	4
		Guinea-kafir	2
Kafir	7	Kafir-bicolor	3
		Kafir-caudatum	2
		Kafir-durra	2
Breeding line (US)			30
East & South Africa (Kenya, Somalia , South Africa, Sudan, Uganda)			11
South and Central America (Central America, Brazil)			2
China			2
India			2
West Africa (Mali, Niger, Nigeria)			8
Not placed			54

Table 5.2: Manhattan and Hays rainfall and temperature data: 2006 and 2007.

Date	Manhattan Temp. 06	Manhattan Precip. 06	Manhattan Temp. 07	Manhattan Precip. 07	Hays Temp. 06	Hays Precip 06	Hays Temp. 07	Hays Precip. 07
5-May	14.1	8.128	19.4	25.7	13.4	10.16	22.9	49.0
12-May	11.9	0	19.8	114.0	14.0	8.89	27.8	0.0
19-May	16.4	0	19.0	11.7	17.0	0.00	24.3	10.7
26-May	23.1	0.254	20.4	115.8	23.9	16.26	24.0	102.1
2-Jun	24.0	28.702	20.8	55.1	23.0	38.35	26.0	60.7
9-Jun	24.0	0	22.0	0.0	25.4	7.62	29.1	0.0
16-Jun	24.2	12.192	25.4	14.7	25.1	34.04	28.0	36.3
23-Jun	26.3	18.542	25.1	42.7	24.7	19.05	31.4	0.0
30-Jun	23.6	9.906	23.3	3.6	23.6	0.00	27.0	0.0
7-Jul	25.6	42.164	24.4	30.5	25.8	12.19	31.8	75.2
14-Jul	26.3	32.766	24.0	2.5	26.7	66.55	30.4	47.2
21-Jul	29.8	1.524	27.5	17.5	29.6	0.00	33.8	0.0
28-Jul	26.7	0	26.4	15.2	26.3	9.65	31.3	9.9
4-Aug	30.2	12.7	25.7	69.9	27.4	16.26	32.5	84.6
11-Aug	30.1	1.27	29.2	0.3	29.5	27.69	36.6	3.6
18-Aug	26.6	67.056	29.9	0.0	26.0	12.45	36.1	1.3
25-Aug	24.8	73.66	29.2	0.8	24.0	20.07	32.8	24.4
1-Sep	21.4	53.34	25.1	1.5	20.6	23.11	30.7	0.0
8-Sep	18.0	2.794	23.7	40.1	19.7	3.56	28.2	1.0
15-Sep	19.5	26.924	16.1	6.9	20.3	1.02	27.8	19.8
22-Sep	17.5	21.336	23.1	12.7	23.1	10.41	29.3	10.9
29-Sep	14.6	1.778	20.8	0.0	20.8	0.00	26.6	5.3
6-Oct	21.4	0.254	21.3	0.3	24.5	0.00	28.3	3.8
13-Oct	11.7	11.176	16.1	12.2	19.7	29.46	20.3	29.5
20-Oct	10.1	3.048	15.1	57.7	16.8	1.02	21.6	2.8
27-Oct	8.8	38.608	9.7	0.8	19.4	11.94	18.7	0.0
Mean/Total	**21.19 (M)**	**468.12 (T)**	**22.41 (M)**	**652.02 (T)**	**22.70 (M)**	**379.7 (T)**	**28.36 (M)**	**578.1 (T)**

M – Mean, T - Total

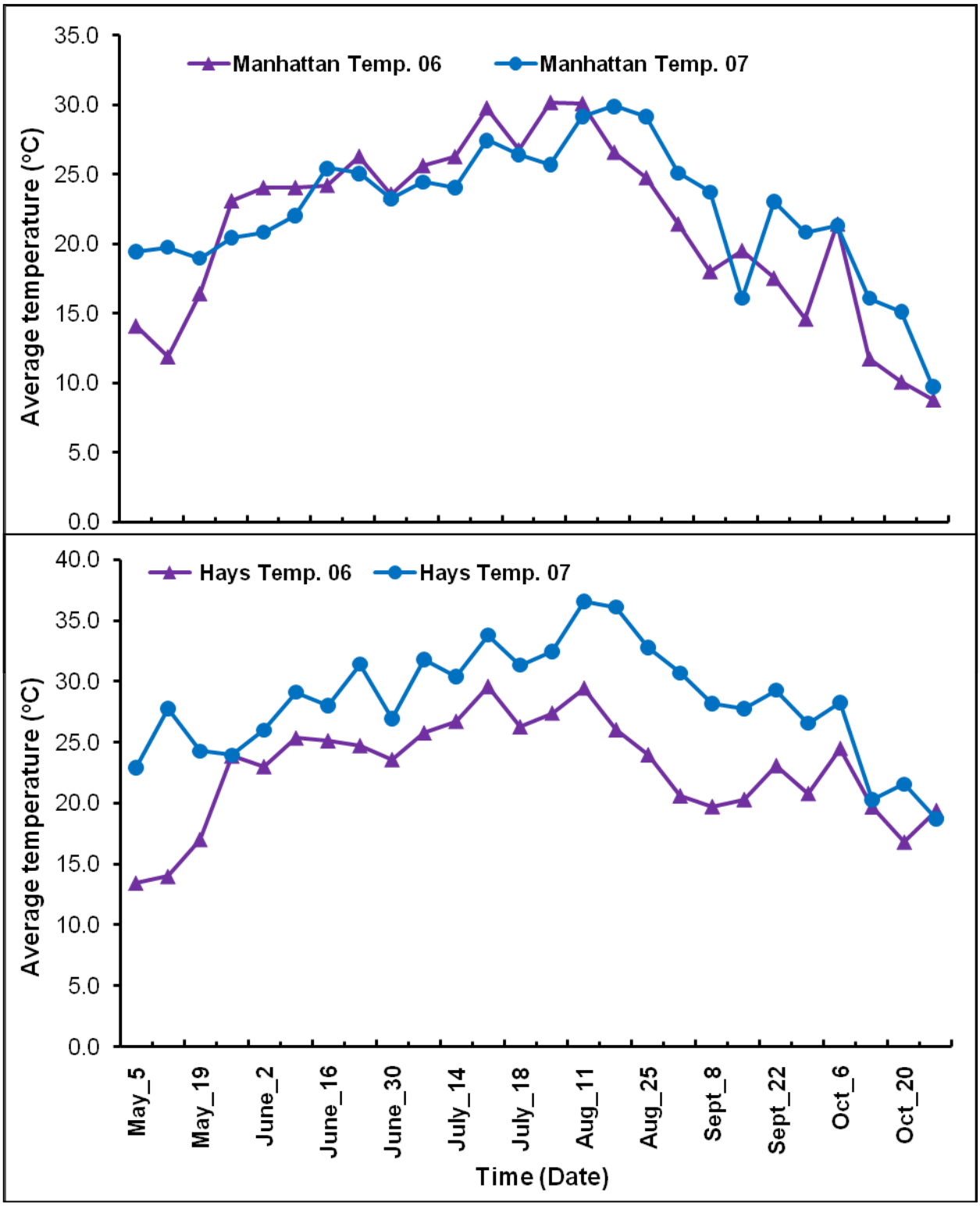
Figure 5.1: Precipitation for Manhattan and Hays during the years 2006 and 2007.



Source: NOAA - National Climatic Data Center:- Data for Manhattan Regional Airport

Source: KSU Weather Library:- Data for Hays.

Figure 5.2: Temperature for Manhattan and Hays during the years 2006 and 2007.



Source: NOAA - National Climatic Data Center: - Data for Manhattan Regional Airport

Source: KSU Weather Library: - Data for Hays.

Table 5.3: Flowering time for rainfed and irrigated plots as well as overall duration based on days after planting (DAP) at Ashland, Manhattan.

Parameter	**Flowering time** (DAP)		
	Rainfed plot (Planted June 5, 2007)	**Irrigated plot** Planted May (18, 2007)	**Overall mean**
Genotype level	59±1.51	72±1.87	65±11.08
Race Level			
Bicolor	59±0.89	70±1.21	65±0.99
Breeding line	60±0.65	74±0.88	67±0.72
Caudatum	58±0.41	71±0.56	64±0.46
Central America	62±2.51	75±3.41	68±2.79
China	55±2.51	67±3.41	61±2.79
Durra	62±0.51	75±0.69	69±0.56
East & South Africa	57±2.05	71±2.79	64±2.28
Guinea	57±0.61	70±0.83	63±0.68
Kafir	58±0.65	70±0.88	64±0.72
Not Placed	59±0.47	72±0.64	65±0.53
West Africa	59±1.77	73±2.41	66±1.97
LSD @ 0.05	3.987	5.423	4.435
P-Value	<0.0001	<0.0001	<0.0001

Figure 5.3: Temperature (°C) and precipitation (mm) at the time of flowering – Ashland (Manhattan) 2007.

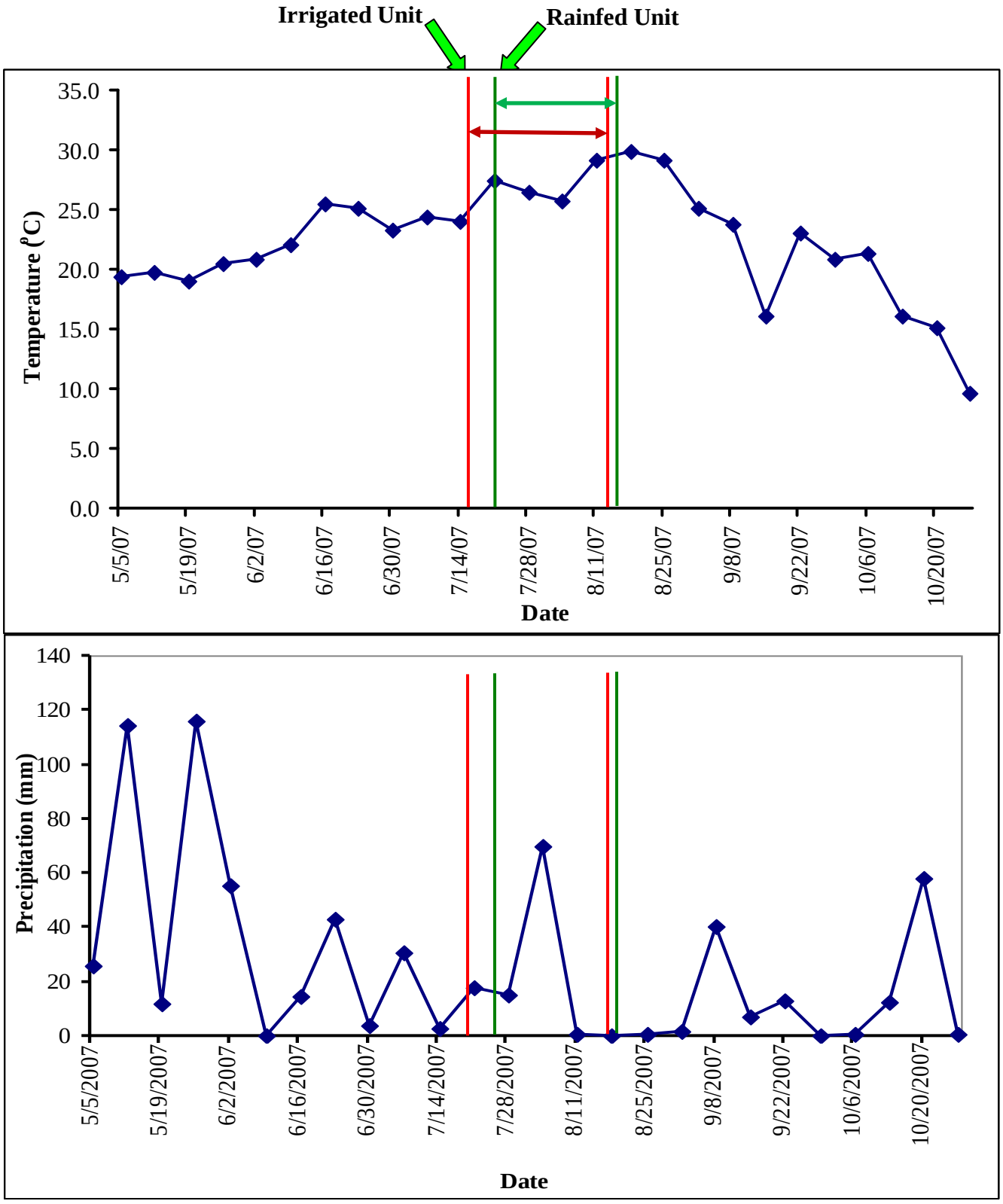


Table 5.4: ANOVA showing significance of P-values for genotype, race, environment and genotype*environment, race*environment interactions.

Trait	Genotype (G)	Race (R)	G*E	R*E
Plant height	***	***	***	***
Grain dry weight per panicle	***	***	***	***
Grain numbers per panicle	***	***	***	***
Harvest index	***	***	***	***
Leaf temperature	**	***	***	***
Chlorophyll content	NS	NS	NS	***
Chlorophyll fluorescence ratio (F_v/F_m)	NS	NS	NS	***
Stomatal conductance	NS	*	NS	***
Grain yield	***	***	***	***

***, **, * Significant at P<0.0001, 0.008, 0.02

Table 5.5: Summary of different physiological and yield traits based on genotypes.

Trait	Maximum	Minimum	Mean(±SE)	LSD	Significance based on P-value
Plant height (cm)	214.1	61.1	102.92±10.73	29.95	***
Grain dry weight panicle^{-1}	57.3	5.3	26.30±5.30	14.90	***
Grain numbers panicle^{-1}	2,524	142	1,001±251.94	708.9	***
Harvest index	0.60	0.05	0.25±0.06	0.162	***
Leaf temperature (°C)	42.5	22.6	30.08±2.16	6.03	**
Chlorophyll content (SPAD)	73.1	39.9	56.61±5.81	16.24	NS
Chlorophyll fluorescence ratio (F_v/F_m)	0.802	0.704	0.751±0.02	0.048	NS
†Stomatal conductance	330.2	7.9	180.23±49.37	139.56	NS
Yield (kg ha^{-1})	6384.6	492.0	3006.5	1016.2	***

***, ** Significant at P<0.0001 and P<0.005, NS – Not significant.

† Data was from four environments (Ashland 2006 rainfed, Ashland 2007 rainfed and irrigated, Hays 2007 rainfed)

Table 5.6: Race/group means (±SE) for physiological and yield traits. These are means±SE for analysis done when genotypes were grouped into the various races/groups and therefore significance may not be the same as when analysis was done at the genotype level.

	Plant height (cm)	**Grain dry weight (g panicle^{-1})**	**Grain numbers per panicle**	**Harvest Index (ratio)**	**Grain Yield (kg ha^{-1})**	**Leaf temperature (°C)**	**Chlorophyll content (SPAD)**	**Chlorophyll fluorescence ratio (F_v/F_m)**	**†Stomatal conductance (mmol/m^2/s)**
Bicolor	106.95±2.7	19.21±1.2	886.14±51.0	0.21±0.01	2256.33±125.8	29.64±0.3	56.54±1.0	0.756±0.003	179.19±10.4
Breeding line	95.14±1.9	30.97±0.9	1242.81±37.6	0.27±0.01	3340.15±91.8	29.81±0.2	58.38±0.7	0.751±0.002	190.72±7.
Caudatum	97.55±1.2	26.29±0.6	1043.36±23.3	0.26±0.01	3340.89±57.5	29.91±0.1	56.77±0.4	0.750±0.001	182.39±4.8
‡Central America	151.53±7.6	26.20±4.1	1162.28±173.4	0.17±0.04	3330.41±386.1	29.85±1.0	54.42±3.0	0.743±0.009	136.07±32.8
‡China	120.28±7.6	38.28±3.5	1219.77±147.1	0.35±0.03	2988.41±386.1	29.11±1.0	56.65±3.0	0.740±0.009	142.30±32.8
Durra	96.12±1.6	26.87±0.7	1084.31±28.8	0.23±0.01	2709.20±71.8	29.79±0.2	56.71±0.6	0.753±0.002	198.57±5.9
East & South Africa	115.06±6.2	36.90±2.5	1452.44±105.9	0.27±0.02	3483.90±265.5	33.56±0.7	54.65±2.2	0.748±0.006	208.75±22.5
Guinea	120.96±1.8	20.90±0.8	893.93±34.4	0.24±0.01	2448.64±85.6	29.87±0.2	56.23±0.7	0.749±0.002	169.95±7.1
Kafir	100.23±2.0	23.86±0.9	1053.32±36.9	0.24±0.01	2944.75±89.9	29.52±0.2	56.24±0.7	0.753±0.002	173.19±7.6
Not Placed	102.47±1.7	27.18±0.7	1040.71±30.6	0.27±0.01	2929.50±72.2	30.97±0.2	56.19±0.6	0.753±0.002	180.45±6.0
‡West Africa	121.75±5.4	32.63±2.6	1243.61±110.3	0.29±0.02	3511.75±252.8	29.31±0.6	57.32±2.0	0.751±0.006	143.27±21.1
Significance	***	***	***	***	***	***	***	***	***

†This is data is from only four environments (Ashland –Manhattan- 2006 & 2007, Hays 2007 only).

‡Genotypes were very few and hence the high ratings in the means due to small sample number (see Table 5.2 for a breakdown of genotypes used in the study for each race/category/group).

*** Significant at P<0.0001

Figure 5.4: Means of traits measured during the study based on races.

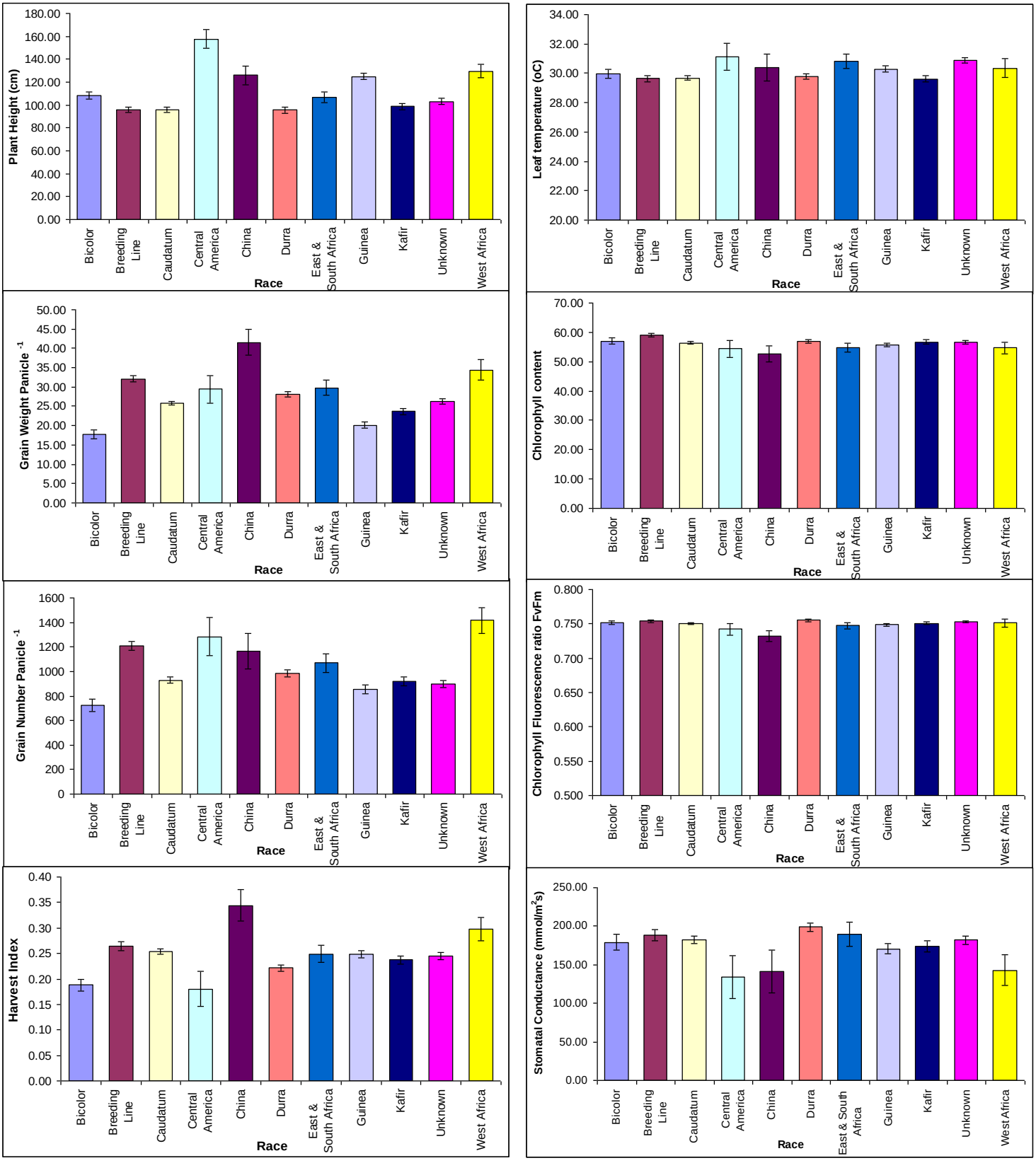
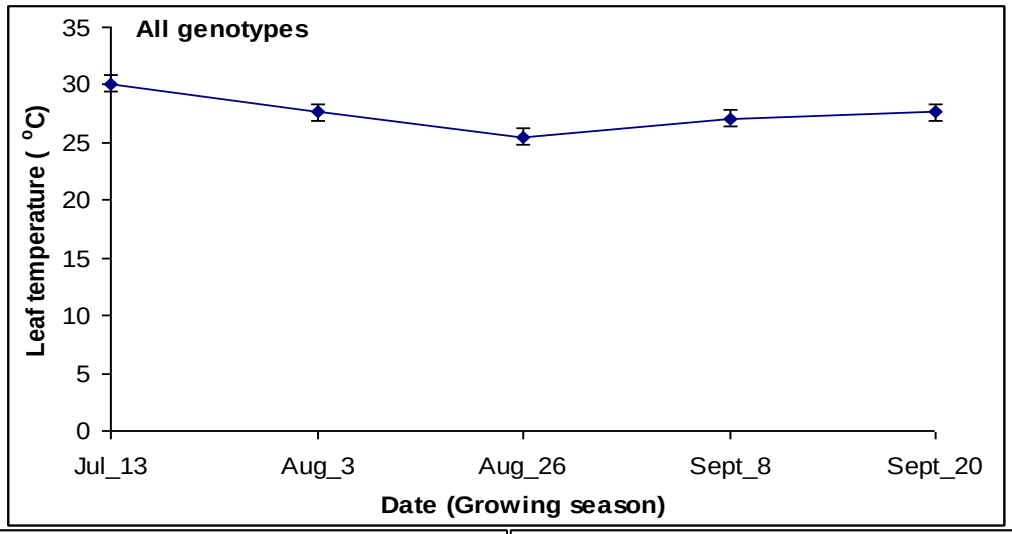
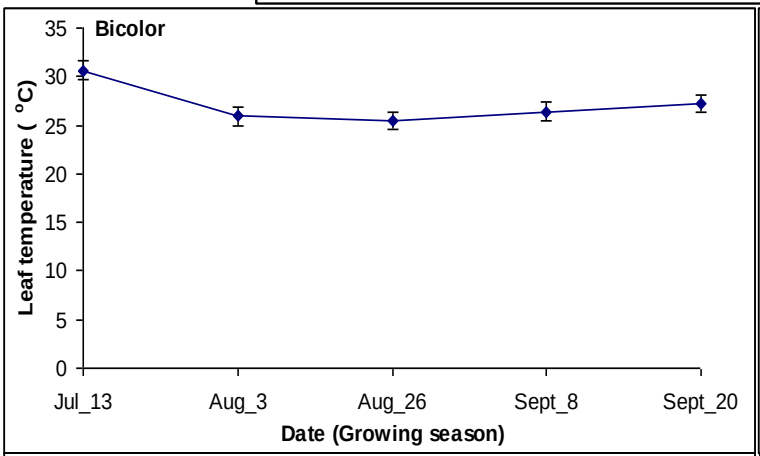
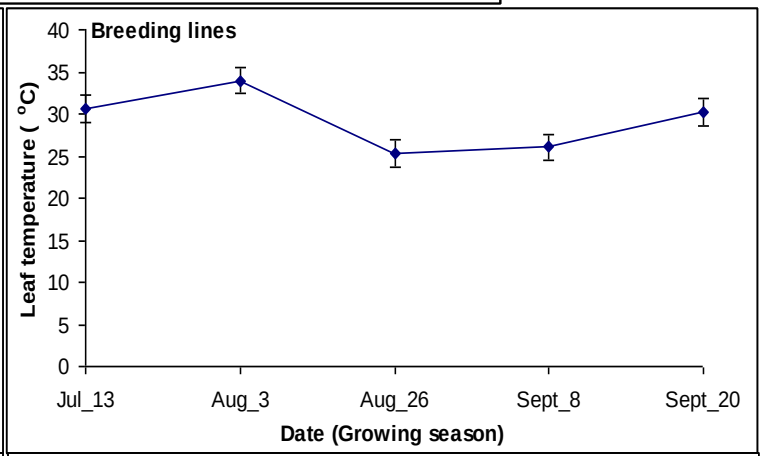
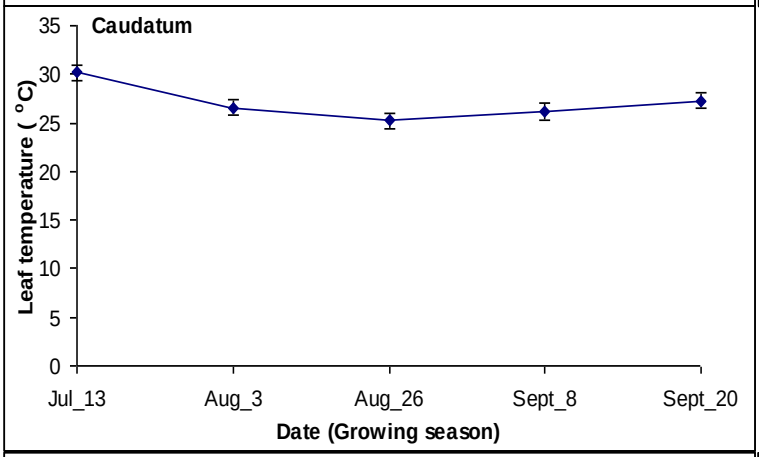


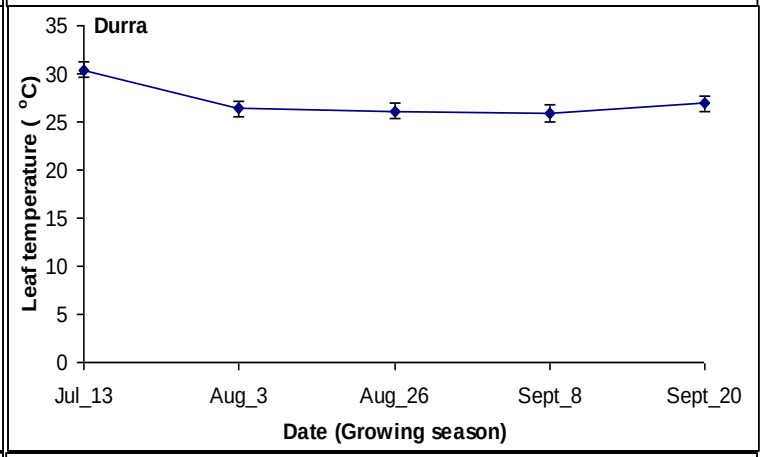
Figure 5.5: Leaf temperature (°C) at different dates during growth at genotype and race level.

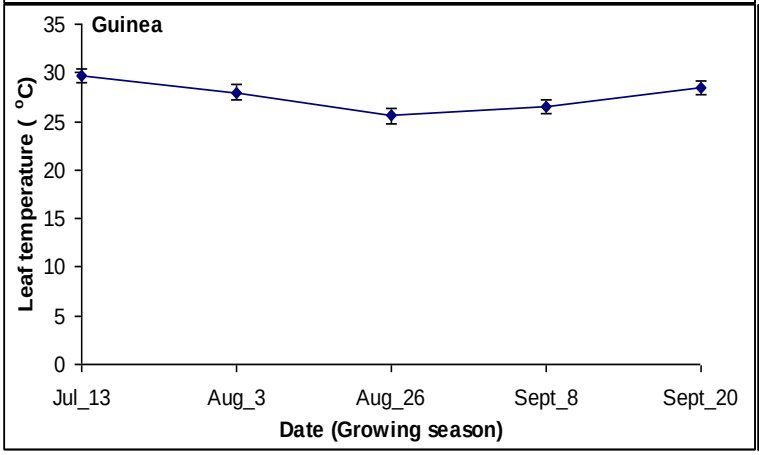

All genotypes
Leaf temperature (°C)
35
30
25
20
15
10
5
0
Jul_13
Aug_3
Aug_26
Sept_8
Sept_20
Date (Growing season)


Bicolor
Leaf temperature (°C)
35
30
25
20
15
10
5
0
Jul_13
Aug_3
Aug_26
Sept_8
Sept_20
Date (Growing season)


Breeding lines
Leaf temperature (°C)
40
35
30
25
20
15
10
5
0
Jul_13
Aug_3
Aug_26
Sept_8
Sept_20
Date (Growing season)


Caudatum
Leaf temperature (°C)
35
30
25
20
15
10
5
0
Jul_13
Aug_3
Aug_26
Sept_8
Sept_20
Date (Growing season)


Durra
Leaf temperature (°C)
35
30
25
20
15
10
5
0
Jul_13
Aug_3
Aug_26
Sept_8
Sept_20
Date (Growing season)


Guinea
Leaf temperature (°C)
35
30
25
20
15
10
5
0
Jul_13
Aug_3
Aug_26
Sept_8
Sept_20
Date (Growing season)

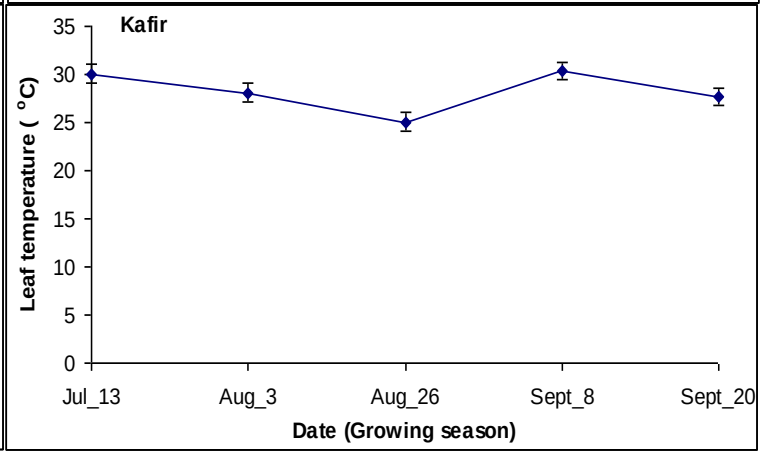

Kafir
Leaf temperature (°C)
35
30
25
20
15
10
5
0
Jul_13
Aug_3
Aug_26
Sept_8
Sept_20
Date (Growing season)

Figure 5.6: Chlorophyll content (SPAD) at different dates during growth at genotype and race level.

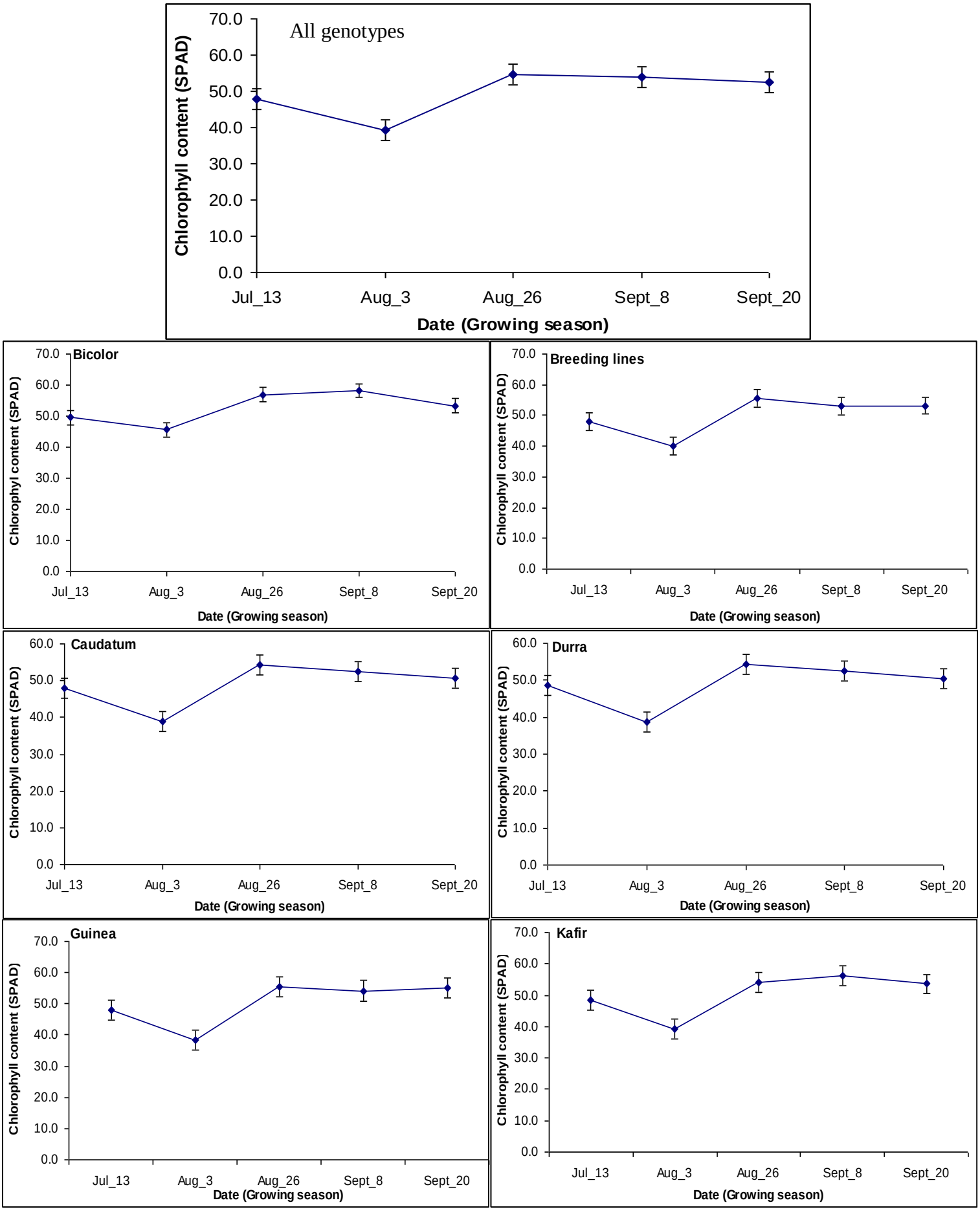
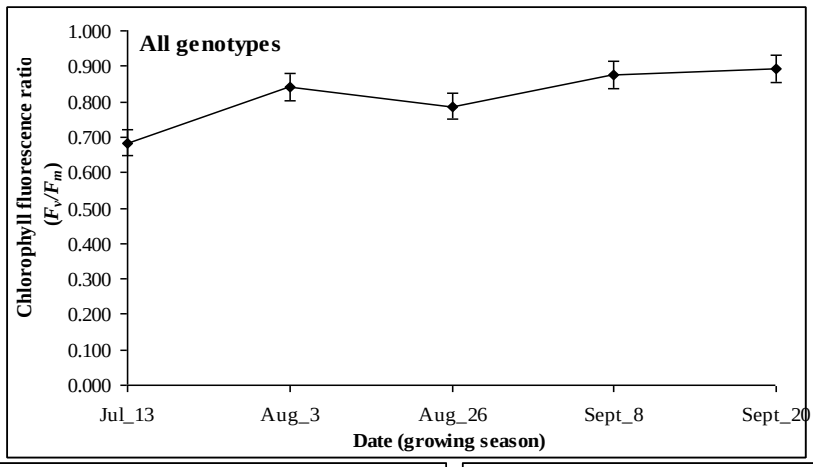
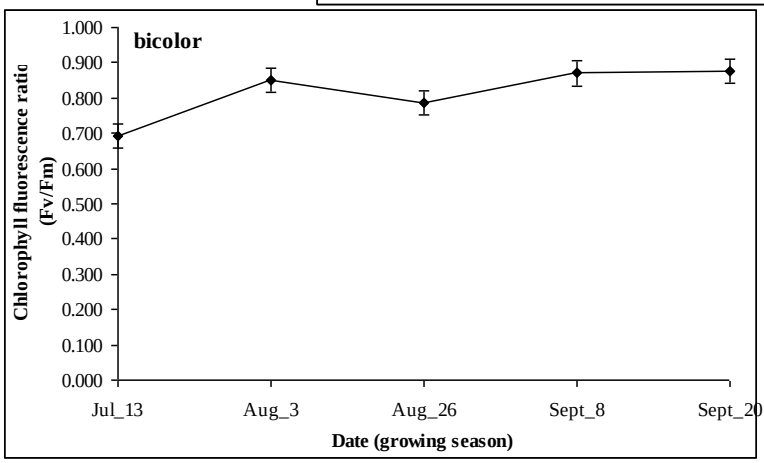
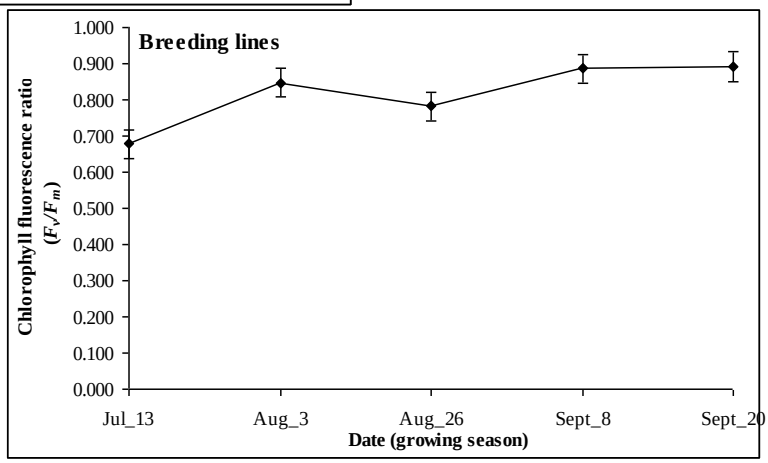
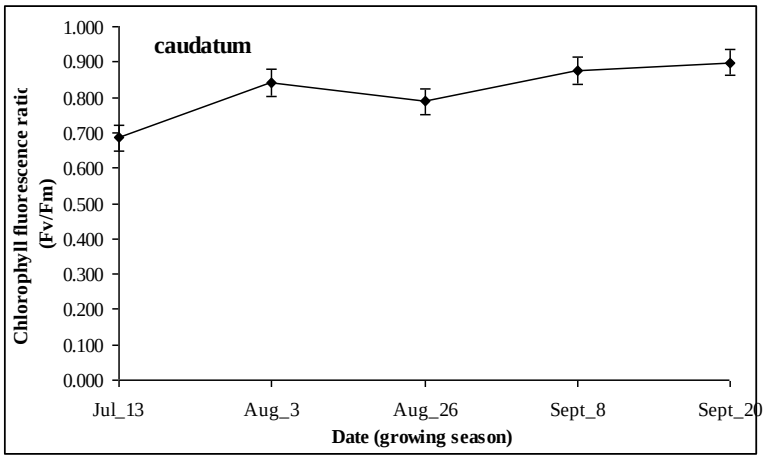


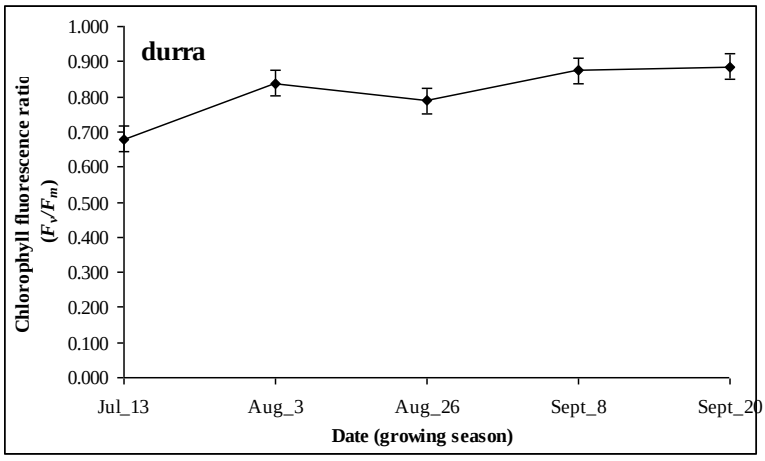
Figure 5.7: Chlorophyll fluorescence ratio (F_v/F_m) at different dates during growth at genotype and race level.

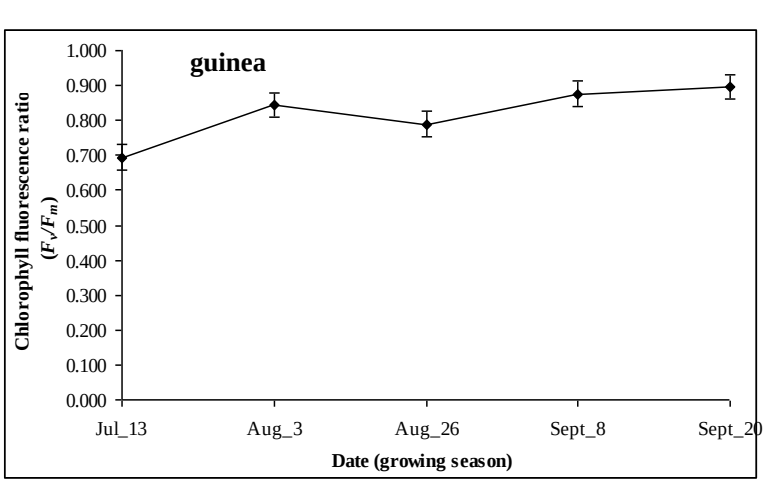












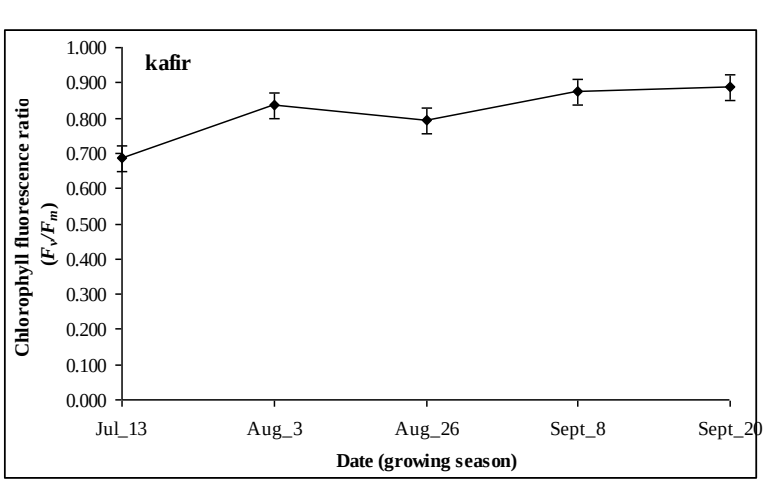


Table 5.7: Highest yielding genotypes based on mean for 2006 (Ashland rainfed) and 200: Hays and Ashland rainfed (Rfed), Ashland irrigated (Irr.)

Genotype	Race	Germplasm Type	Ashland 06	Hays 07	Ashland 07 rfed	Ashland 07 irr.	Mean
SC1019	Caudatum	Breeding-research material	39.67	6375.56	9065.37	8260.37	5935.24
HEGARI	Not Paced (NP)	Traditional cultivar-landrace	1099.63	7929.63	8040.37	5376.30	5611.48
SC471	NP	Breeding-research material	.	6434.44	5534.07	4192.59	5387.04
SC702	Caudatum	Breeding-research material	299.63	6711.67	7072.96	6661.30	5186.39
SC405	NP	Breeding-research material	1395.37	8509.26	5864.63	4780.00	5137.31
SC333	Caudatum	Breeding-research material	1342.04	5900.93	6749.26	6010.93	5000.79
SC704	Caudatum	breeding-research material	1616.30	6560.37	6956.30	4741.30	4968.56
Dorado	NP	Breeding-research material	1877.41	5535.56	6488.33	5594.07	4873.84
SC720	Caudatum	Breeding-research material	2535.74	5287.78	5531.67	5507.04	4715.56
SC964	Caudatum	Breeding-research material	860.74	4187.41	7099.26	6635.93	4695.83
SC504	NP	Breeding-research material	.	5699.44	3067.04	5063.33	4609.94
SC175	Caudatum	Breeding-research material	666.30	6022.78	6203.33	5510.00	4600.60
SC1079	Caudatum	Breeding-research material	1642.59	5136.67	5958.70	5550.00	4571.99
SC103	Caudatum	Breeding-research material	1437.59	6657.04	6330.93	3859.63	4571.30
Segaolane	NP	Breeding-research material	2059.07	5569.26	5762.41	4429.07	4454.95
SC424	Caudatum	Breeding-research material	2010.37	5451.67	4850.93	5436.30	4437.31
SC701	Caudatum	Breeding-research material	1088.70	5283.52	5402.59	5912.41	4421.81
SC1211	Kafir	Breeding-research material	2528.70	4321.85	5760.93	4705.37	4329.21
SU629	NP	Breeding-research material	.	3586.85	4863.33	4495.37	4315.19
SURENO	Central America	Cultivar	1773.33	3343.15	6887.04	5208.70	4303.06
SC391	Caudatum	Breeding-research material	2357.96	6178.15	3887.41	4752.41	4293.98
SC623	Durra	Breeding-research material	1872.96	4418.33	5592.59	5215.00	4274.72
SC1074	Kafir	Breeding-research material	2836.30	3204.63	5300.74	5657.04	4249.68
SC301	Guinea	Breeding-research material	914.63	5632.22	5857.04	4585.74	4247.41
SC51	Caudatum	Breeding-research material	2085.00	6102.59	4627.04	4147.59	4240.56
Malisor 84-7	West Africa	Cultivar	2990.37	4363.89	5552.41	4049.26	4238.98
SC1057	Caudatum	Breeding-research material	289.07	6867.04	6559.26	3220.93	4234.07
SC332	NP	Breeding-research material	2072.41	4153.89	6583.70	3932.96	4185.74
SC1345	Caudatum	Breeding-research material	1127.04	5014.81	5189.07	5379.26	4177.55
SC110	Caudatum	Breeding-research material	1442.96	4943.33	5232.59	5060.19	4169.77
SC373	Caudatum	Breeding-research material	2025.37	5115.56	5469.63	4028.33	4159.72

Table 5.8: Genotypes that performed well in 2006 (a dry year) and their performance in 2007 in Ashland and Hays (Yield in kg ha^{-1}).

Genotype	Race	Germplasm Type	Ashland 06 rainfed	Hays 07 rainfed	Ashland 07 rainfed	Ashland 07 irrigated	Mean
SC420	Kafir	breeding-research material	3357.41	2221.85	3015.00	1781.67	2593.98
SC738	Caudatum	breeding-research material	3104.63	4498.15	3470.00	3852.96	3731.44
SC708	Caudatum	breeding-research material	3037.59	3750.56	3042.41	4072.04	3475.65
SC760	Kafir	breeding-research material	3010.00	3393.52	4720.37	3331.67	3613.89
Malisor 84-7	West Africa	cultivar	2990.37	4363.89	5552.41	4049.26	4238.98
SC192	Durra	breeding-research material	2986.30	1667.41	2425.37	2395.74	2368.70
SC1074	Kafir	breeding-research material	2836.30	3204.63	5300.74	5657.04	4249.68
SC1337	Guinea	breeding-research material	2804.07	3002.96	4159.07	3542.41	3377.13
SC1416	Durra	breeding-research material	2772.04	3347.41	4254.07	3853.70	3556.81
SC1328	Caudatum	breeding-research material	2701.30	3733.89	5331.67	3863.33	3907.55
SC557	Caudatum	breeding-research material	2644.63	1318.89	2157.04	4347.96	2617.13
SC329	NP	breeding-research material	2602.41	4498.15	3738.33	4028.33	3716.81
SC720	Caudatum	breeding-research material	2535.74	5287.78	5531.67	5507.04	4715.56
SC1211	Kafir	breeding-research material	2528.70	4321.85	5760.93	4705.37	4329.21
SC118	Caudatum	breeding-research material	2480.37	4535.93	4430.00	3642.04	3772.08
SC121	Caudatum	breeding-research material	2420.74	1789.26	5101.67	5435.74	3686.85
SC265	Guinea	breeding-research material	2406.30	1680.00	2273.33	2983.70	2335.83
SC391	Caudatum	breeding-research material	2357.96	6178.15	3887.41	4752.41	4293.98
Macia	East & South Africa	cultivar	2290.74	2347.78	5186.67	4723.70	3637.22
SC396	Caudatum	breeding-research material	2152.96	2041.11	2566.67	956.67	1929.35
SC51	Caudatum	breeding-research material	2085.00	6102.59	4627.04	4147.59	4240.56
SC332	NP	breeding-research material	2072.41	4153.89	6583.70	3932.96	4185.74
Segaolane	NP	breeding-research material	2059.07	5569.26	5762.41	4429.07	4454.95
SC605	Guinea	breeding-research material	2032.41	1982.41	1628.33	2070.74	1928.47
SC373	Caudatum	breeding-research material	2025.37	5115.56	5469.63	4028.33	4159.72
SC424	Caudatum	breeding-research material	2010.37	5451.67	4850.93	5436.30	4437.31
SC855	Durra	breeding-research material	2005.37	2360.37	3631.67	2684.63	2670.51
SC1218	Guinea	breeding-research material	2002.04	613.15	624.63	1931.30	1292.78

Table 5.9: Genotypes that whose means remained high for the three years (over 2,000 kg ha^{-1} in Ashland 2006 rainfed).

Genotype	Race	Germplasm Type	Ashland 2006 rainfed	Hays 2007 rainfed	Ashland 2007 rainfed	Ashland 2007 irrigated	Mean
SC720	Caudatum	breeding-research material	2535.74	5287.78	5531.67	5507.04	4715.56
Segaolane	Not Placed	breeding-research material	2059.07	5569.26	5762.41	4429.07	4454.95
SC424	Caudatum	breeding-research material	2010.37	5451.67	4850.93	5436.30	4437.31
SC1211	Kafir	breeding-research material	2528.70	4321.85	5760.93	4705.37	4329.21
SC391	Caudatum	breeding-research material	2357.96	6178.15	3887.41	4752.41	4293.98
SC1074	Kafir	breeding-research material	2836.30	3204.63	5300.74	5657.04	4249.68
SC51	Caudatum	breeding-research material	2085.00	6102.59	4627.04	4147.59	4240.56
Malisor 84-7	West Africa	cultivar	2990.37	4363.89	5552.41	4049.26	4238.98
SC332	Not Placed	breeding-research material	2072.41	4153.89	6583.70	3932.96	4185.74
SC373	Caudatum	breeding-research material	2025.37	5115.56	5469.63	4028.33	4159.72

Figure 5.8: Yield stability for the 300 genotypes investigated as indicated by the relation between mean yield and regression coefficient. Genotypes falling in the region with mean yield of over mean yield +1SD and the two lines for the regression coefficient (Mean Regression±1SD) were stable across the four environments under study.

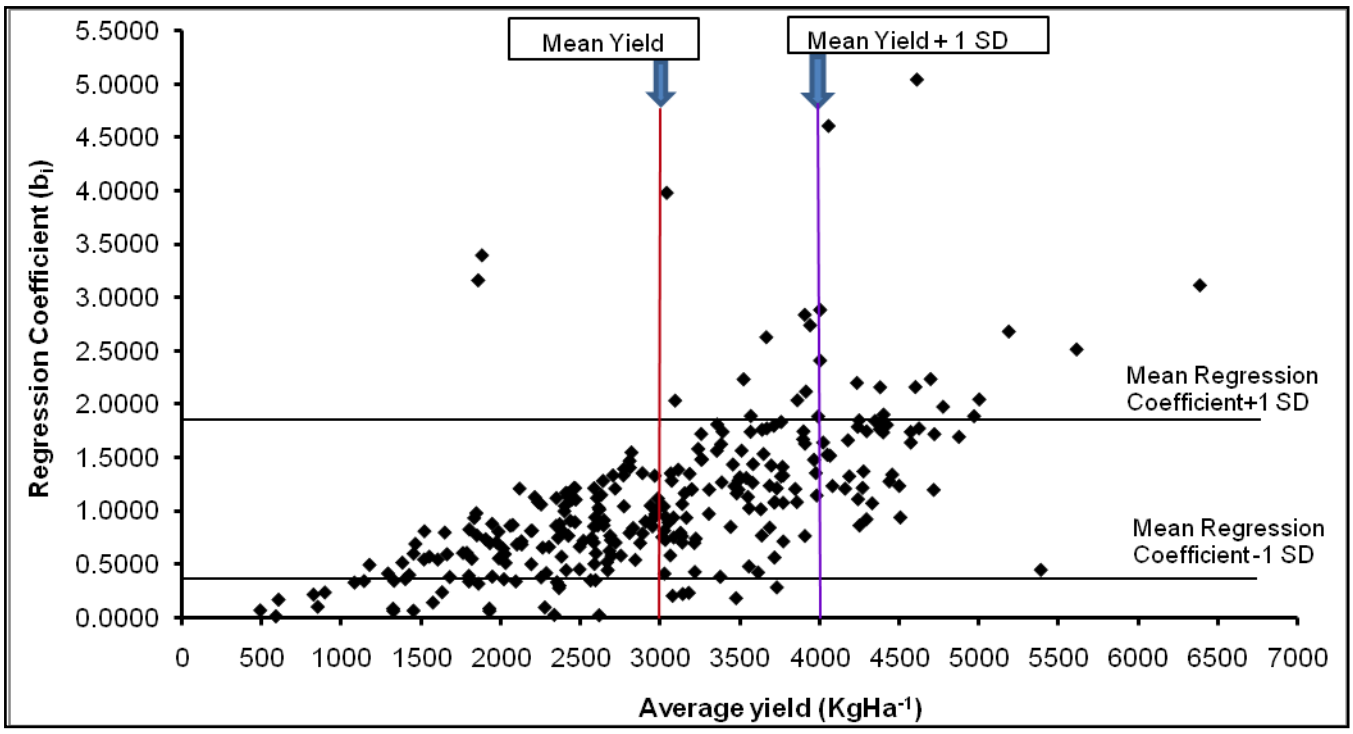


Table 5.10: Thirty one (31) genotypes with the highest yield stability based on regression coefficient (b=1).

	Genotype	Race	Germplasm type	SS (Reg)	SS (Dev)	Var (Dev)	Mean Yld	Reg. Coeff.
1	SC749	Caudatum	Breeding-research material	11748788	678751	339376	4022	1.6423
2	SC564	Caudatum	Breeding-research material	10158361	10082736	5041368	4048	1.5271
3	RTX2536	Breeding line	Inbred line	6343774	128922	128922	4081	1.2343
4	SC373	Caudatum	Breeding-research material	6366109	836427	418213	4160	1.2089
5	SC1345	Not Placed	Breeding-research material	12050130	424027	212013	4178	1.6632
6	SC332	Caudatum	Breeding-research material	7646276	2635161	1317581	4186	1.3249
7	MR732	West Africa	Cultivar	13954013	1357710	678855	4239	1.7898
8	SC51	Caudatum	Breeding-research material	5370280	2901317	1450658	4241	1.1103
9	SC301	Guinea	Breeding-research material	14917328	812691	406345	4247	1.8505
10	SC1074	Kafir	Breeding-research material	3246461	2928402	1464201	4250	0.8633
11	RTx437	Breeding line	Inbred line	6448804	2908618	1454309	4269	1.2167
12	SC623	Durra	Breeding-research material	8193930	216082	108041	4275	1.3715
13	SC391	Caudatum	Breeding-research material	3704550	3969203	1984602	4294	0.9222
14	BTx645	Breeding line	Inbred line	13313557	3246918	1623459	4295	1.7482
15	SC1211	Kafir	Breeding-research material	5006772	426731	213365	4329	1.0721
16	SC60	Caudatum	Breeding-research material	14829900	2953928	1476964	4347	1.8451
17	RTx430	Breeding line	Inbred line	13608827	349947	174973	4377	1.7675
18	SC563	Caudatum	Breeding-research material	14779792	455425	227712	4390	1.8420
19	(SN149)SA7000 CAPROCK	Breeding line	Inbred line	13145421	722132	361066	4399	1.7372
20	SC701	Caudatum	Breeding-research material	14228978	807288	403644	4422	1.8073
21	SC424	Caudatum	Breeding-research material	7112443	975744	487872	4437	1.2778
22	Segaolane	Not Placed	Breeding-research material	7832271	859783	429892	4455	1.3409
23	RTx2783	Breeding line	Inbred line	6645755	218165	109083	4499	1.2352
24	Tx2741	Breeding line	Inbred line	3672814	1299019	1299019	4506	0.9391
25	SC103	Caudatum	Breeding-research material	13206177	4566591	2283296	4571	1.7412
26	SC1079	Caudatum	Breeding-research material	11742262	36834	18417	4572	1.6418
27	SURENO	Central America	Cultivar	13111163	478138	478138	4623	1.7744
28	SC720	Caudatum	Breeding-research material	6249718	122083	61041	4716	1.1978
29	BTx399	Breeding line	Inbred line	12905012	79438	39719	4720	1.7212
30	Dorado	Not Placed	Breeding-research material	12517686	24512	12256	4874	1.6952
31	SC471	Guinea	Breeding-research material	29536	2515551	2515551	5387	0.4467

Table 5.11: Correlation between yield traits and physiological traits.

		Physiological Traits								
		Leaf temperature			Chlorophyll Content (SPAD)			Chlorophyll Fluorescence (F_v/F_m)		
Yield trait	**Race**	**Correlation**	**r - value**	**P-value**	**Correlation**	**r - value**	**P-value**	**Correlation**	**r - value**	**P-value**
Grain weight per panicle	Genotype level	Positive	0.1868	**	Positive	0.0871	NS	Negative	0.1456	**
	Breeding lines	Positive	0.1077	**	Positive	0.1476	**	Negative	0.3642	NS
	Durra	Positive	0.1865	*	Positive	0.2037	NS	Negative	0.1792	*
	Caudatum	Positive	0.2848	**	Positive	0.1066	NS	Positive	0.3330	**
	Guinea	Positive	0.1217	NS	Positive	0.2632	**	Negative	0.2711	**
	Kafir	Positive	0.3924	**	Positive	0.2874	**	Negative	0.1758	NS
	Bicolor	Positive	0.2880	*	Negative	0.0000	NS	Negative	0.1122	NS
Grain numbers per panicle	Genotype level	Positive	0.1715	**	Positive	0.0872	NS	Negative	0.0656	NS
	Breeding lines	Positive	0.1628	***	Positive	0.2274	***	Negative	0.4491	**
	Durra	Positive	0.0819	**	Positive	0.3010	NS	Negative	0.3686	***
	Caudatum	Positive	0.3812	**	Positive	0.1179	NS	Positive	0.3094	**
	Guinea	Positive	0.0374	NS	Positive	0.2968	**	Negative	0.3658	**
	Kafir	Positive	0.3890	**	Positive	0.1892	NS	Negative	0.3040	**
	Bicolor	Positive	0.3933	**	Positive	0.2205	NS	Negative	0.2012	NS
Harvest Index	Genotype level	Positive	0.2492	***	Positive	0.1533	**	Negative	0.1715	**
	Breeding lines	Positive	0.2166	***	Positive	0.2972	**	Negative	0.4042	**
	Durra	Positive	0.0954	NS	Positive	0.2307	*	Negative	0.1536	NS
	Caudatum	Positive	0.4562	***	Positive	0.3300	**	Positive	0.3378	**
	Guinea	Positive	0.1308	NS	Positive	0.3233	**	Negative	0.3396	**
	Kafir	Positive	0.1803	NS	Positive	0.1136	NS	Negative	0.1330	NS
	Bicolor	Positive	0.1884	NS	Negative	0.0101	NS	Negative	0.0980	NS
Grain yield per hactare	Genotype level	Positive	0.2200	***	Positive	0.1540	**	Negative	0.0964	NS
	Breeding lines	Positive	0.3311	***	Negative	0.0900	*	Positive	0.2482	**
	Durra	Negative	0.0616	NS	Negative	0.1676	NS	Positive	0.3585	**
	Caudatum	Positive	0.4484	***	Positive	0.6220	NS	Positive	0.3540	**
	Guinea	Positive	0.4205	**	Positive	0.1764	NS	Negative	0.1086	NS
	Kafir	Positive	0.6184	***	Positive	0.4405	**	Negative	0.0889	NS
	Bicolor	Negative	0.2848	NS	Positive	0.6177	**	Positive	0.2693	NS

***, **, *, Significant at P<0.0001 and P<0.005, P<0.01, NS – Not significant.

Figure 5.9: Correlation between yield and physiological traits: US Breeding lines.

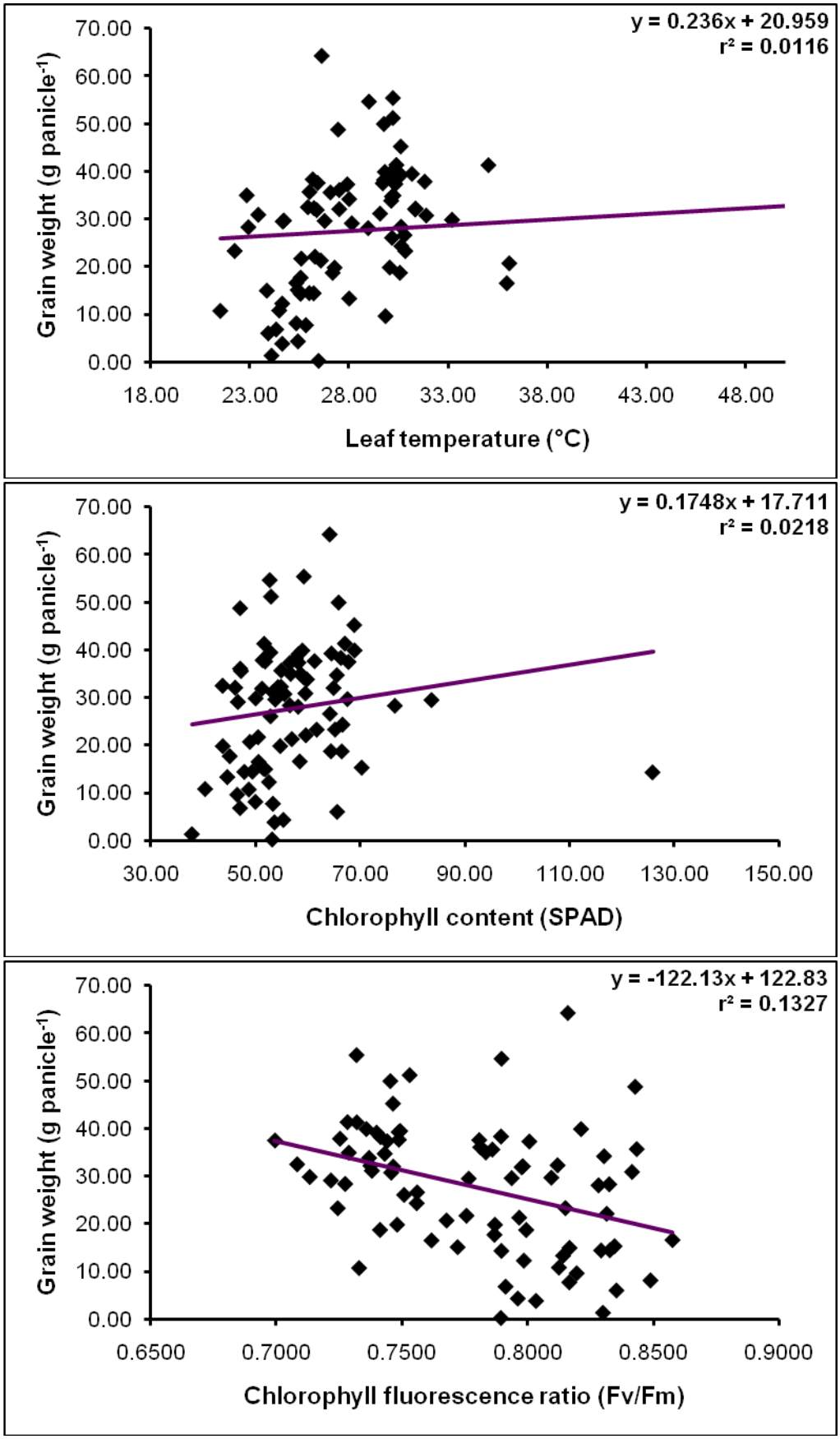


Figure 5.10: Correlation between yield and physiological traits: Durra.

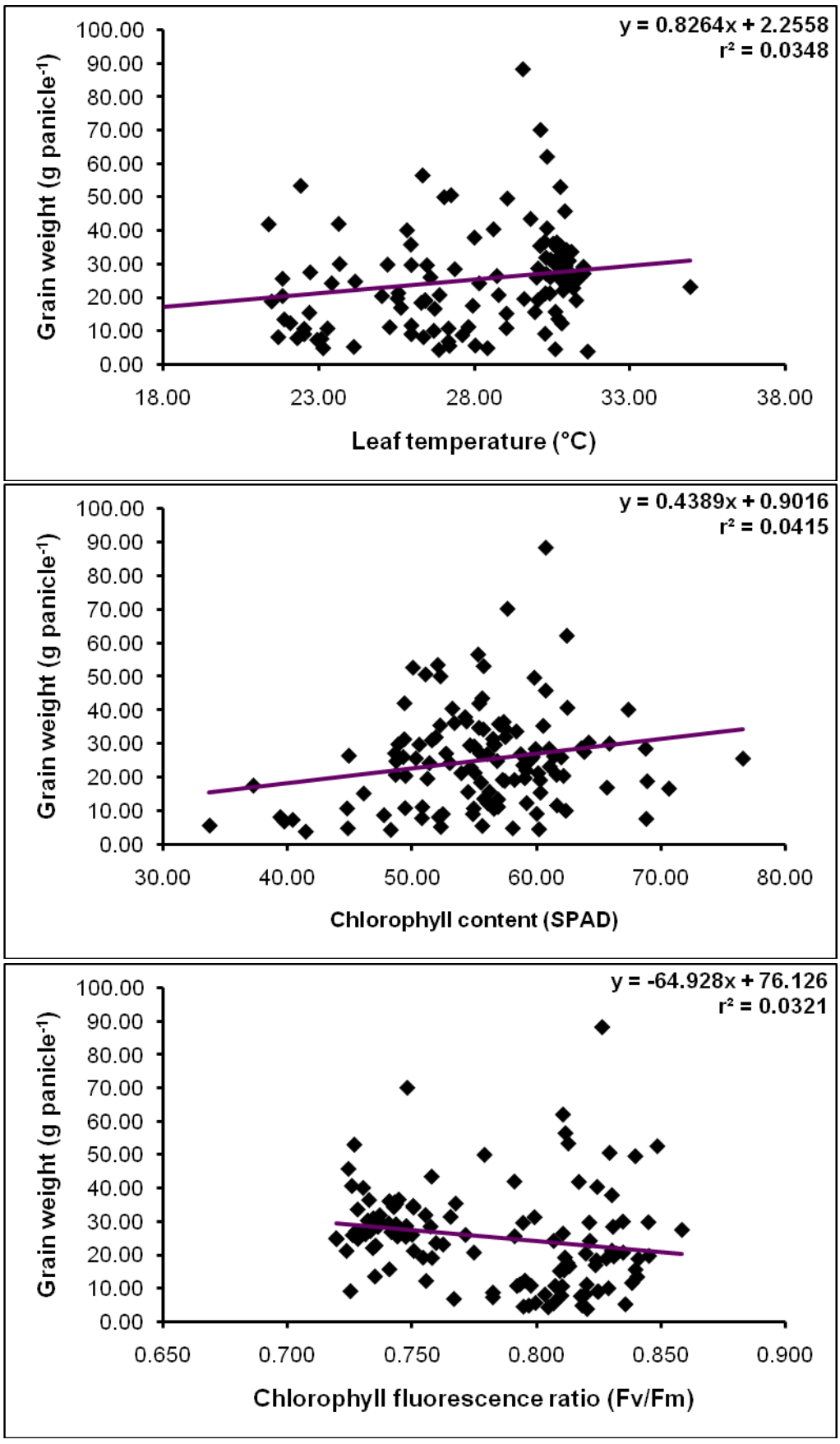


Figure 5.11: Correlation between yield and physiological traits: Caudatum.

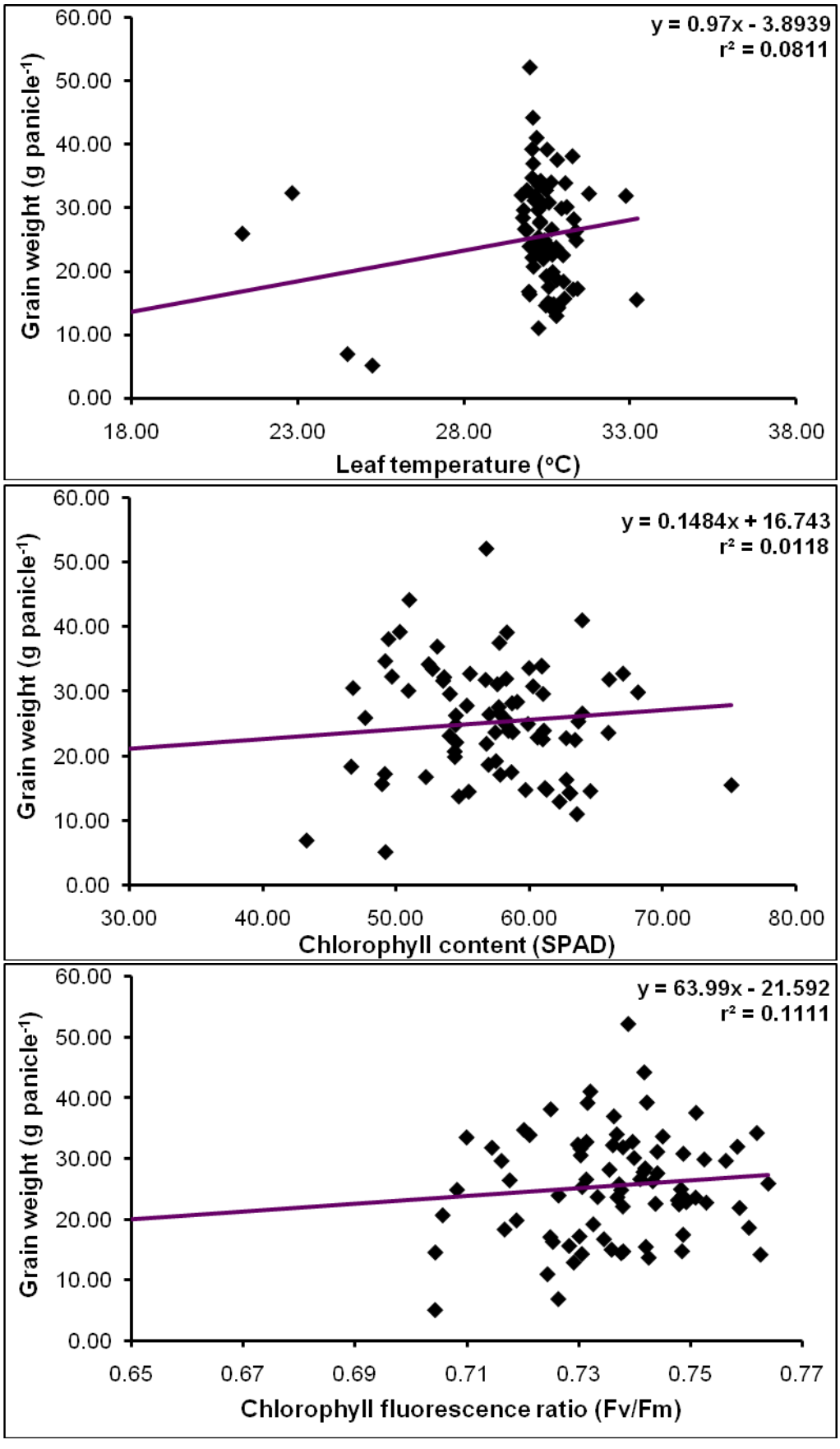


Figure 5.12: Correlation between yield and physiological traits: Guinea.

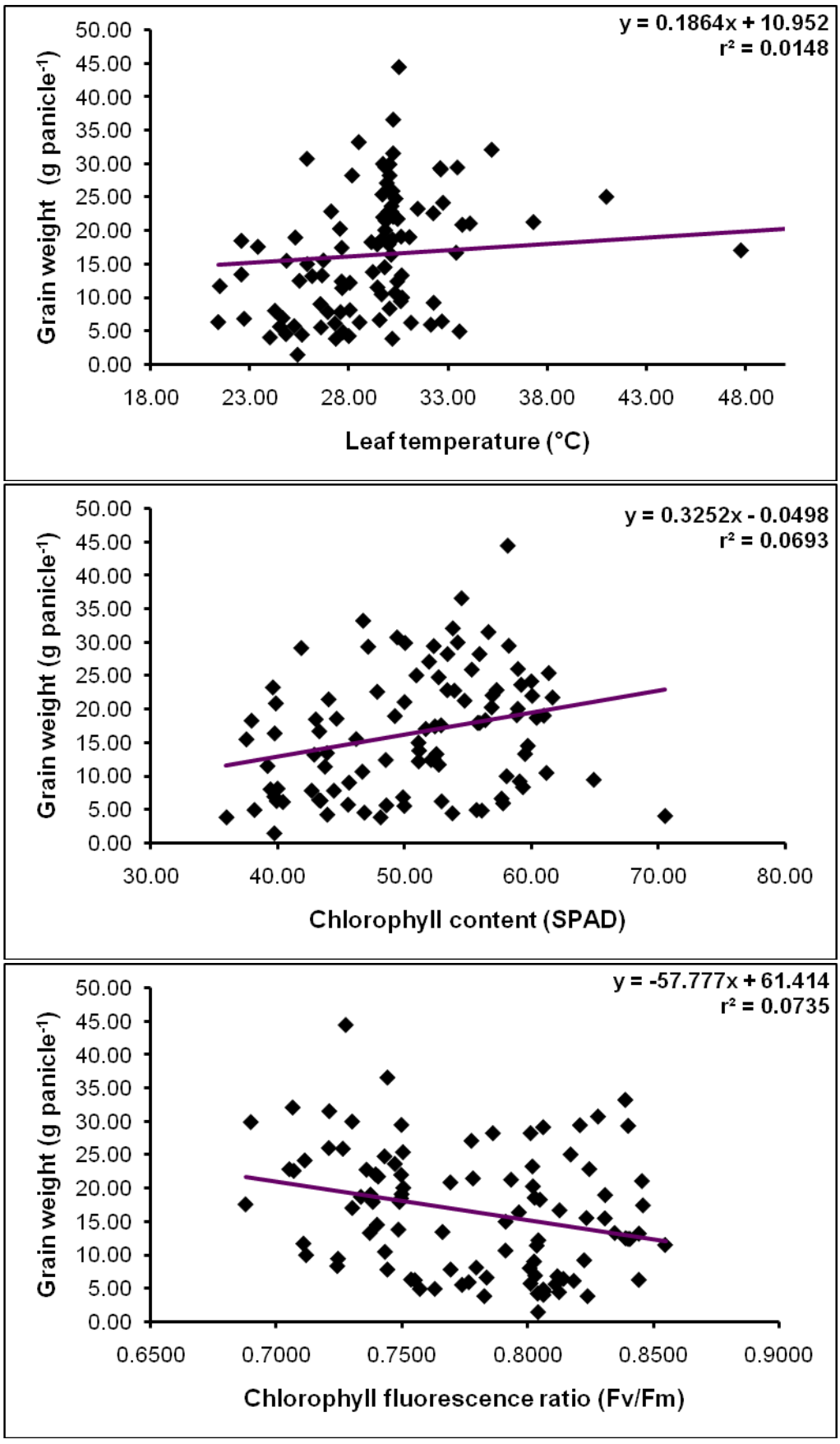
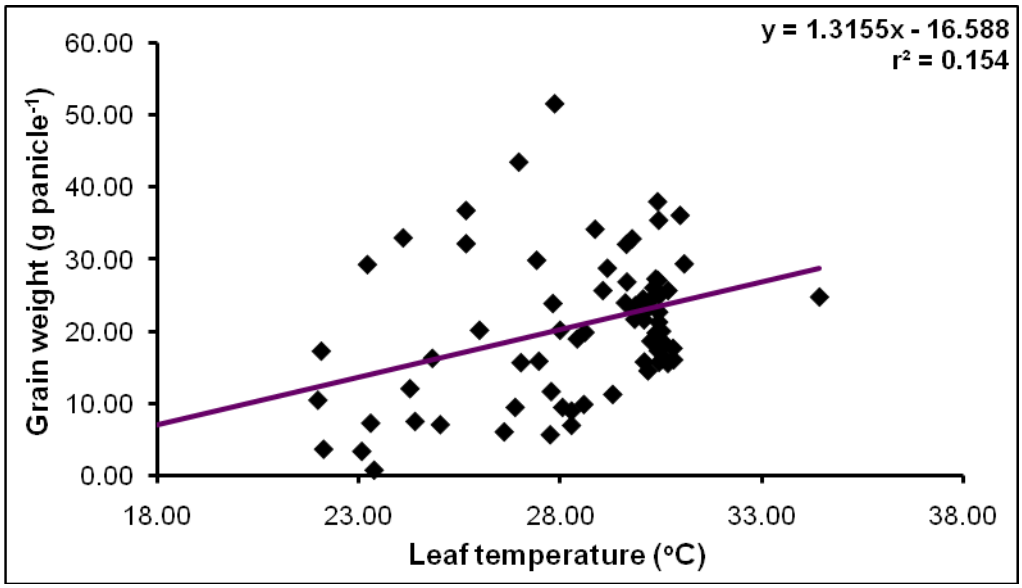
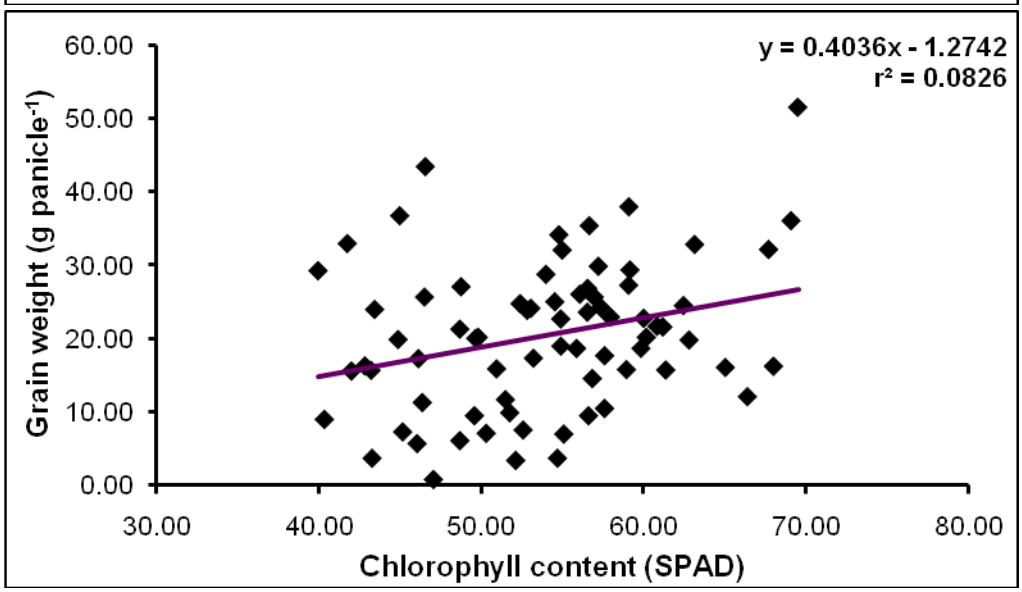


Figure 5.13: Correlation between yield and physiological traits: Kafir.





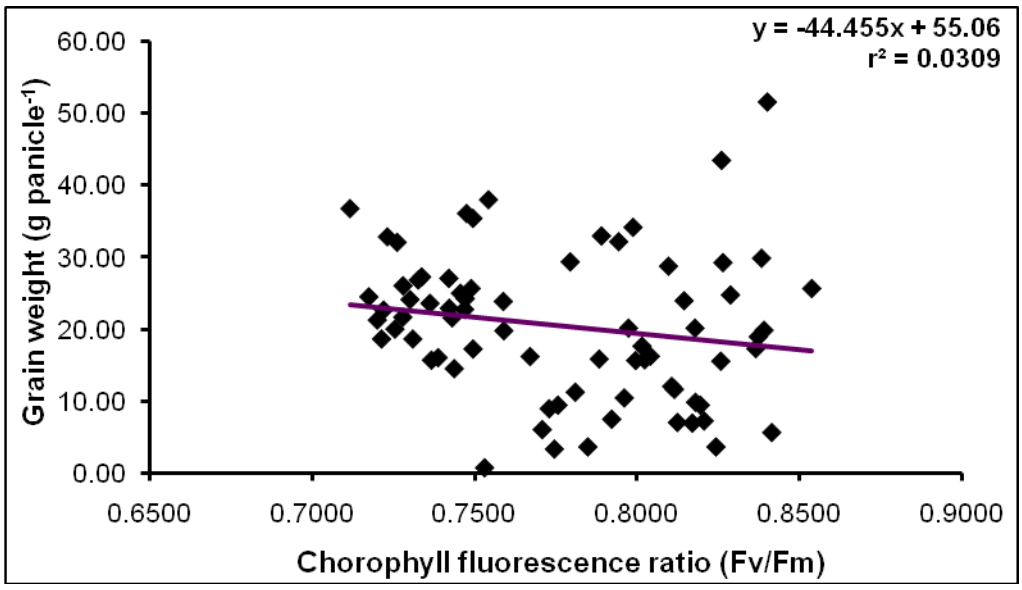


Figure 5.14: Correlation between yield and physiological traits: Bicolor.

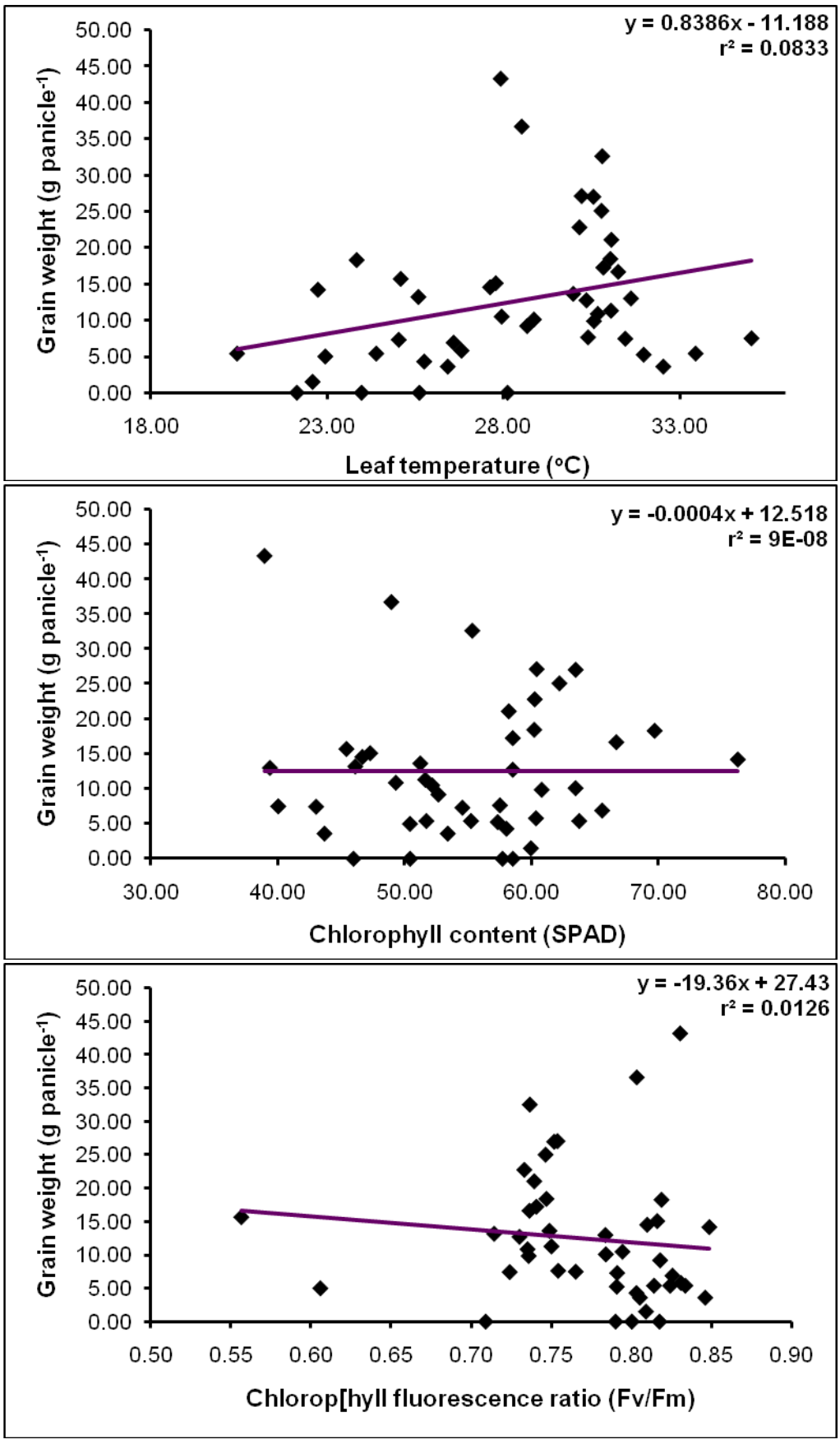
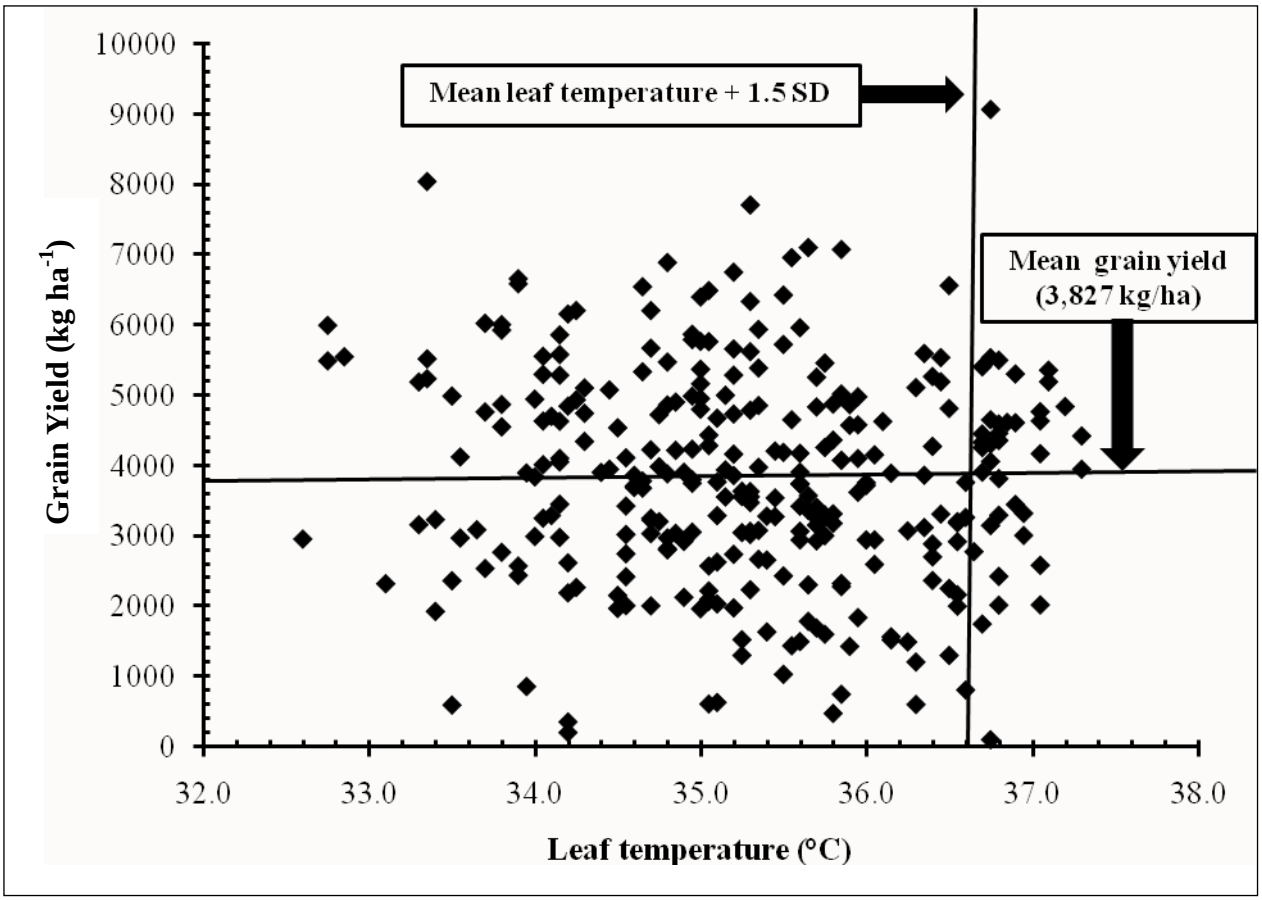


Figure 5.15: Genotypes that had above average grain yield and recorded a high leaf temperature under fully irrigated conditions (Ashland – Manhattan – 2007 irrigated united).



Note: Mean maximum air temperature for the days that data was collected was 32°C

Table 5.12: Genotypes that recorded high leaf temperature and had above average grain yields under fully irrigated conditions (Ashland – Manhattan - 2007 irrigated unit).

Genotype	Race/group	Leaf temperature (°C)	Grain yield (kg ha^{-1})
SC610	bicolor	36.8	4055
SC614	bicolor	36.7	4327
SC782	caudatum	37.3	3944
SC803	caudatum	37.1	5354
SC979	caudatum	37.1	5189
SC1451	caudatum	37.1	4630
SC1251	caudatum	36.9	4606
SC1212	caudatum	36.8	4588
SC1319	caudatum	36.8	4456
SC725	caudatum	36.8	4354
SC1019	caudatum	36.8	9065
SC720	caudatum	36.8	5532
SC564	caudatum	36.7	3903
SC599	caudatum	36.7	4447
SC701	caudatum	36.7	5403
SC1057	caudatum	36.5	6559
SC1345	caudatum	36.5	5189
SC1047	durra	36.8	5496
SC987	durra (*durra-bicolor)	37.2	4836
SC1471	durra (*durra-bicolor)	37.1	4165
SC1014	durra (*durra-bicolor)	36.9	4611
SC1074	kafir	36.9	5301
SC627	kafir	36.8	4302
SC625	kafir	36.7	4251
SC645	kafir (*kafir-caudatum)	36.5	4810
SC971	kafir-durra	37.1	4763
SC284	Not placed	37.3	4418
SC337	Not placed	36.8	4648
SC471	Not placed	36.5	5534

*intermediate race

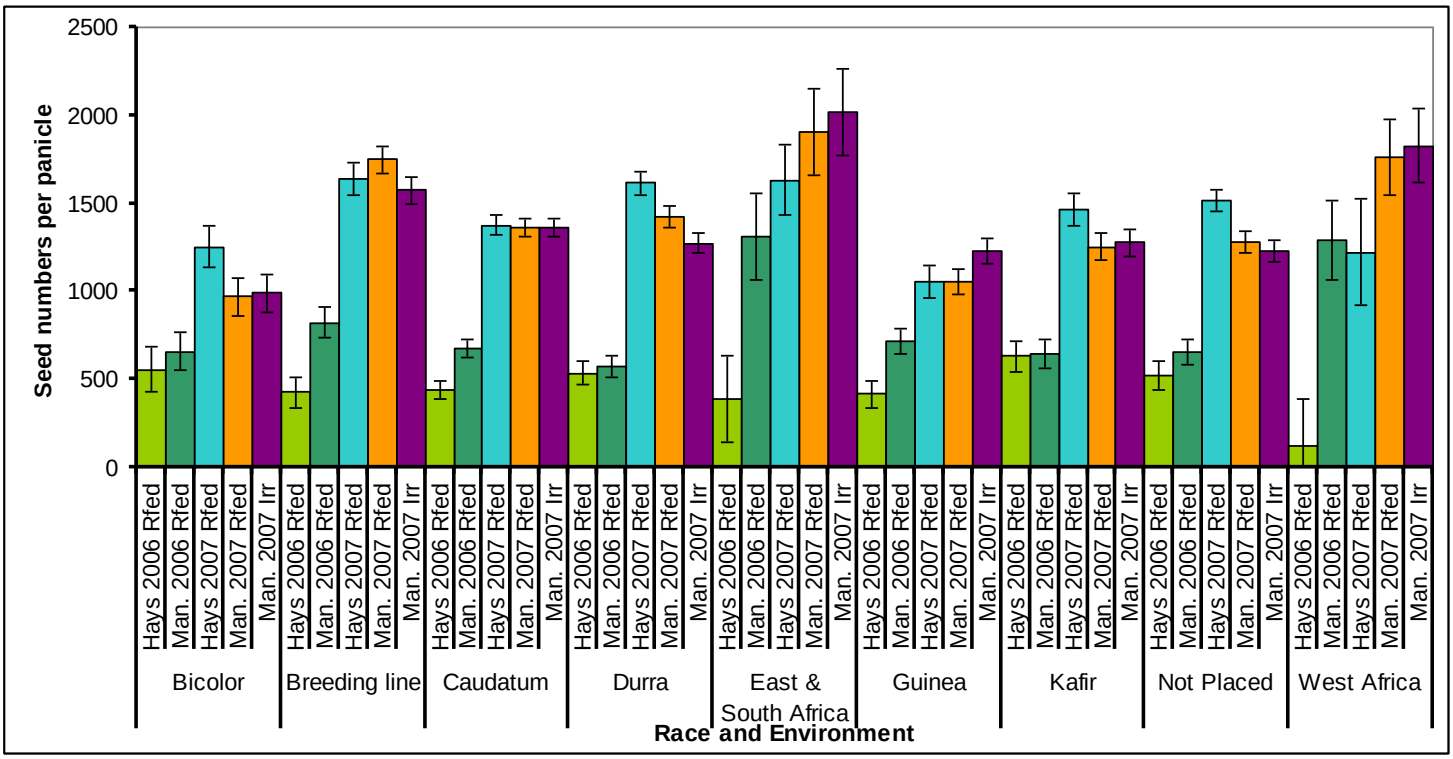
Note: Mean maximum air temperature for the days that data was collected was 32°C.

Caudatum (15) - 51.72%, durra (4) - 13.79%, kafir (5) - 17.24%, not placed (3) - 10.34%, bicolor (2) - 6.90%.

Table 5.13: Effects of Environment on seed numbers per panicle and harvest index.

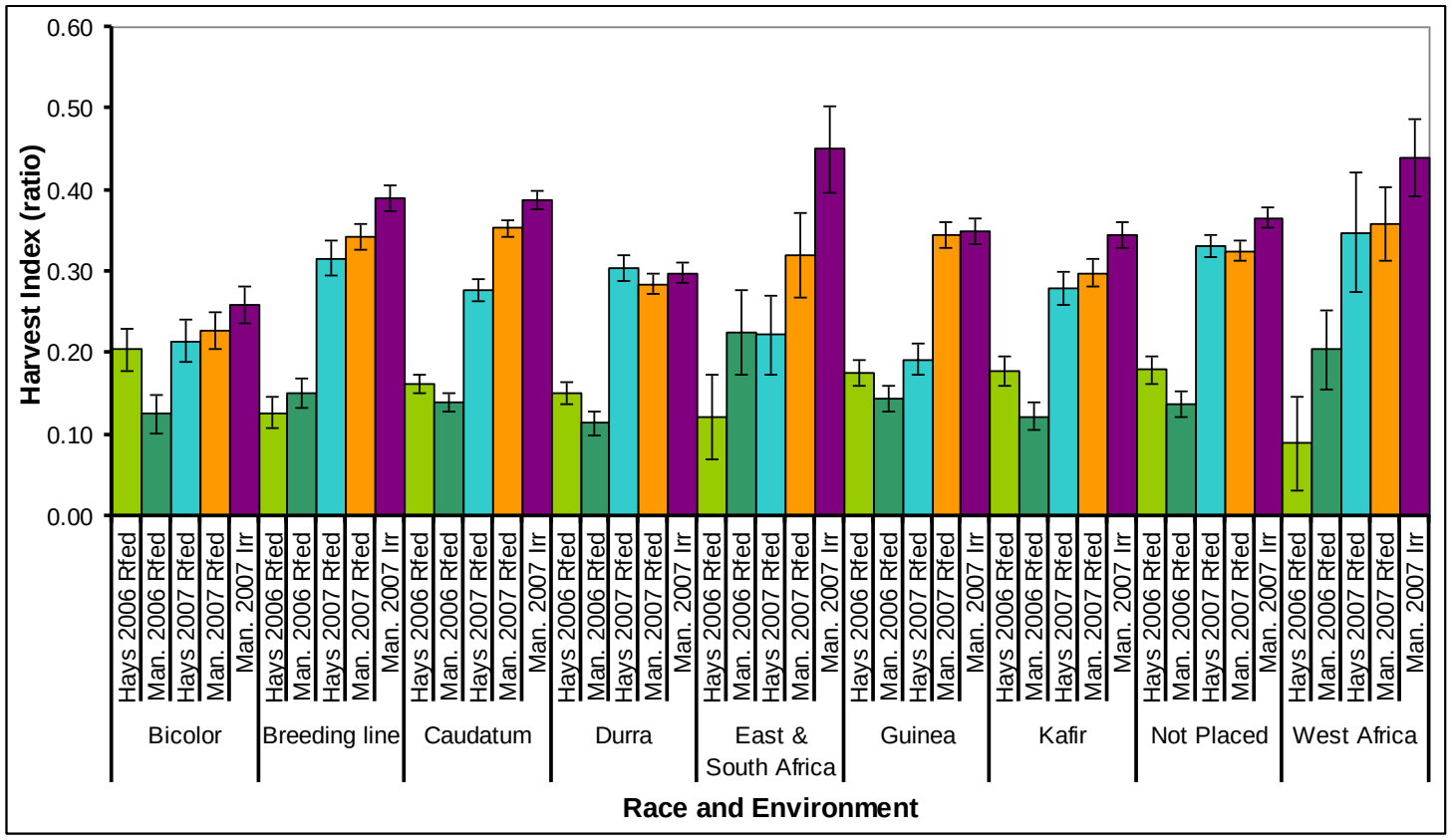
Race	Location	Seed Numbers panicle^{-1}			Harvest Index		
		2006	2007	% reduction	2006	2007	% reduction
Bicolor	Hays	558	1255	55.5	0.20	0.21	4.76
	Manhattan	659	969	32.0	0.13	0.23	45.17
Breeding line	Hays	427	1638	73.9	0.13	0.32	59.91
	Manhattan	824	1750	52.9	0.15	0.34	55.67
Caudatum	Hays	441	1377	68.0	0.16	0.28	41.82
	Manhattan	675	1361	50.4	0.14	0.35	60.27
Durra	Hays	537	1616	66.8	0.15	0.30	50.54
	Manhattan	574	1420	59.6	0.11	0.29	60.00
East & South Africa	Hays	391	1633	76.1	0.12	0.22	45.40
	Manhattan	1312	1905	31.1	0.23	0.32	29.59
Guinea	Hays	416	1055	60.6	0.18	0.19	8.14
	Manhattan	713	1054	32.4	0.14	0.35	58.37
Kafir	Hays	630	1463	56.9	0.18	0.28	36.29
	Manhattan	642	1252	48.7	0.12	0.30	58.90
Not Placed	Hays	522	1517	65.6	0.18	0.33	45.88
	Manhattan	659	1279	48.5	0.14	0.33	57.65
West Africa	Hays	119	1224	90.3	0.09	0.35	74.31
	Manhattan	1289	1760	26.7	0.20	0.36	42.81
	Mean	**633**	**1418**	**55.3**	**0.15**	**0.30**	**46.4**
Minimum reduction (%)				**26.74**			**4.76**
Maximum reduction (%)				**90.28**			**74.31**

Figure 5.16: Effects of environment on seed numbers per panicle.



Note: Rfed – Rainfed, Irr - Irrigated

Figure 5.17: Effects of environment on harvest index.



Note: Rfed – Rainfed, Irr - Irrigated

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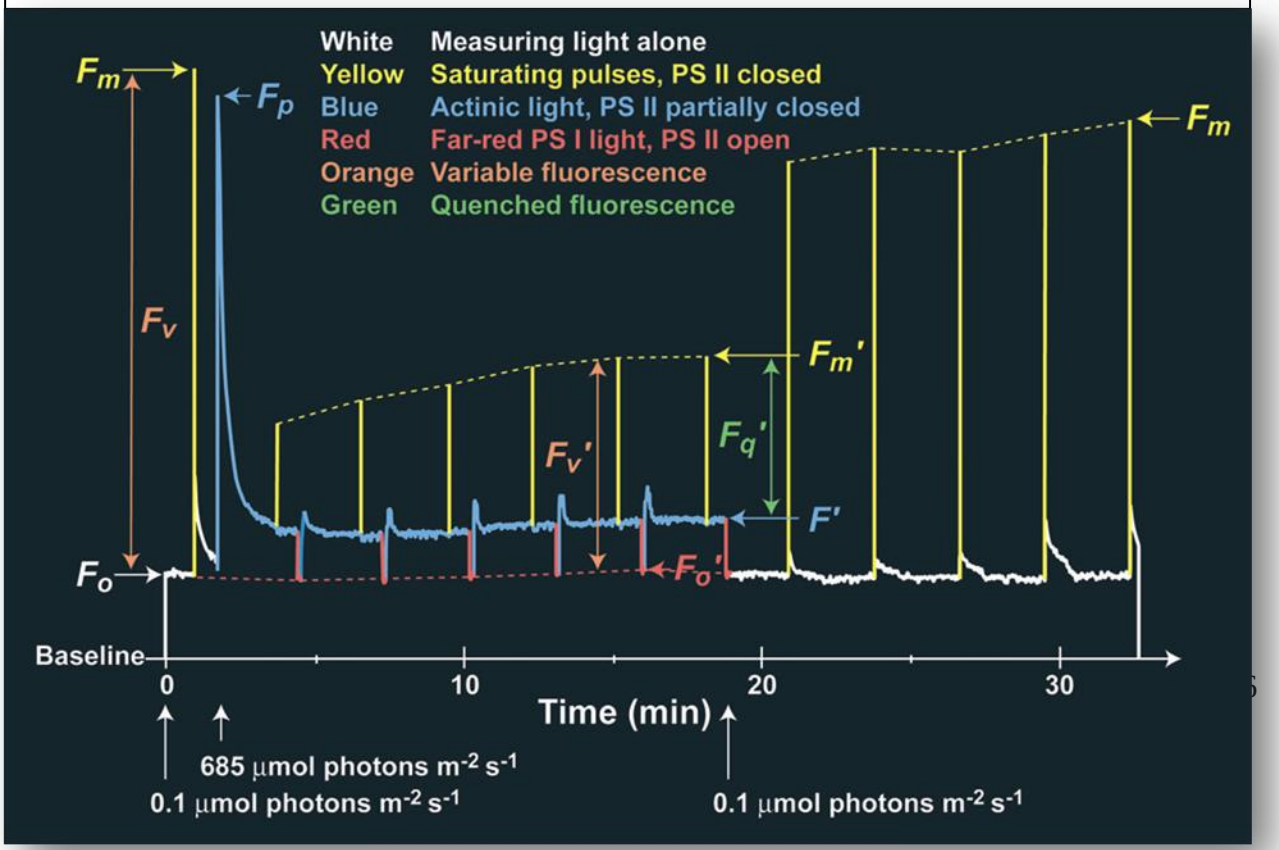
Appendix A - 5.9: Appendix and Supplementary tables

5.9.1 Appendix A. Protocol for quenching analysis using modulated fluorescence.

A dark-adapted leaf is exposed to various light treatments. The fluorescence parameters denoted with a prime originate from the illuminated leaf, where energy-dependent, non-photochemical quenching is present. The parameters without a prime are obtained from the leaf in the dark-adapted state, where there is no energy-dependent non-photochemical quenching. The different colors of the trace denote different light treatments. White, weak measuring light alone (0.1 µmol photons $m^{-2}s^{-1}$) that gives F_o. Yellow, saturating light pulse (<1 s duration, >6000 µmol photons m^{-2} s^{-1}) that gives F_m in darkness and F'_m in light. Blue; actinic light that drives photosynthesis (in this case 685 µmol photons $m^{-2}s^{-1}$) that gives F' (if steady-state has been reached this has often been denoted by F'_s). The actinic light can be produced from a range of sources, for example, sunlight, halogen lamp, light-emitting

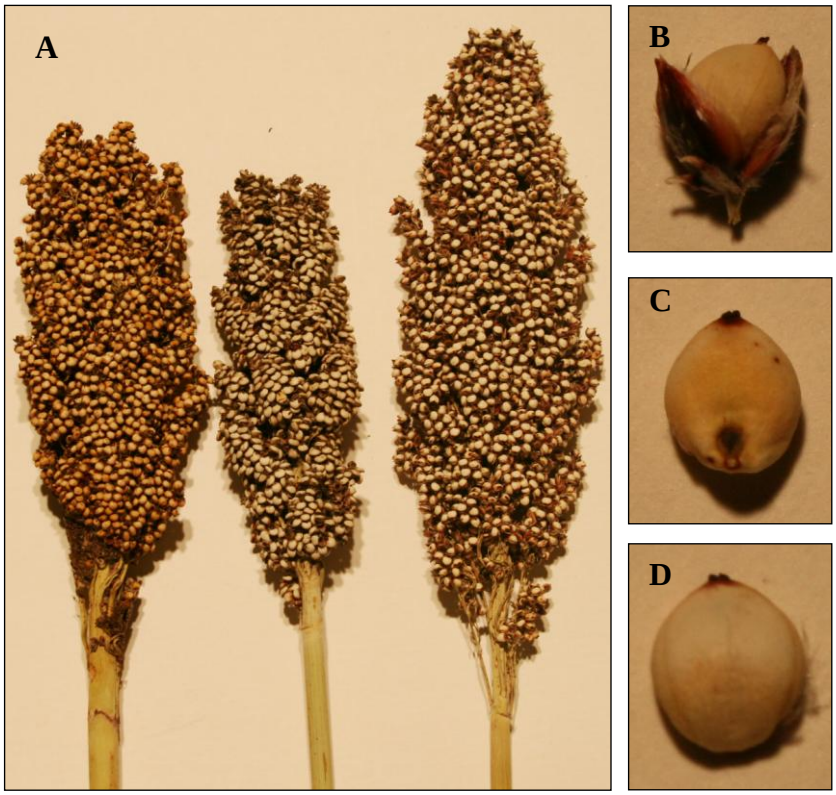


Summary of the major fluorescence parameters (Baker & Rosenqvist, 2004)

Fluorescence Parameter	Definition	Physiological significance
F	Fluorescence emission from dark- adapted leaf	Provide little information of photosynthetic performance as they are influenced by many factors
F'	Fluorescence emission from leaf adapted to actinic light	
F_o	Minimal fluorescence from dark-adapted leaf	Level of fluorescence when primary quinone electron acceptors of PSII (Q_A) are maximally oxidized (PSII centers are open)
F'_o	Minimal fluorescence from light-adapted leaf	
F_m	Maximal fluorescence from dark-adapted leaf	Level of fluorescence when Q_A is maximally reduced (PSII centers are closed)
F'_m	Maximal fluorescence from light-adapted leaf	
F_v	Variable fluorescence from dark-adapted leaf	Demonstrates the ability of PSII to perform primary photochemistry (photoreduction of Q_A)
F'_v	Variable fluorescence from light-adapted leaf	
F'_q	Difference in fluorescence between F'm and F'	Photochemical quenching of fluorescence due to open PSII centers
F_v/F_m	Maximum quantum efficiency of PSII photochemistry	Maximum efficiency at which light absorbed by light-harvesting antennae of PSII is converted to chemical energy (Q_A reduction)
F'_q/F'_m	PSII operating efficiency	Estimates the efficiency at which light absorbed by PSII antennae is used for photochemistry (QA reduction). At a given light intensity it provides a measure of the quantum efficiency of linear electron transport through PSII. Has previously been termed $\Delta F/$ F'm and Φ_{PSII}
F'_v/F'_m	PSII maximum efficiency	Provides an estimate of the maximum efficiency of PSII photochemistry at a given light intensity, which is the PSII operating efficiency if all the PSII centers are open (Q_A oxidized)
F'_q/F'_v	PSII efficiency factor	Is non-linearly related to the proportion of PSII centers that are open (with QA oxidized). Relates the PSII maximum efficiency to the PSII operating efficiency. Mathematically identical to the coefficient of photochemical quenching, *qP*
NPQ	Non-photochemical quenching	Estimates the non-photochemical quenching from F_m to F'_m. Monitors the apparent rate constant for non-radioactive decay (heat loss) from PSII and its antennae.

5.9.2 Appendix B: Description of sorghum races

5.9.2.1 Race: Caudatum



Picture 5.1: Caudatum panicles (A), seed with glumes (B), seed without glumes (C, D) of caudatum

In tracing its origin, the caudatum race was associated with the speakers of the Chari-Nile languages in Africa and it is widely distributed throughout northeastern Nigeria, Chad, Sudan, Ethiopia and Uganda (Stemler et al., 1975). The caudatums are restricted primarily to the area of early bicolor domestication hence could be a derivation from an introgressed cross with early bicolor and the wild sorghum complex (Harlan and Stemler, 1976). Dogget (1988) believes that this race is younger than guinea or durra because it does not occur in India and does not arise

from all the guinea and durra crosses. This is an important race agronomically and has provided genetic material for high yield and good seed quality hence becoming an important source of germplasm in modern breeding programs globally.

Some of the distinguishing features for this race include panicles that are dense to slightly open with a stout peduncle (Picture 5.1). The glumes are pubescent or coriaceuos and partially cover the grain which is turtleback in shape. Rachis and branches are rigid. Plants are generally medium to tall and are usually high yielding.

5.9.2.2 Race: Guinea

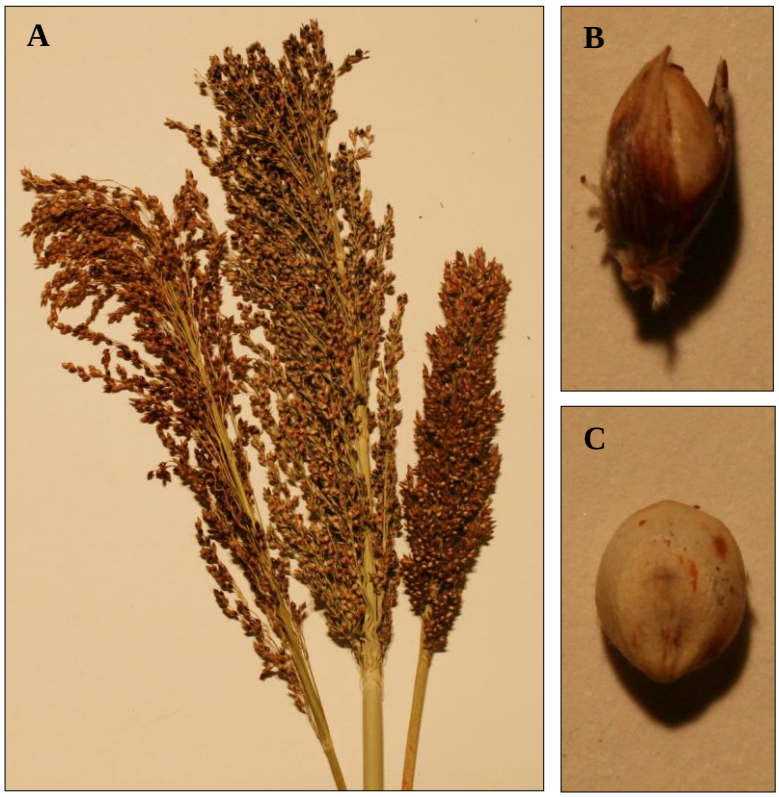
Picture 5.2: Guinea panicles (A), seed with glumes (B) seed without glumes (C)

Harlan et al. (1976) suggested that the guinea race originated some 3,000 years ago. Portères (1962) proposed the origin of this race to be from the wild race arundinaceum, a primarily forest grass because the guineas are exclusively grown on forest regions in West Africa and race is also sympatric with the wild arundinaceum. But de Wet et al., (1972) did not find any closer affinities with arundinaceum than the verticilliflorum-aethiopicum complex. Although the guinea race is grown in the forest, it is a savanna cereal and therefore originated in the West African savanna. This race extends across the savannas of Africa and is also grown widely in Asia as well as in humid areas of southern Africa. Due to the similarities that exist between the

guineas of west and southern Africa, de Wet et al., (1972) speculates that it should be assumed that the guinea race originated from West Africa.

Characteristic features for this race include panicle are long, loose and pendulous (Picture 5.2), involuted glumes that cover most of the grain which is flattened, twisting and ovate. Rachis is long with short branches. Plants are medium to tall height and tend to be low yielding.

5.9.2.3 Race: Bicolor

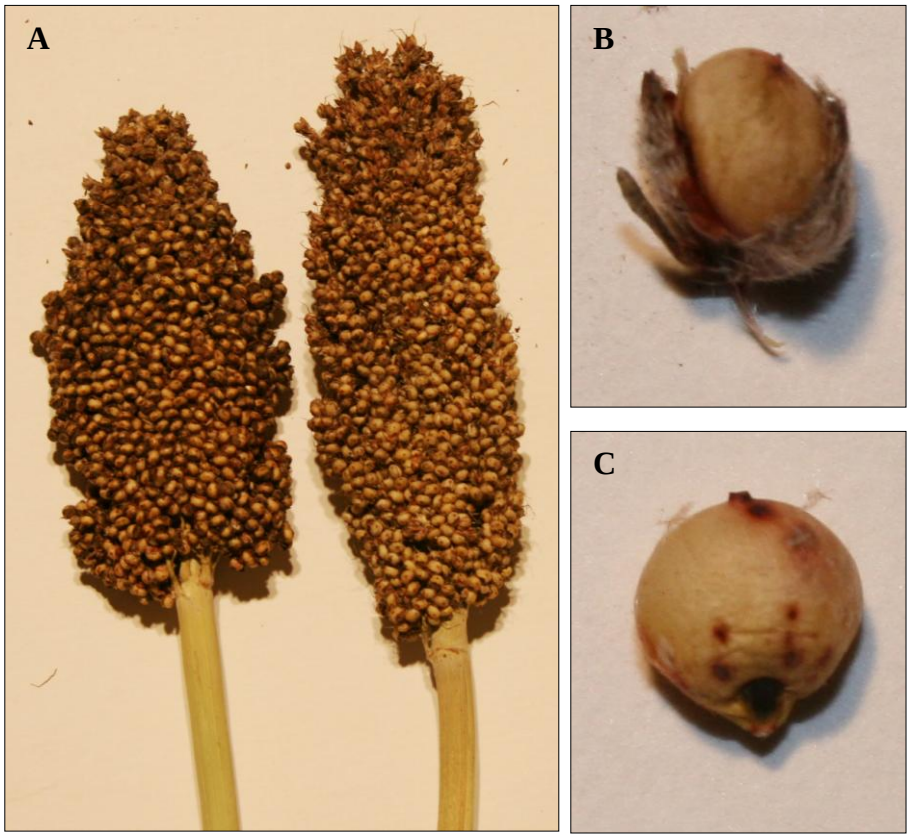


Picture 5.3: Bicolor panicles (A), seed with glumes (B), seed without glumes (C)

The race bicolor is thought to be the most primitive grain sorghum and believed to have evolved from the subspecies *verticiflorum* complex. Its centre if origin is not definite (Harlan, 1975b). Since its domestication this race has spread throughout many agricultural areas of Africa, Asia and from India to Indonesia (de Wet and Price, 1976).

The race is characterized by open panicles that are medium in size, glumes that are clasping and cover three quarters or more of the grain (Picture 5.3). The grains are, elongated, symmetrical and small. The race has typically long rachis with long, slightly stiff branches and plants are medium in height. This race is fairly low yielding and tends to produce a lot of tillers.

5.9.2.4 Race: Durra



Picture 5.4: Durra panicles (A), seed with glumes (B), seed without glumes (C)

Snowden (1936) suggested that the durra race may have arisen from introgression with wild aethiopicum while Harlan and Stemler (1976) felt that the durras were selected from early bicolors. Dogget (1988) argues that the durra race originated in Ethiopia since the entire sequence of wild-type bicolor-durra is clearly represented in this country. Doggett also suggests that early bicolor introgressed with wild form and adapted to drier conditions thus leading to the development of the durra race. This race was then moved westward through Sudan and began to occupy the drier regions below the southern margin of the Sahara. This movement continued through the Horn of Africa and finally to India (Dogget, 1988).

The durras are characterized by panicles that are stiff, dense and compact (Picture 5.4). The tips of the glumes are of different texture and normally have pronounced transverse wrinkle which cover wedge-shaped obovate grains. The rachis is stout, hidden, and sometimes recurved with short, erect, and often hairy branches.

5.9.2.5 Race: Kafir

Picture 5.5: Kafir panicles (A), seed with glumes (B), seed without glumes (C)

This race is dominant in the southern region of Africa and is also widely distributed in northern Nigeria. Although the kafir race is thought to be a derivation from early bicolor in northern Africa and carried south (Harlan and Stemler, 1976), de Wet and Hackabay (1967) suggest that the distribution and morphology of the kafirs point to a closer link with the wild verticilliflorum and electrophoretic data seem to strengthen that argument (Shechter and de Wet, 1975).

Some of the characteristics that distinguish this race will panicles that are erect and cylindrical, clasping glumes that are variable in length covering symmetrical, spherical grains

(Picture 5.5). The rachis is long and branches tend to be hairy. Plants are usually medium in height and generally high yielding.

Table 5.14: Supplementary Table 1. *Sorghum bicolor* accessions evaluated in this study.

Pedigree	**PI**	**Line**	**Germplasm type**	**Origin Country**	**Origin State/ province**	**Race/ Intermediate race**	**Working Group**[‡]
Ajabsido R		Breeding	cultivar	Sudan			
BOK11 B		Breeding	inbred line	United States	Oklahoma		
BQL41 B							
BTx2752 B		Breeding	inbred line	United States	Texas		
BTx3042 B		Breeding	inbred line	United States	Texas		
BTx3197 B		Breeding	inbred line	United States	Texas		
BTx378 B		Breeding	inbred line	United States	Texas		
BTx399 B		Breeding	inbred line	United States	Texas		
BTx615 B		Breeding	inbred line	United States	Texas		
BTx623 B		Breeding	inbred line	United States	Texas		
BTx641 B		Breeding	inbred line	United States	Texas		
BTx642 B		Breeding	inbred line	United States	Texas		
BTx643 B		Breeding	inbred line	United States	Texas		
BTx645 B		Breeding	inbred line	United States	Texas		
BTxARG-1 B		Breeding	inbred line	United States	Texas		
Day R							
Dorado R		Breeding	cultivar				
El Mota R		Breeding	cultivar	Niger			
Feterita Gishesh R		Breeding	cultivar				
HEGARI R		Breeding	TCL				
KS115 R	PI613536	Breeding	BRM	United States	Kansas		
KS19 R	NSL110174	Breeding	inbred line	United States	Kansas		
Macia R		Breeding	cultivar	South Africa			
Malisor 84-7 R		Breeding	cultivar	Mali			
MR732 R		Breeding	cultivar	Niger			
P9517 R		Breeding	inbred line	United States	Indiana		
PR 3089 R							
PR 3095 R							
QL3(India) R		Breeding	cultivar	India	.		
RTAM2566 R		Breeding	inbred line	United States	Texas		
RTAM428 R		Breeding	inbred line	United States	Texas		
RTX2536 R		Breeding	inbred line	United States	Texas		
RTX2737 R		Breeding	inbred line	United States	Texas		
RTx2741 R							
RTx2783 R		Breeding	inbred line	United States	Texas		
RTx2917 R		Breeding	inbred line	United States	Texas		

RTx430 R		Breeding	inbred line	United States	Texas		
RTx436 R		Breeding	inbred line	United States	Texas		
RTx437 R		Breeding	inbred line	United States	Texas		
SA386 REDBINE-60 R							
SA5330/Martin R	IS412-8354, NSL4012	Breeding	cultivar				
SA7000 CAPROCK R							
SA7078 COMBINE 7078 R							
San Chi San R		Breeding	cultivar	China			
SC1014 Col. No. R-7 R	PI576375, IS11443C	CTr	BRM	Ethiopia	Shoa	durra-bicolor	93/92:Subglabrescens/Durra-dochna
SC1017 Col. No. R-2 R	PI576376, IS11549C	CTr	BRM	Ethiopia	Tigre	durra-bicolor	93/92:Subglabrescens/Durra-dochna
SC1019 R	IS11569C	CTr	BRM	Ethiopia	Tigre	caudatum	31:Caudatum-nigricans
SC103 Witchweed Re R	PI533752, IS2403C	CTr	BRM	South Africa	North West	caudatum	30:Caudatum
SC1033 Col. No. P-4 R	PI576426, IS11894C	CTr	BRM	Ethiopia	Wollo	durra-bicolor	93/92:Subglabrescens/Durra-dochna
SC1038 Col. No. P-6 R	PI576381, IS12170C	CTr	BRM	Ethiopia	Tigre	durra-bicolor	93/92:Subglabrescens/Durra-dochna
SC1047 Mashila R	IS11069C	CTr	BRM	Ethiopia	Harrar	durra	50:Durra
SC1055 Werakan R	PI595739	CTr	BRM	Sudan	Equatoria	caudatum	37:Zerazera
SC1056 Awanlek R	PI576387	CTr	BRM	Sudan	Equatoria		
SC1057 lwera #669 R	PI595740	CTr	BRM	Uganda	Northern	caudatum	31:Caudatum-nigricans
SC1063 CE 83-174 R	PI595741, NSL55215	CTr	BRM	Senegal		guinea	23:Roxburghii
SC1070 Line 410 R	PI576385, IS17209C, NSL365695	CTr	BRM	Nigeria			
SC1074 Line 502 R	IS17213C	CTr	BRM	Nigeria		kafir	40:Caffrorum
SC1076 Line SK-MDW R	PI597960, IS17215C, NSL365701	CTr	BRM	Nigeria		caudatum-bicolor	70:Caudatum-bicolor
SC1077 Sorgho 137-6 R	PI597961, IS17216C, NSL 365702	CTr	BRM	Nigeria		caudatum	37:Zerazera
SC1079 Gadam El Ham R	PI595714, IS9290C	CTr	BRM	Sudan		caudatum	30:Caudatum
SC108 Gambela No.1 R	PI533792, IS12608C	CTr	BRM	Ethiopia	Gambela	caudatum	37:Zerazera
SC1080 No 221 R	PI576422, IS9370C, NSL76373	CTr	BRM	South Africa	Gauteng	kafir	40:Caffrorum
SC1085 Mehra-Sonthi R	PI576401, IS4307C	CTr	BRM	India	Madhya Predesh	durra	52:Cernuum
SC110 Gambela No.5 R	PI533794, IS12610C	CTr	BRM	Ethiopia	Gambela	caudatum	37:Zerazera
SC1103 Ex-mubi R	PI576434, IS1103C	CTr	BRM	Nigeria		kafir-bicolor	80:Bicolor-kafir
SC1104 Lula (?) R	PI576435, IS1104C	CTr	BRM	Uganda	Sere (city)	kafir-bicolor	80:Bicolor-kafir
SC1108 Tella Jonna R	PI597949, IS5168C, NSL52327	CTr	BRM	India	Andhra Pradesh	guinea	23:Roxburghii

SC1124 ZA 92 Jana D R	PI576418, IS7801C, NSL50754	CTr	BRM	Nigeria	Jamaa Nor (city)	guinea	21:Conspicuum
SC115 J-73 R	PI533965, IS2683C	CTr	BRM	Uganda		caudatum-bicolor	72:Nigricans-bicolor
SC1154 Col. No. R-5 R	PI595720, IS11814C	CTr	BRM	Ethiopia	Harrar	durra-bicolor	92:Durra-dochna
SC1155 Col. No. R-5 R	PI576425, IS11815C	CTr	BRM	Ethiopia	Eritrea	durra/durra-bicolor	50/93:Durra/Subglabrescens
SC1158 Col. No. P-1 R	PI597957, IS11930C	CTr	BRM	Ethiopia	Eritrea	durra-bicolor	92:Durra-dochna
SC118 Mugbash 56/5 R	PI267459, IS2801C	CTr	BRM	Sudan		caudatum	30:Caudatum
SC120 Zerazera whi R	PI267474, IS20945C	CTr	BRM	Sudan		caudatum	37:Zerazera
SC1201 OR-1 R	PI595743, NSL355020	CTr	BRM			guinea-caudatum	100:Caudatum-guineense
SC1203 AF-28 R	PI576437, IS1203C	CTr	BRM	Brazil			
SC1205 CE90-16-3 R							
SC121 Wit Lightenb R	PI533961, IS2553C	CTr	BRM	South Africa		caudatum	30:Caudatum
SC1211 Cacho de Che R	PI595744	CTr	BRM	Guatemala		kafir-caudatum	130:Caudatum-kafir
SC1212 SL-PR-32650 R	PI597966, NSL365719	CTr	BRM	Venezuela		caudatum	30:Caudatum
SC1214 Red Roasting R	PI595745	CTr	BRM	Burkina Faso		guinea-caudatum	100:Caudatum-guineense
SC1215 A4 D4 R							
SC1218 (US 1959) R	IS2499C	CTr	BRM	Sudan		guinea-caudatum	100:Caudatum-guineense
SC124 Unnamed-R1 R	PI533919, IS12615C	CTr	BRM	Ethiopia	Dire Dawa	durra-bicolor	92:Durra-dochna
SC1246 No. 739 Dua R	PI595718, IS10759C, NSL77228	CTr	BRM	Chad		kafir-caudatum	130:Caudatum-kafir
SC1251 FC 4544 Tar R	IS956C	CTr	BRM	Sudan		caudatum	37:Zerazera
SC1271 R	NSL 365721	CTr	BRM	Ethiopia		caudatum	37:Zerazera
SC1277 Bargon Warni R							
SC13 Gobo No. 25 R	PI534123, IS12533C	CTr	BRM	Ethiopia	Kaichama (city)	durra-bicolor	93:Subglabrescens
SC1319 Nyaluwal Tu R	PI597964, IS23607C, NSL365749	CTr	BRM	Ethiopia	Gambela	caudatum	37:Zerazera
SC132 Unnamed-R1 1 R							
SC1320 P967083 R	PI597967, NSL365750	CTr	BRM	Ethiopia		caudatum	37:Zerazera
SC1321 Col. El Obei R	PI597968, NSL365751	CTr	BRM	Sudan	North Kurdufan	guinea-caudatum	100:Caudatum-guineense
SC1322 Col. El Obei R	PI597969, NSL365752	CTr	BRM	Sudan	North Kurdufan	guinea-durra	122:Durra-membranaceum
SC1328 Col. El Obei R	PI597971, NSL365758	CTr	BRM	Sudan	North Kurdufan	caudatum	30:Caudatum
SC1329 Col. El Obei R							
SC1330 Col. El Obei R	PI597973, NSL 365760	CTr	BRM	Sudan	North Kurdufan	durra-bicolor	90:Durra-bicolor

SC1337 CSM-388 R	PI597976, NSL 365766	CTr	BRM	Mali		guinea	20:Guineense
SC134 Unnamed-R1 2 R							
SC1345 CSM-90 R	PI597980, NSL 365773	CTr	BRM	Mali		caudatum	30:Caudatum
SC135 Unnamed-R1 R	PI534148, IS12626C	CTr	BRM	Ethiopia	Dire Dawa	durra-bicolor	92:Durra-dochna
SC1356 Shot Damon # R	PI597982, NSL365781	CTr	BRM	Sudan	South Kurdufan	caudatum	30:Caudatum
SC1416 Col#279 R	.	CTr	BRM	Niger		durra-bicolor	90:Durra-bicolor
SC1424 CSM-932 R	.	CTr	BRM	Mali		kafir-durra	150:Durra-kafir
SC1426 CSM-205 R	IS2267C	CTr	BRM	Mali	Sotuba (city)	guinea	20:Guineense
SC1429 R	IS14384C	CTr	BRM	Zimbabwe	.	guinea	20:Guineense
SC1439 Kinte Wuleng R	.	CTr	BRM	Gambia	Naniko Village	guinea	22:Margaritiferum
SC144 Unnamed-R1 R	PI533921, IS12635C	CTr	BRM	Ethiopia	Dire Dawa	durra-caudatum	143:Durra-feterita/kaura
SC1440 Bachara R							
SC145 Unnamed-R1 J R	IS12636C	CTr	BRM	Ethiopia	Dire Dawa	bicolor	11:Dochna
SC1451 R		CTr	BRM	Malawi	.	caudatum	30:Caudatum
SC146 No.4 Hadoui R							
SC1463 Bautingay R	NSL360537	CTr	BRM	Sudan	North Kurdufan	caudatum	31:Caudatum-nigricans
SC1465 Safra R		CTr	BRM	Sudan	North Kurdufan		
SC1471 Beit Eltour R		CTr	BRM	Sudan	North Kurdufan	durra-bicolor	90:Durra-bicolor
SC1476 Eish Jabal R	NSL365799	CTr	BRM	Sudan	North Kurdufan		
SC1484 SS120 R	NSL360545	CTr	BRM	Somalia			
SC1489 SS58 R	NSL360549	CTr	BRM	Somalia		durra	50:Durra
SC1494 Aduholio R	PI570380, IS26836	CTr	BRM	Sudan	West Equitoria	guinea-caudatum	100:Caudatum-guineense
SC15 Bundy R	PI534124, IS12535C	CTr	BRM	Ethiopia	Koleche	guinea-bicolor	61:Dochna-honey
SC15 Lule No. 28 R							
SC155 Unnamed-R3 R	PI534155, IS12646C	CTr	BRM	Ethiopia	Dire Dawa	durra-bicolor	92-93:Durra-dochna/subglabrescens
SC1552 SU1765 R							
SC17 No. 35 R	PI533903, IS12537C	CTr	BRM	Ethiopia	Mab	bicolor	11:Dochna
SC170 Unnamed-R4 R	PI534157, IS12661C	CTr	BRM	Ethiopia	Dire Dawa	caudatum	37:Zerazera
SC172 Unnamed-R4 B		CTr	BRM	United States	Texas		
SC173 Unnamed-R4 R							
SC175 Unnamed-R4 R							
SC184 Suki PS295 R	PI597958, IS12675C	CTr	BRM	South Africa	Gauteng	kafir-caudatum	133:Caffrorum-feterita
SC192 Kharuth Wara R	PI576390, IS1105C	CTr	BRM	India	.	durra	52:Cernuum
SC199 Karad 2-7-11 R	PI533810, IS1121C	CTr	BRM	India	.	durra	51:Nandyal
SC206 Cherukupatch R	PI533814, IS1140C	CTr	BRM	India	Andhra Pradeesh	durra	50:Durra
SC209 Aispuri R	IS1151C, PI533817	CTr	BRM	India	Maharashtra	durra	52:Cernuum

SC21 Uki No. 37 R	PI534127, IS12541C	CTr	BRM	Ethiopia	Albelti	kafir-bicolor	82:Dochna-kafir
SC213 K. 1 Irunga R	PI576391, IS1596C	CTr	BRM	India	Tamil Nadu	bicolor	11:Dochna
SC214 K.3 Periaman R	PI533750, IS1598C	CTr	BRM	India	Maharashtra	bicolor	11:Dochna
SC22 No. 71 R	IS12542C	CTr	BRM	Ethiopia	Adesh	durra	50:Durra
SC223 Bankum R	PI533807, IS12684C	CTr	BRM	Nigeria		kafir-caudatum	130:Caudatum-kafir
SC224 J.A.T.S. #67 R	PI533927, IS12685C	CTr	BRM	Ethiopia		bicolor	11:Dochna
SC23 Amelsie No. R	PI534128, IS12543C	CTr	BRM	Ethiopia	Amara	durra	50:Durra
SC240 Nandyal R	PI533842, IS3814C	CTr	BRM	India	Karnataka	durra	51:Nandyal
SC241 SV 34 R							
SC243 EC18246 R							
SC25 No. 73 R	IS12545C	CTr	BRM	Ethiopia	Berilie	durra	50:Durra
SC261 ZA 41 Danye R							
SC279 Ihera BE 25 R	PI534070, IS7419C, NSL50595	CTr	BRM	Nigeria	Bissauia (city?)	guinea	21:Conspicuum
SC283 Msumbji R	PI533869, IS7173C, NSL50876	CTr	BRM	Tanzania	Tanganyika	guinea	21:Conspicuum
SC295 BE 34 R	IS7427C	CTr	BRM	Nigeria		guinea	21:Conspicuum
SC299 SO 16 Sanba R	PI533785, IS7920C, NSL50827	CTr	BRM	Nigeria	Zamfara	guinea	21:Conspicuum
SC301 Bank Oumano R	IS3817C	CTr	BRM	Mali	Bamako Capital District	guinea	20:Guineense
SC303 KO 37 Canjin R	PI533839, IS3620C, NSL51039	CTr	BRM	Nigeria	Katsina	guinea	22:Margaritiferum
SC305 428 Sian R	PI534037, IS6842C	CTr	BRM	Chad		guinea-caudatum	121:Membranaceum
SC309 Ankolib Khaf R	PI533754, IS2483C	CTr	BRM	Sudan	Blue Nile	bicolor	11:Dochna
SC317 Chanan Singo R	PI533855, IS6271C, NSL51374	CTr	BRM	India	Assam	guinea-bicolor	62:Dochna-roxburghii
SC319 Sorghum Soro R	PI533833, IS2757C	CTr	BRM	Uganda		caudatum-bicolor	73:Dochna-nigricans
SC320 Oua Berr R	PI533863, IS6882C	CTr	BRM	Chad		kafir	40:Caffrorum
SC322 AS 4660 (Kik R	PI533821, IS1309C, NSL51676	CTr	BRM	Tanzania	Tanganyka	caudatum	32:Nigricans
SC323 Kemurit Whit R	PI576399, IS3515C	CTr	BRM	Sudan	Tozi (institute)	caudatum	32:Nigricans
SC324 J 27 R	PI576396, IS2681C	CTr	BRM	Uganda		caudatum	32:Nigricans
SC325 Sorghum vulg R	PI533957, IS2462C	CTr	BRM	United States		caudatum	32:Nigricans
SC328 EC 21463 ST R	PI534112, IS8263C	CTr	BRM	Uganda		caudatum	35:Dobbs
SC329 BA 45 Faria R							
SC33 Bekedjie No. R	PI534132, IS12553C, MN683	CTr	BRM	Ethiopia	Kembolcha	durra	50:Durra
SC331 Bonkum R							
SC333 R	PI533761, IS3063C	CTr	BRM	Ethiopia	Assela (city?)	caudatum	30:Caudatum

SC334 Huria White R	PI533986, IS3499C	CTr	BRM	Sudan	Tozi (institute)	caudatum	30:Caudatum
SC348 Kaura KA 24 R	PI534075, IS7455C	CTr	BRM	Nigeria		caudatum	30:Caudatum
SC35 Mashela Ting R	PI534133, IS12555C, MN693	CTr	BRM	Ethiopia		durra	50:Durra
SC370 KA 3 R							
SC372 KA 21 (Gajer R							
SC373 Kaura R	IS7461C, NSL54218	CTr	BRM	Nigeria	Tambu	caudatum	36:Caudatum-kaura
SC38 Netch No. 64 R	PI534135, IS12558C	CTr	BRM	Ethiopia	Addesho (city?)	durra	50:Durra
SC382 Kanura Maima R	PI534088, IS7724C	CTr	BRM	Nigeria		caudatum	36:Caudatum-kaura
SC386 Kaura Dantse R							
SC391 Dawa U. A. R	IS7182C, NSL54120	CTr	BRM	Egypt		caudatum	36:Caudatum-kaura
SC396 KA 15 (Yazga R	PI533877, IS7447C	CTr	BRM	Nigeria	Gundawa (city?)	caudatum	36:Caudatum-kaura
SC399 KO 61 (Barag R	PI533882, IS7537C	CTr	BRM	Nigeria	Kano	caudatum	36:Caudatum-kaura
SC411 255 Tirter R	PI533866, IS6964C	CTr	BRM	Sudan		caudatum-bicolor	71:Caudatum-dochna
SC413 Farin Bwanku R	PI534079, IS7577C	CTr	BRM	Nigeria	Plateau	caudatum-bicolor	71:Caudatum-dochna
SC414 Deburr Kass R	PI533831, IS2508C	CTr	BRM	Sudan		kafir-caudatum	130:Caudatum-kafir
SC418 AS 4616 Bala R	PI533822, IS1335C	CTr	BRM	Tanzania	Tanganyka	kafir-caudatum	130:Caudatum-kafir
SC42 (No Name) R	PI576393, IS2463C	CTr	BRM	Ethiopia	Neghelli (city)	caudatum	32:Nigricans
SC420 290 Feterita R	PI533769, IS7064C	CTr	BRM	Sudan		kafir-caudatum	130:Caudatum-kafir
SC423 Nyithin R	PI533758, IS2579C	CTr	BRM	Sudan	Equatoria	caudatum	37:Zerazera
SC424 A-96 R	PI533901, IS8100C	CTr	BRM	Japan		caudatum	31:Caudatum-nigricans
SC425 Tabroro 7 R	PI533762, IS3579C	CTr	BRM	Sudan	Tozi (institute)	durra-caudatum	140:Caudatum-durra
SC441 Yerra Jonna R	PI534009, IS5142C	CTr	BRM	India	Andhra Pradeesh	durra	50:Durra
SC449 Karkatia Sal R	PI597950, IS5763C	CTr	BRM	India	Bihar	guinea-durra	120:Durra-roxburghii
SC450 Cholia Talij R							
SC465 S. subglabre R	PI533997, IS3646C	CTr	BRM	Arabia	Aden	guinea-durra	120:Durra-roxburghii
SC467 AS 2613 (N. R	PI533943, IS1387C	CTr	BRM	India	Tamil Nadu	durra-bicolor	92:Durra-dochna
SC473 Jowar Tamarg R	PI534028, IS6404C	CTr	BRM	India	Maharashtra	durra	51:Nandyal
SC480 Jowar Kalgun R	IS6408C	CTr	BRM	India	Maharashtra	durra	51:Nandyal
SC489 Jola Nandyal R	PI533856, IS6389C	CTr	BRM	India	Karnataka	durra	51:Nandyal
SC49 Ankolib–Red R	PI152595, IS2484C	CTr	BRM	Sudan	Kurdufan	guinea-caudatum	100:Caudatum-guineense
SC498 Jowar Shenol R	IS6436C, NSL55743	CTr	BRM	India	Maharashtra	durra	51:Nandyal
SC500 Shenoli Loca R	IS6452C	CTr	BRM	India	Maharashtra	durra	51:Nandyal
SC502 Hamaisi 38 R	PI533996, IS3598C	CTr	BRM	Sudan		durra-caudatum	142:Durra-nigricans
SC52 Culum brick R	PI533830, IS2501C	CTr	BRM	Sudan	Kurdufan	caudatum	34:Nigricans-feterita
SC525 NG104 R	IS7671C	CTr	BRM	Nigeria		guinea	21:Conspicuum
SC53 Feterita Fuy R	PI533788, IS12567C	CTr	BRM	Sudan	Anglo-Egyptian	durra-caudatum	142:Durra-nigricans
SC532 132 AB Farak R	PI597951, IS6733C	CTr	BRM	West Volta		guinea	21:Conspicuum
SC55 Feterita Gon R	PI152662, IS2541C	CTr	BRM	Sudan	Anglo-Egyptian	caudatum	30:Caudatum
SC553 Lekkite Bund R							

SC557 AS 4055 (Mka R	PI533939, IS1318C	CTr	BRM	Mosambique	Fika	caudatum	32:Nigricans
SC558 AS 5826 (Hol R	PI533938, IS1311C	CTr	BRM	Zaire		caudatum	32:Nigricans
SC56 Klor R	PI533910, IS12568C	CTr	BRM	Sudan	Kurdufan	caudatum	31:Caudatum-nigricans
SC562 Kireniga 317 R	PI533987, IS3509C	CTr	BRM	Sudan	Tozi (institute)	caudatum	30:Caudatum
SC563 KA 12 (Janja R	PI533876, IS7444C	CTr	BRM	Nigeria	Kofinsoli	caudatum	30:Caudatum
SC564 T-28 R	PI534053, IS7142C	CTr	BRM	Uganda		caudatum	30:Caudatum
SC566 M1 R	PI533871, IS7254C	CTr	BRM	Nigeria		caudatum	30:Caudatum
SC569 Kaura Mai Ma R	PI534092, IS7780C	CTr	BRM	Nigeria		caudatum	36:Caudatum-kaura
SC57 Kodilib R	PI533789, IS12569C	CTr	BRM	Sudan	Kurdufan	guinea-caudatum	100:Caudatum-guineense
SC572 (unknown) R	PI533980, IS3390C	CTr	BRM	China	Peking	kafir-caudatum	130:Caudatum-kafir
SC574 Accho Karunh R	PI534114, IS8337C	CTr	BRM	Pakistan	Sindh	caudatum	31:Caudatum-nigricans
SC58 Kokla R	PI533911, IS12570C	CTr	BRM	Sudan	Kurdufan	caudatum	30:Caudatum
SC587 Jola Nandyal R	PI534021, IS6356C	CTr	BRM	India	Karnataka	durra	51:Nandyal
SC59 Magbago Felu R	PI152719, IS2567C	CTr	BRM	Sudan	Equatoria	caudatum-bicolor	72:Nigricans-bicolor
SC598 SG 4 Bulk R	PI576337, IS2748C	CTr	BRM	Uganda			182:Virgatum
SC599 Manawan Rex R	PI534163, IS17459C, NSL3484, MN1048	CTr	BRM	United States		caudatum	31:Caudatum-nigricans
SC6 Orange No. 1 R	PI533902, IS12526C	CTr	BRM	Ethiopia	Shoa	durra-bicolor	93:Subglabrescens
SC60 Malwalawail R	PI533962, IS2569C	CTr	BRM	Sudan	Equatoria	caudatum	31:Caudatum-nigricans
SC603 Nyahila AS R	PI533936, IS1168C	CTr	BRM	Tanzania	Maswadt (city?)	guinea	21:Conspicuum
SC605 Malle SO 85 R	PI534096, IS7979C	CTr	BRM	Kenya		guinea	22:Margaritiferum
SC606 A-2789 S. N R	PI597946, IS3106C	CTr	BRM	China		guinea-bicolor	62:Dochna-roxburghii
SC609 AS 5200 R	PI576332, IS1213C	CTr	BRM	China		bicolor	13:Nervosum-kaoliang
SC610 Tsinan R	IS1220C, NSL51074	CTr	BRM	China		bicolor	13:Nervosum-kaoliang
SC614 AS 4601 (Paw R	PI533940, IS1333C	CTr	BRM	Tanzania		bicolor	10:Bicolor
SC62 Matchikah R							
SC621 Anji R	IS5030C, NSL51265	CTr	BRM	India	Maharashtra	bicolor	11:Dochna
SC623 Sweet Sorghu R	PI533956, IS2456C	CTr	BRM	Congo		durra-bicolor	91:Dochna-durra
SC624 Jowar Red Ja R	PI576366, IS6164C	CTr	BRM	India	Uttar Pradesh	durra-bicolor	91:Dochna-durra
SC625 HG 6028 R	PI534097, IS8003C	CTr	BRM	Japan		kafir	40:Caffrorum
SC627 DL/60/99 R	PI576345, IS3138C	CTr	BRM	South Africa		kafir	40:Caffrorum
SC628 Bulfontein K R	PI533979, IS3169C	CTr	BRM	South Africa	Pretoria	kafir	40:Caffrorum
SC63 Mendo R	PI533912, IS12573C	CTr	BRM	Sudan	Kurdufan	caudatum	31:Caudatum-nigricans
SC630 AS 4136 (Ma R	PI533937, IS1269C	CTr	BRM	Zambia		kafir	40:Caffrorum
SC637 EC 21361 G3 R	PI534105, IS8167C	CTr	BRM	Uganda		kafir-caudatum	132:Caffrorum-darso
SC639 EC 21359G28 R	IS8165C	CTr	BRM	India		kafir-caudatum	132:Caffrorum-darso
SC64 Monshal R	PI152736, IS2573C	CTr	BRM	Sudan		kafir-caudatum	130:Caudatum-kafir
SC641 EC 21360 G2 R	PI534104, IS8166C	CTr	BRM	Uganda		kafir-caudatum	132:Caffrorum-darso
SC645 EC 21428 SB	PI534108, IS8231C	CTr	BRM	Uganda		kafir-caudatum	132:Caffrorum-darso
SC648 P 3749 (Q2-5 R	PI533955, IS2419C	CTr	BRM	South Africa		kafir-caudatum	131:Caffrorum-birdproof

SC650 Mtuli Swazil R	PI576340, IS2856C	CTr	BRM	South Africa	Pretoria	kafir-caudatum	131:Caffrorum-birdproof
SC655 Framiola DL/ R	PI533976, IS2862C	CTr	BRM	South Africa	Pretoria	kafir-caudatum	131:Caffrorum-birdproof
SC659 Nebraska 633 R	PI576333, IS2225C	CTr	BRM	United States	Nebraska	guinea-kafir	110:Caffrorum-roxburghii
SC66 Nyan Dok R	PI533913, IS12575C	CTr	BRM	Sudan	Equatoria	guinea-caudatum	101:Nigricans-guineense
SC663 Nebraska 635 R	PI533948, IS2232C	CTr	BRM	United States	Nebraska	guinea-kafir	110:Caffrorum-roxburghii
SC67 Tuery 11 R	PI534139, IS12576C	CTr	BRM	Sudan	Equatoria	guinea-caudatum	101:Nigricans-guineense
SC671 194 Kano R	PI534054, IS7148C	CTr	BRM	Kenya	.	kafir-caudatum	133:Caffrorum-feterita
SC672 Hoarkdoom 19 R	PI595702, IS2837C	CTr	BRM	Zimbabwe	Matabeleland North	kafir-caudatum	133:Caffrorum-feterita
SC673 Bathoen Whit R	PI576339, IS2840C	CTr	BRM	Zimbabwe	Matabeleland North	kafir-caudatum	133:Caffrorum-feterita
SC679 Kalatilansa R	PI586788, IS7005, 65I 2523	CTr	BRM			guinea-caudatum	101:Nigricans-guineense
SC695 EC 21471 STR	IS8270C	CTr	BRM	Tanzania		caudatum	35:Dobbs
SC701 Barking 119 R	PI533985, IS3462C	CTr	BRM	Sudan	Tozi (institute)	caudatum	30:Caudatum
SC702 Fanda 128 R	IS3485C	CTr	BRM	Sudan	Tozi (institute)	caudatum	30:Caudatum
SC704 A 84 R	PI534099, IS8087C	CTr	BRM	Japan		caudatum	30:Caudatum
SC708 2033 Z 3 R	PI533970, IS2740C	CTr	BRM	Uganda		caudatum	30:Caudatum
SC720 Matama R	IS7151C	CTr	BRM	Kenya		caudatum	31:Caudatum-nigricans
SC725 A 106 R	PI534101, IS8112C	CTr	BRM	Japan		caudatum	30:Caudatum
SC734 Lambas R	PI576394, IS2562C	CTr	BRM	Sudan	Kurdufan	caudatum	30:Caudatum
SC738 Nagad White R	PI597952, IS6960C	CTr	BRM	Sudan	Tozi (institute)	caudatum	30:Caudatum
SC748 Sinidyil 177 R	PI533991, IS3552C	CTr	BRM	Sudan	Tozi (institute)	guinea-caudatum	100:Caudatum-guineense
SC749 A 112-3 R	PI576373, IS8120C	CTr	BRM	Japan		caudatum-bicolor	70:Caudatum-bicolor
SC755 Purdue No. 8 R							
SC757 Marupanste R	PI576352, IS3402C	CTr	BRM	Botswana	Central	kafir-caudatum	130:Caudatum-kafir
SC760 Maga Abiad (R	PI533949, IS2288C	CTr	BRM	Sudan	Al Jazirah	kafir-caudatum	130:Caudatum-kafir
SC782 Chori Uri R	PI576364, IS6057C	CTr	BRM	India	Punjab	caudatum	31:Caudatum-nigricans
SC79 Muzeda No. 7 R	PI533915, IS12588C	CTr	BRM	Kenya	VOI Teita Hills		
SC790 Gangari Rais R							
SC798 Nyithin 259 R	PI533989, IS3541C, NSL54540	CTr	BRM	Sudan	Tozi (institute)	caudatum	37:Zerazera
SC803 Safara Kord R	PI533964, IS2586C	CTr	BRM	Sudan		caudatum	37:Zerazera
SC805 SB 283 T32 R	PI533967, IS2723C	CTr	BRM	Uganda		caudatum	37:Zerazera
SC833 Desi R	IS4748C	CTr	BRM	India	Gujarat	durra	50:Durra
SC84 No. 491 Kabu R	PI534144, IS12593C	CTr	BRM	Uganda	Kampala	durra-caudatum	142:Durra-nigricans
SC855 Giza 123 S10 R	PI597945, IS2871C	CTr	BRM	Egypt	Orman	durra	50:Durra
SC888 Kempu Jola M R	IS4495C	CTr	BRM	India	Karnataka	durra	50:Durra
SC91 No. 902 Sorg R	PI534145, IS12600C	CTr	BRM	Zimbabwe	Southern	bicolor	57: S. nitidum (old classification)

SC910 Butivori R	PI576359, IS5037C	CTr	BRM	India	Maharashtra	guinea-durra	122:Durra-membranaceum
SC929 IC3443 (impr R	PI595699, IS1029C	CTr	BRM	India	Maharashtra	durra	52:Cernuum
SC937 Purdue No. 8 R	PI576348, IS3201C	CTr	BRM	United States		bicolor	15:Sudanense
SC941 Purdue No. 8 R	PI576347, IS3196C	CTr	BRM	United States		bicolor	15:Sudanense
SC942 Purdue No 81 R	PI576349, IS3212C	CTr	BRM	United States		bicolor	15:Sudanense
SC947 R							
SC949 Brawley R	PI533998, IS3648C	CTr	BRM	United States	Nebraska	bicolor	
SC964 Kenya var. R	PI533972, IS2765C	CTr	BRM	Uganda		caudatum	35:Dobbs
SC968 S-50-74 R		CTr	BRM	Zimbabwe		durra-bicolor	93:Subglabrescens
SC970 E-51 R	PI576386	CTr	BRM	Uganda			
SC971 Millo Blanco R	IS21910C	CTr	BRM	United States	Puerto Rico	kafir-durra	150:Durra-kafir
SC979 Col. No. P-5 R	PI576428, IS12153C	CTr	BRM	Ethiopia	Gambele	caudatum	37:Zerazera
SC982 Col. No. P-5 R	PI576380, IS12156C	CTr	BRM	Ethiopia	Gambele	caudatum	37:Zerazera
SC984 Akwuu Col. R	PI534115, IS12158C	CTr	BRM	Ethiopia	Pokomo Village	caudatum	37:Zerazera
SC987 Mashica Col R	PI534116, IS12179C	CTr	BRM	Ethiopia	Robi Fiche	durra-bicolor	93:Subglabrescens
SC991 Mashica Col R	PI534117, IS12219C	CTr	BRM	Uganda	Hoima	bicolor	10:Bicolor
SC998 F.R.Miller R							
Segaolane R							
Shan Qui Red R		Breeding	cultivar	China			
SRN39 R		Breeding	cultivar		.		
SURENO R		Breeding	cultivar	Central America			
Tx2911 R		Breeding	inbred line	United States	Texas		
Ajabsido R		Breeding	cultivar	Sudan			
BOK11 B		Breeding	inbred line	United States	Oaklahoma		
BQL41 B		.	.	.	.		
BTx2752 B		Breeding	inbred line	United States	Texas		
BTx3042 B		Breeding	inbred line	United States	Texas		
BTx3197 B		Breeding	inbred line	United States	Texas		
BTx378 B		Breeding	inbred line	United States	Texas		
BTx399 B		Breeding	inbred line	United States	Texas		
BTx615 B		Breeding	inbred line	United States	Texas		
BTx623 B		Breeding	inbred line	United States	Texas		
BTx641 B		Breeding	inbred line	United States	Texas		
BTx642 B		Breeding	inbred line	United States	Texas		
BTx643 B		Breeding	inbred line	United States	Texas		
BTx645 B		Breeding	inbred line	United States	Texas		
BTxARG-1 B		Breeding	inbred line	United States	Texas		
Day R							
Dorado R		Breeding	cultivar				

El Mota R		Breeding	cultivar	Niger			
Feterita Gishesh R		Breeding	cultivar				
HEGARI R		Breeding	TCL				
KS115 R	PI613536	Breeding	BRM	United States	Kansas		
KS19 R	NSL110174	Breeding	inbred line	United States	Kansas		
Macia R		Breeding	cultivar	South Africa			
Malisor 84-7 R		Breeding	cultivar	Mali			
MR732 R		Breeding	cultivar	Niger			
P9517 R		Breeding	inbred line	United States	Indiana		
PR 3089 R							
PR 3095 R							
QL3(India) R		Breeding	cultivar	India			
RTAM2566 R		Breeding	inbred line	United States	Texas		
RTAM428 R		Breeding	inbred line	United States	Texas		
RTX2536 R		Breeding	inbred line	United States	Texas		
RTX2737 R		Breeding	inbred line	United States	Texas		
RTx2741 R							
RTx2783 R		Breeding	inbred line	United States	Texas		
RTx2917 R		Breeding	inbred line	United States	Texas		
RTx430 R		Breeding	inbred line	United States	Texas		
RTx436 R		Breeding	inbred line	United States	Texas		
RTx437 R		Breeding	inbred line	United States	Texas		
SA386 REDBINE-60 R							
SA5330/Martin R	IS412-8354, NSL4012	Breeding	cultivar				
SA7000 CAPROCK R							
SA7078 COMBINE 7078 R							
San Chi San R		Breeding	cultivar	China			
SC 987 Mashica Col R							
SC1014 Col. No. R-7 R	PI576375, IS11443C	CTr	BRM	Ethiopia	Shoa	durra-bicolor	93/92:Subglabrescens/Durra-dochna
SC1017 Col. No. R-2 R	PI576376, IS11549C	CTr	BRM	Ethiopia	Tigre	durra-bicolor	93/92:Subglabrescens/Durra-dochna
SC1019 R	IS11569C	CTr	BRM	Ethiopia	Tigre	caudatum	31:Caudatum-nigricans
SC103 Witchweed Re R	PI533752, IS2403C	CTr	BRM	South Africa	North West	caudatum	30:Caudatum
SC1033 Col. No. P-4 R	PI576426, IS11894C	CTr	BRM	Ethiopia	Wollo	durra-bicolor	93/92:Subglabrescens/Durra-dochna
SC1038 Col. No. P-6 R	PI576381, IS12170C	CTr	BRM	Ethiopia	Tigre	durra-bicolor	93/92:Subglabrescens/Durra-dochna
SC1047 Mashila R	IS11069C	CTr	BRM	Ethiopia	Harrar	durra	50:Durra
SC1055 Werakan R	PI595739	CTr	BRM	Sudan	Equatoria	caudatum	37:Zerazera

SC1056 Awanlek R	PI576387	CTr	BRM	Sudan	Equatoria		
SC1057 lwera #669 R	PI595740	CTr	BRM	Uganda	Northern	caudatum	31:Caudatum-nigricans
SC1063 CE 83-174 R	PI595741, NSL55215	CTr	BRM	Senegal		guinea	23:Roxburghii
SC1070 Line 410 R	PI576385, IS17209C, NSL365695	CTr	BRM	Nigeria			
SC1074 Line 502 R	IS17213C	CTr	BRM	Nigeria		kafir	40:Caffrorum
SC1076 Line SK-MDW R	PI597960, IS17215C, NSL365701	CTr	BRM	Nigeria		caudatum-bicolor	70:Caudatum-bicolor
SC1077 Sorgho 137-6 R	PI597961, IS17216C, NSL 365702	CTr	BRM	Nigeria		caudatum	37:Zerazera
SC1079 Gadam El Ham R	PI595714, IS9290C	CTr	BRM	Sudan		caudatum	30:Caudatum
SC108 Gambela No.1 R	PI533792, IS12608C	CTr	BRM	Ethiopia	Gambela	caudatum	37:Zerazera
SC1080 No 221 R	PI576422, IS9370C, NSL76373	CTr	BRM	South Africa	Gauteng	kafir	40:Caffrorum
SC1085 Mehra-Sonthi R	PI576401, IS4307C	CTr	BRM	India	Madhya Predesh	durra	52:Cernuum
SC110 Gambela No.5 R	PI533794, IS12610C	CTr	BRM	Ethiopia	Gambela	caudatum	37:Zerazera
SC1103 Ex-mubi R	PI576434, IS1103C	CTr	BRM	Nigeria		kafir-bicolor	80:Bicolor-kafir
SC1104 Lula (?) R	PI576435, IS1104C	CTr	BRM	Uganda	Sere (city)	kafir-bicolor	80:Bicolor-kafir
SC1108 Tella Jonna R	PI597949, IS5168C, NSL52327	CTr	BRM	India	Andhra Pradeesh	guinea	23:Roxburghii
SC1124 ZA 92 Jana D R	PI576418, IS7801C, NSL50754	CTr	BRM	Nigeria	Jamaa Nor (city)	guinea	21:Conspicuum
SC115 J-73 R	PI533965, IS2683C	CTr	BRM	Uganda		caudatum-bicolor	72:Nigricans-bicolor
SC1154 Col. No. R-5 R	PI595720, IS11814C	CTr	BRM	Ethiopia	Harrar	durra-bicolor	92:Durra-dochna
SC1155 Col. No. R-5 R	PI576425, IS11815C	CTr	BRM	Ethiopia	Eritrea	durra/durra-bicolor	50/93:Durra/Subglabrescens
SC1158 Col. No. P-1 R	PI597957, IS11930C	CTr	BRM	Ethiopia	Eritrea	durra-bicolor	92:Durra-dochna
SC118 Mugbash 56/5 R	PI267459, IS2801C	CTr	BRM	Sudan		caudatum	30:Caudatum
SC120 Zerazera whi R	PI267474, IS20945C	CTr	BRM	Sudan		caudatum	37:Zerazera
SC1201 OR-1 R	PI595743, NSL355020	CTr	BRM			guinea-caudatum	100:Caudatum-guineense
SC1203 AF-28 R	PI576437, IS1203C	CTr	BRM	Brazil			
SC1205 CE90-16-3 R							
SC121 Wit Lightenb R	PI533961, IS2553C	CTr	BRM	South Africa		caudatum	30:Caudatum
SC1211 Cacho de Che R	PI595744	CTr	BRM	Guatemala		kafir-caudatum	130:Caudatum-kafir
SC1212 SL-PR-32650 R	PI597966, NSL365719	CTr	BRM	Venezuela		caudatum	30:Caudatum
SC1214 Red Roasting R	PI595745	CTr	BRM	Burkina Faso		guinea-caudatum	100:Caudatum-guineense
SC1215 A4 D4 R							
SC1218 (US 1959) R	IS2499C	CTr	BRM	Sudan		guinea-caudatum	100:Caudatum-guineense
SC124 Unnamed-R1 R	PI533919, IS12615C	CTr	BRM	Ethiopia	Dire Dawa	durra-bicolor	92:Durra-dochna

SC1246 No. 739 Dua R	PI595718, IS10759C, NSL77228	CTr	BRM	Chad		kafir-caudatum	130:Caudatum-kafir
SC1251 FC 4544 Tar R	IS956C	CTr	BRM	Sudan		caudatum	37:Zerazera
SC1271 R	NSL 365721	CTr	BRM	Ethiopia		caudatum	37:Zerazera
SC1277 Bargon Warni R							
SC13 Gobo No. 25 R	PI534123, IS12533C	CTr	BRM	Ethiopia	Kaichama (city)	durra-bicolor	93:Subglabrescens
SC1319 Nyaluwal Tu R	PI597964, IS23607C, NSL365749	CTr	BRM	Ethiopia	Gambela	caudatum	37:Zerazera
SC132 Unnamed-R1 1 R							
SC1320 P967083 R	PI597967, NSL365750	CTr	BRM	Ethiopia		caudatum	37:Zerazera
SC1321 Col. El Obei R	PI597968, NSL365751	CTr	BRM	Sudan	North Kurdufan	guinea-caudatum	100:Caudatum-guineense
SC1322 Col. El Obei R	PI597969, NSL365752	CTr	BRM	Sudan	North Kurdufan	guinea-durra	122:Durra-membranaceum
SC1328 Col. El Obei R	PI597971, NSL365758	CTr	BRM	Sudan	North Kurdufan	caudatum	30:Caudatum
SC1329 Col. El Obei R							
SC1330 Col. El Obei R	PI597973, NSL 365760	CTr	BRM	Sudan	North Kurdufan	durra-bicolor	90:Durra-bicolor
SC1337 CSM-388 R	PI597976, NSL 365766	CTr	BRM	Mali		guinea	20:Guineense
SC134 Unnamed-R1 2 R							
SC1345 CSM-90 R	PI597980, NSL 365773	CTr	BRM	Mali		caudatum	30:Caudatum
SC135 Unnamed-R1 R	PI534148, IS12626C	CTr	BRM	Ethiopia	Dire Dawa	durra-bicolor	92:Durra-dochna
SC1356 Shot Damon # R	PI597982, NSL365781	CTr	BRM	Sudan	South Kurdufan	caudatum	30:Caudatum
SC1416 Col#279 R	.	CTr	BRM	Niger		durra-bicolor	90:Durra-bicolor
SC1424 CSM-932 R	.	CTr	BRM	Mali	.	kafir-durra	150:Durra-kafir
SC1426 CSM-205 R	IS2267C	CTr	BRM	Mali	Sotuba (city)	guinea	20:Guineense
SC1429 R	IS14384C	CTr	BRM	Zimbabwe		guinea	20:Guineense
SC1439 Kinte Wuleng R		CTr	BRM	Gambia	Naniko Village	guinea	22:Margaritiferum
SC144 Unnamed-R1 R		CTr	BRM	Ethiopia	Dire Dawa	durra-caudatum	143:Durra-feterita/kaura
SC1440 Bachara R							
SC145 Unnamed-R1 J R	IS12636C	CTr	BRM	Ethiopia	Dire Dawa	bicolor	11:Dochna
SC1451 R		CTr	BRM	Malawi		caudatum	30:Caudatum
SC146 No.4 Hadoui R							
SC1463 Bautingay R	NSL360537	CTr	BRM	Sudan	North Kurdufan	caudatum	31:Caudatum-nigricans
SC1465 Safra R		CTr	BRM	Sudan	North Kurdufan		

SC1471 Beit Eltour R		CTr	BRM	Sudan	North Kurdufan	durra-bicolor	90:Durra-bicolor
SC1476 Eish Jabal R	NSL365799	CTr	BRM	Sudan	North Kurdufan		
SC1484 SS120 R	NSL360545	CTr	BRM	Somalia			
SC1489 SS58 R	NSL360549	CTr	BRM	Somalia		durra	50:Durra
SC1494 Aduholio R	PI570380, IS26836	CTr	BRM	Sudan	West Equitoria	guinea-caudatum	100:Caudatum-guineense
SC15 Budy R	PI534124, IS12535C	CTr	BRM	Ethiopia	Koleche	guinea-bicolor	61:Dochna-honey
SC15 Lule No. 28 R							
SC155 Unnamed-R3 R	PI534155, IS12646C	CTr	BRM	Ethiopia	Dire Dawa	durra-bicolor	92-93:Durra-dochna/subglabrescens
SC1552 SU1765 R							
SC17 No. 35 R	PI533903, IS12537C	CTr	BRM	Ethiopia	Mab	bicolor	11:Dochna
SC170 Unnamed-R4 R	PI534157, IS12661C	CTr	BRM	Ethiopia	Dire Dawa	caudatum	37:Zerazera
SC172 Unnamed-R4 B	.	CTr	BRM	United States	Texas		
SC173 Unnamed-R4 R							
SC175 Unnamed-R4 R	PI533800, IS12666C	CTr	BRM	Ethiopia	Dire Dawa	caudatum	37:Zerazera
SC184 Suki PS295 R	PI597958, IS12675C	CTr	BRM	South Africa	Gauteng	kafir-caudatum	133:Caffrorum-feterita
SC192 Kharuth Wara R	PI576390, IS1105C	CTr	BRM	India		durra	52:Cernuum
SC199 Karad 2-7-11 R	PI533810, IS1121C	CTr	BRM	India		durra	51:Nandyal
SC206 Cherukupatch R	PI533814, IS1140C	CTr	BRM	India	Andhra Pradeesh	durra	50:Durra
SC209 Aispuri R	IS1151C, PI533817	CTr	BRM	India	Maharashtra	durra	52:Cernuum
SC21 Uki No. 37 R	PI534127, IS12541C	CTr	BRM	Ethiopia	Albelti	kafir-bicolor	82:Dochna-kafir
SC213 K. 1 Irunga R	PI576391, IS1596C	CTr	BRM	India	Tamil Nadu	bicolor	11:Dochna
SC214 K.3 Periaman R	PI533750, IS1598C	CTr	BRM	India	Maharashtra	bicolor	11:Dochna
SC22 No. 71 R	IS12542C	CTr	BRM	Ethiopia	Adesh	durra	50:Durra
SC223 Bankum R	PI533807, IS12684C	CTr	BRM	Nigeria		kafir-caudatum	130:Caudatum-kafir
SC224 J.A.T.S. #67 R	PI533927, IS12685C	CTr	BRM	Ethiopia		bicolor	11:Dochna
SC23 Amelsie No. R	PI534128, IS12543C	CTr	BRM	Ethiopia	Amara	durra	50:Durra
SC240 Nandyal R	PI533842, IS3814C	CTr	BRM	India	Karnataka	durra	51:Nandyal
SC241 SV 34 R							
SC243 EC18246 R							
SC25 No. 73 R	IS12545C	CTr	BRM	Ethiopia	Berilie	durra	50:Durra
SC261 ZA 41 Danye R							
SC279 Ihera BE 25 R	PI534070, IS7419C, NSL50595	CTr	BRM	Nigeria	Bissauia (city?)	guinea	21:Conspicuum
SC283 Msumbji R	PI533869, IS7173C	CTr	BRM	Tanzania	Tanganyka	guinea	21:Conspicuum
SC295 BE 34 R	IS7427C	CTr	BRM	Nigeria		guinea	21:Conspicuum
SC299 SO 16 Sanba R	PI533785, IS7920C	CTr	BRM	Nigeria	Zamfara	guinea	21:Conspicuum
SC301 Bank Oumano R	IS3817C	CTr	BRM	Mali	Bamako	guinea	20:Guineense
SC303 KO 37 Canjin R	PI533839, IS3620C	CTr	BRM	Nigeria	Katsina	guinea	22:Margaritiferum
SC305 428 Sian R	PI534037, IS6842C	CTr	BRM	Chad		guinea-caudatum	121:Membranaceum

SC309 Ankolib Khaf R	PI533754, IS2483C	CTr	BRM	Sudan	Blue Nile	bicolor	11:Dochna
SC317 Chanan Singo R	PI533855, IS6271C	CTr	BRM	India	Assam	guinea-bicolor	62:Dochna-roxburghii
SC319 Sorghum Soro R	PI533833, IS2757C	CTr	BRM	Uganda		caudatum-bicolor	73:Dochna-nigricans
SC320 Oua Berr R	PI533863, IS6882C	CTr	BRM	Chad		kafir	40:Caffrorum
SC322 AS 4660 (Kik R	PI533821, IS1309C, NSL51676	CTr	BRM	Tanzania	Tanganyika	caudatum	32:Nigricans
SC323 Kemurit Whit R	PI576399, IS3515C	CTr	BRM	Sudan	Tozi (institute)	caudatum	32:Nigricans
SC324 J 27 R	PI576396, IS2681C	CTr	BRM	Uganda		caudatum	32:Nigricans
SC325 Sorghum vulg R	PI533957, IS2462C	CTr	BRM	United States		caudatum	32:Nigricans
SC328 EC 21463 ST R	PI534112, IS8263C	CTr	BRM	Uganda		caudatum	35:Dobbs
SC329 BA 45 Faria R							
SC33 Bekedjie No. R	PI534132, IS12553C	CTr	BRM	Ethiopia	Kembolcha	durra	50:Durra
SC331 Bonkum R							
SC333 R	PI533761, IS3063C	CTr	BRM	Ethiopia	Assela (city?)	caudatum	30:Caudatum
SC334 Huria White R	PI533986, IS3499C	CTr	BRM	Sudan	Tozi (institute)	caudatum	30:Caudatum
SC348 Kaura KA 24 R	PI534075, IS7455C	CTr	BRM	Nigeria		caudatum	30:Caudatum
SC35 Mashela Ting R	PI534133, IS12555C	CTr	BRM	Ethiopia		durra	50:Durra
SC370 KA 3 R							
SC372 KA 21 (Gajer R							
SC373 Kaura R	IS7461C, NSL54218	CTr	BRM	Nigeria	Tambu	caudatum	36:Caudatum-kaura
SC38 Netch No. 64 R	PI534135, IS12558C	CTr	BRM	Ethiopia	Addesho (city?)	durra	50:Durra
SC382 Kanura Maima R	PI534088, IS7724C	CTr	BRM	Nigeria		caudatum	36:Caudatum-kaura
SC386 Kaura Dantse R							
SC391 Dawa U. A. R	IS7182C, NSL54120	CTr	BRM	Egypt		caudatum	36:Caudatum-kaura
SC396 KA 15 (Yazga R	PI533877, IS7447C	CTr	BRM	Nigeria	Gundawa (city?)	caudatum	36:Caudatum-kaura
SC399 KO 61 (Barag R	PI533882, IS7537C	CTr	BRM	Nigeria	Kano	caudatum	36:Caudatum-kaura
SC411 255 Tirter R	PI533866, IS6964C	CTr	BRM	Sudan		caudatum-bicolor	71:Caudatum-dochna
SC413 Farin Bwanku R	PI534079, IS7577C	CTr	BRM	Nigeria	Plateau	caudatum-bicolor	71:Caudatum-dochna
SC414 Deburr Kass R	PI533831, IS2508C	CTr	BRM	Sudan		kafir-caudatum	130:Caudatum-kafir
SC418 AS 4616 Bala R	PI533822, IS1335C	CTr	BRM	Tanzania	Tanganyka	kafir-caudatum	130:Caudatum-kafir
SC42 (No Name) R	PI576393, IS2463C	CTr	BRM	Ethiopia	Neghelli (city)	caudatum	32:Nigricans
SC420 290 Feterita R	PI533769, IS7064C	CTr	BRM	Sudan		kafir-caudatum	130:Caudatum-kafir
SC423 Nyithin R	PI533758, IS2579C	CTr	BRM	Sudan	Equatoria	caudatum	37:Zerazera
SC424 A-96 R	PI533901, IS8100C	CTr	BRM	Japan		caudatum	31:Caudatum-nigricans
SC425 Tabroro 7 R	PI533762, IS3579C	CTr	BRM	Sudan	Tozi (institute)	durra-caudatum	140:Caudatum-durra
SC441 Yerra Jonna R	PI534009, IS5142C	CTr	BRM	India	Andhra Pradeesh	durra	50:Durra
SC449 Karkatia Sal R	PI597950, IS5763C	CTr	BRM	India	Bihar	guinea-durra	120:Durra-roxburghii
SC450 Cholia Talij R							
SC465 S. subglabre R	PI533997, IS3646C	CTr	BRM	Arabia	Aden	guinea-durra	120:Durra-roxburghii
SC467 AS 2613 (N. R	PI533943, IS1387C	CTr	BRM	India	Tamil Nadu	durra-bicolor	92:Durra-dochna

SC473 Jowar Tamarg R	PI534028, IS6404C	CTr	BRM	India	Maharashtra	durra	51:Nandyal
SC480 Jowar Kalgun R	IS6408C	CTr	BRM	India	Maharashtra	durra	51:Nandyal
SC489 Jola Nandyal R	PI533856, IS6389C	CTr	BRM	India	Karnataka	durra	51:Nandyal
SC49 Ankolib-Red R	PI152595, IS2484C	CTr	BRM	Sudan	Kurdufan	guinea-caudatum	100:Caudatum-guineense
SC498 Jowar Shenol R	IS6436C, NSL55743	CTr	BRM	India	Maharashtra	durra	51:Nandyal
SC500 Shenoli Loca R	IS6452C	CTr	BRM	India	Maharashtra	durra	51:Nandyal
SC502 Hamaisi 38 R	PI533996, IS3598C	CTr	BRM	Sudan		durra-caudatum	142:Durra-nigricans
SC52 Culum brick R	PI533830, IS2501C	CTr	BRM	Sudan	Kurdufan	caudatum	34:Nigricans-feterita
SC525 NG104 R	IS7671C	CTr	BRM	Nigeria		guinea	21:Conspicuum
SC53 Feterita Fuy R	PI533788, IS12567C	CTr	BRM	Sudan	Anglo-Egyptian	durra-caudatum	142:Durra-nigricans
SC532 132 AB Farak R	PI597951, IS6733C	CTr	BRM	West Volta		guinea	21:Conspicuum
SC55 Feterita Gon R	PI152662, IS2541C	CTr	BRM	Sudan	Anglo-Egyptian	caudatum	30:Caudatum
SC553 Lekkite Bund R							
SC557 AS 4055 (Mka R	PI533939, IS1318C	CTr	BRM	Mosambique	Fika	caudatum	32:Nigricans
SC558 AS 5826 (Hol R	PI533938, IS1311C	CTr	BRM	Zaire		caudatum	32:Nigricans
SC56 Klor R	PI533910, IS12568C	CTr	BRM	Sudan	Kurdufan	caudatum	31:Caudatum-nigricans
SC562 Kireniga 317 R	PI533987, IS3509C	CTr	BRM	Sudan	Tozi (institute)	caudatum	30:Caudatum
SC563 KA 12 (Janja R	PI533876, IS7444C	CTr	BRM	Nigeria	Kofinsoli	caudatum	30:Caudatum
SC564 T-28 R	PI534053, IS7142C	CTr	BRM	Uganda		caudatum	30:Caudatum
SC566 M1 R	PI533871, IS7254C	CTr	BRM	Nigeria		caudatum	30:Caudatum
SC569 Kaura Mai Ma R	PI534092, IS7780C	CTr	BRM	Nigeria		caudatum	36:Caudatum-kaura
SC57 Kodilib R	PI533789, IS12569C	CTr	BRM	Sudan	Kurdufan	guinea-caudatum	100:Caudatum-guineense
SC572 (unknown) R	PI533980, IS3390C	CTr	BRM	China	Peking	kafir-caudatum	130:Caudatum-kafir
SC574 Accho Karunh R	PI534114, IS8337C	CTr	BRM	Pakistan	Sindh	caudatum	31:Caudatum-nigricans
SC58 Kokla R	PI533911, IS12570C	CTr	BRM	Sudan	Kurdufan	caudatum	30:Caudatum
SC587 Jola Nandyal R	PI534021, IS6356C	CTr	BRM	India	Karnataka	durra	51:Nandyal
SC59 Magbago Felu R	PI152719, IS2567C	CTr	BRM	Sudan	Equatoria	caudatum-bicolor	72:Nigricans-bicolor
SC598 SG 4 Bulk R	PI576337, IS2748C	CTr	BRM	Uganda			182:Virgatum
SC599 Manawan Rex R	PI534163, IS17459C,	CTr	BRM	United States		caudatum	31:Caudatum-nigricans
SC6 Orange No. 1 R	PI533902, IS12526C	CTr	BRM	Ethiopia	Shoa	durra-bicolor	93:Subglabrescens
SC60 Malwalawail R	PI533962, IS2569C	CTr	BRM	Sudan	Equatoria	caudatum	31:Caudatum-nigricans
SC603 Nyahila AS R	PI533936, IS1168C	CTr	BRM	Tanzania	Maswadt (city?)	guinea	21:Conspicuum
SC605 Malle SO 85 R	PI534096, IS7979C	CTr	BRM	Kenya		guinea	22:Margaritiferum
SC606 A-2789 S. N R	PI597946, IS3106C	CTr	BRM	China		guinea-bicolor	62:Dochna-roxburghii
SC609 AS 5200 R	PI576332, IS1213C	CTr	BRM	China		bicolor	13:Nervosum-kaoliang
SC610 Tsinan R	IS1220C, NSL51074	CTr	BRM	China		bicolor	13:Nervosum-kaoliang
SC614 AS 4601 (Paw R	PI533940, IS1333C	CTr	BRM	Tanzania		bicolor	10:Bicolor
SC62 Matchikah R							
SC621 Anji R	IS5030C, NSL51265	CTr	BRM	India	Maharashtra	bicolor	11:Dochna
SC623 Sweet Sorghu R	PI533956, IS2456C	CTr	BRM	Congo		durra-bicolor	91:Dochna-durra

SC624 Jowar Red Ja R	PI576366, IS6164C	CTr	BRM	India	Uttar Pradesh	durra-bicolor	91:Dochna-durra
SC625 HG 6028 R	PI534097, IS8003C	CTr	BRM	Japan		kafir	40:Caffrorum
SC627 DL/60/99 R	PI576345, IS3138C	CTr	BRM	South Africa		kafir	40:Caffrorum
SC628 Bulfontein K R	PI533979, IS3169C	CTr	BRM	South Africa	Pretoria	kafir	40:Caffrorum
SC63 Mendo R	PI533912, IS12573C	CTr	BRM	Sudan	Kurdufan	caudatum	31:Caudatum-nigricans
SC630 AS 4136 (Ma R	PI533937, IS1269C	CTr	BRM	Zambia		kafir	40:Caffrorum
SC637 EC 21361 G3 R	PI534105, IS8167C	CTr	BRM	Uganda		kafir-caudatum	132:Caffrorum-darso
SC639 EC 21359G28 R	IS8165C	CTr	BRM	India		kafir-caudatum	132:Caffrorum-darso
SC64 Monshal R	PI152736, IS2573C	CTr	BRM	Sudan		kafir-caudatum	130:Caudatum-kafir
SC641 EC 21360 G2 R	PI534104, IS8166C	CTr	BRM	Uganda		kafir-caudatum	132:Caffrorum-darso
SC645 EC 21428 SB	PI534108, IS8231C	CTr	BRM	Uganda		kafir-caudatum	132:Caffrorum-darso
SC648 P 3749 (Q2-5 R	PI533955, IS2419C	CTr	BRM	South Africa		kafir-caudatum	131:Caffrorum-birdproof
SC650 Mtuli Swazil R	PI576340, IS2856C	CTr	BRM	South Africa	Pretoria	kafir-caudatum	131:Caffrorum-birdproof
SC655 Framiola DL/ R	PI533976, IS2862C	CTr	BRM	South Africa	Pretoria	kafir-caudatum	131:Caffrorum-birdproof
SC659 Nebraska 633 R	PI576333, IS2225C	CTr	BRM	United States	Nebraska	guinea-kafir	110:Caffrorum-roxburghii
SC66 Nyan Dok R	PI533913, IS12575C	CTr	BRM	Sudan	Equatoria	guinea-caudatum	101:Nigricans-guineense
SC663 Nebraska 635 R	PI533948, IS2232C	CTr	BRM	United States	Nebraska	guinea-kafir	110:Caffrorum-roxburghii
SC67 Tuery 11 R	PI534139, IS12576C	CTr	BRM	Sudan	Equatoria	guinea-caudatum	101:Nigricans-guineense
SC671 194 Kano R	PI534054, IS7148C	CTr	BRM	Kenya		kafir-caudatum	133:Caffrorum-feterita
SC672 Hoarkdoom 19 R	PI595702, IS2837C	CTr	BRM	Zimbabwe	Matabeleland N.	kafir-caudatum	133:Caffrorum-feterita
SC673 Bathoen Whit R	PI576339, IS2840C	CTr	BRM	Zimbabwe	Matabeleland N.	kafir-caudatum	133:Caffrorum-feterita
SC679 Kalatilansa R	PI586788, IS7005,	CTr	BRM			guinea-caudatum	101:Nigricans-guineense
SC695 EC 21471 STR	IS8270C	CTr	BRM	Tanzania		caudatum	35:Dobbs
SC701 Barking 119 R	PI533985, IS3462C	CTr	BRM	Sudan	Tozi (institute)	caudatum	30:Caudatum
SC702 Fanda 128 R	IS3485C	CTr	BRM	Sudan	Tozi (institute)	caudatum	30:Caudatum
SC704 A 84 R	PI534099, IS8087C	CTr	BRM	Japan		caudatum	30:Caudatum
SC708 2033 Z 3 R	PI533970, IS2740C	CTr	BRM	Uganda		caudatum	30:Caudatum
SC720 Matama R	IS7151C	CTr	BRM	Kenya		caudatum	31:Caudatum-nigricans
SC725 A 106 R	PI534101, IS8112C	CTr	BRM	Japan		caudatum	30:Caudatum
SC734 Lambas R	PI576394, IS2562C	CTr	BRM	Sudan	Kurdufan	caudatum	30:Caudatum
SC738 Nagad White R	PI597952, IS6960C	CTr	BRM	Sudan	Tozi (institute)	caudatum	30:Caudatum
SC748 Sinidyil 177 R	PI533991, IS3552C	CTr	BRM	Sudan	Tozi (institute)	guinea-caudatum	100:Caudatum-guineense
SC749 A 112-3 R	PI576373, IS8120C	CTr	BRM	Japan		caudatum-bicolor	70:Caudatum-bicolor
SC755 Purdue No. 8 R							
SC757 Marupanste R	PI576352, IS3402C	CTr	BRM	Botswana	Central	kafir-caudatum	130:Caudatum-kafir
SC760 Maga Abiad (R	PI533949, IS2288C	CTr	BRM	Sudan	Al Jazirah	kafir-caudatum	130:Caudatum-kafir
SC782 Chori Uri R	PI576364, IS6057C	CTr	BRM	India	Punjab	caudatum	31:Caudatum-nigricans
SC79 Muzeda No. 7 R	PI533915, IS12588C	CTr	BRM	Kenya	VOI Teita Hills		
SC790 Gangari Rais R							
SC798 Nyithin 259 R	PI533989, IS3541C,	CTr	BRM	Sudan	Tozi (institute)	caudatum	37:Zerazera

SC803 Safara Kord R	PI533964, IS2586C	CTr	BRM	Sudan		caudatum	37:Zerazera
SC805 SB 283 T32 R	PI533967, IS2723C	CTr	BRM	Uganda		caudatum	37:Zerazera
SC833 Desi R	IS4748C	CTr	BRM	India	Gujarat	durra	50:Durra
SC84 No. 491 Kabu R	PI534144, IS12593C	CTr	BRM	Uganda	Kampala	durra-caudatum	142:Durra-nigricans
SC855 Giza 123 S10 R	PI597945, IS2871C	CTr	BRM	Egypt	Orman	durra	50:Durra
SC888 Kempu Jola M R	IS4495C	CTr	BRM	India	Karnataka	durra	50:Durra
SC91 No. 902 Sorg R	PI534145, IS12600C	CTr	BRM	Zimbabwe	Southern	bicolor	57: S. nitidum (old classif.)
SC910 Butivori R	PI576359, IS5037C	CTr	BRM	India	Maharashtra	guinea-durra	122:Durra-membranaceum
SC929 IC3443 (impr R	PI595699, IS1029C	CTr	BRM	India	Maharashtra	durra	52:Cernuum
SC937 Purdue No. 8 R	PI576348, IS3201C	CTr	BRM	United States		bicolor	15:Sudanense
SC941 Purdue No. 8 R	PI576347, IS3196C	CTr	BRM	United States		bicolor	15:Sudanense
SC942 Purdue No 81 R	PI576349, IS3212C	CTr	BRM	United States		bicolor	15:Sudanense
SC947 R							
SC949 Brawley R	PI533998, IS3648C	CTr	BRM	United States	Nebraska	bicolor	
SC964 Kenya var. R	PI533972, IS2765C	CTr	BRM	Uganda		caudatum	35:Dobbs
SC968 S-50-74 R	.	CTr	BRM	Zimbabwe	.	durra-bicolor	93:Subglabrescens
SC970 E-51 R	PI576386	CTr	BRM	Uganda			
SC971 Millo Blanco R	IS21910C	CTr	BRM	United States	Puerto Rico	kafir-durra	150:Durra-kafir
SC979 Col. No. P-5 R	PI576428, IS12153C	CTr	BRM	Ethiopia	Gambele	caudatum	37:Zerazera
SC982 Col. No. P-5 R	PI576380, IS12156C	CTr	BRM	Ethiopia	Gambele	caudatum	37:Zerazera
SC984 Akwuu Col. R	PI534115, IS12158C	CTr	BRM	Ethiopia	Pokomo Village	caudatum	37:Zerazera
SC991 Mashica Col R	PI534117, IS12219C	CTr	BRM	Uganda	Hoima	bicolor	10:Bicolor
SC998 F.R.Miller R							
Segaolane R							
Shan Qui Red R		Breeding	cultivar	China			
SRN39 R		Breeding	cultivar				
SURENO R		Breeding	cultivar	Cen. America			
Tx2911 R		Breeding	inbred line	United States	Texas		

BRM – Breeding research material,

CTr – Converted tropical

TCL – Traditional cultivar landrace

‡ - Dahlberg, J.A. 2000. Classification and characterization of sorghum. p. 99-130. In C.W. Smith and R.A. Frederiksen (ed.) Sorghum: origin, history, technology, and production. John Wiley & Sons, Inc. New York.

Table 5.15: Supplementary Table 2: Genotypic stability for lines in the association panel.

	Genotype	SS (Reg)	SS (Dev)	Var (Dev)	Mean Yld (kg ha^{-1})	Reg. Coeff.
1	SC172	19627	619977	309989	492	0.0671
2	SC1076	526	471033	471033	590	0.0114
3	SC15	121528	986377	493188	607	0.1670
4	SC553	201589	886937	443468	826	0.2151
5	SC1103	43883	225189	112594	852	0.1004
6	SC1439	240657	173273	86637	897	0.2350
7	SC1440	468086	295674	147837	1083	0.3278
8	SC480	509243	1317565	658782	1143	0.3419
9	SC450	1064025	115322	57661	1177	0.4942
10	SC1218	743583	1075365	537682	1293	0.4132
11	SC382	29239	38097	19049	1325	0.0819
12	KS19	16261	1550504	775252	1327	0.0611
13	SC135	518374	5987292	2993646	1331	0.3450
14	SC303	1153165	49133	24567	1383	0.5145
15	SC532	568939	1449026	724513	1401	0.3614
16	SC942	696657	2217728	1108864	1427	0.3999
17	SC386	18072	1378045	689023	1453	0.0644
18	SC624	1561233	561111	280555	1453	0.5987
19	SC970	2078393	81097	40549	1465	0.6907
20	SC25	1291851	1780438	890219	1519	0.5446
21	RTAM428	2853399	3979	1989	1521	0.8093
22	SC134	1418481	436119	218060	1552	0.5706
23	SC53	85776	35891	17945	1574	0.1403
24	SC562	1288155	848713	424356	1605	0.5438
25	SC57	225508	99519	99519	1632	0.2367
26	SC224	2771139	174784	87392	1649	0.7976
27	SC336	52176	952886	952886	1663	0.5938
28	SC609	627159	34768	17384	1681	0.3794
29	SC679	1595729	81592	40796	1763	0.6053
30	BTx615	1604612	841082	420541	1787	0.6069
31	SC606	666486	1087707	543854	1800	0.3912
32	SC937	498628	1043008	521504	1801	0.3383
33	SC173	2973260	739188	369594	1803	0.8262
34	SC968	1320580	3278677	1639338	1818	0.5506
35	SC331	3792237	164965	82483	1833	0.9330
36	BTx642	4176109	13873	6937	1847	0.9791
37	SC1484	2590747	4120416	2060208	1851	0.7712
38	SC84	1482541	290885	290885	1859	3.1650
39	SC941	439133	41157	20578	1860	0.3175
40	SC348	1710123	7152	7152	1882	3.3993
41	SC59	2350917	2224572	1112286	1905	0.7346

42	SC605	30230	93768	46884	1928	0.0833
43	SC396	16382	1398434	699217	1929	0.0613
44	SC558	2119688	880490	440245	1932	0.6976
45	SC1215	3367641	394486	197243	1946	0.8793
46	SC91	641148	298181	149091	1947	0.3837
47	SC108	2171012	323298	161649	1973	0.7060
48	SC38	2822253	2446582	1223291	1986	0.8049
49	SC79	1340375	477672	238836	1988	0.5547
50	SC21	1820969	236167	118084	2015	0.6466
51	SC449	561612	7677496	3838748	2020	0.3591
52	SC1214	1537392	3275299	1637650	2025	0.5941
53	SC279	1091342	1167309	1167309	2030	0.5119
54	SRN39	3084514	284484	284484	2059	0.8607
55	SC663	3287123	38918	19459	2076	0.8687
56	SC67	499969	600880	300440	2094	0.3388
57	SC982	2044861	2758018	1379009	2101	0.6852
58	SC322	6376123	854027	427014	2118	1.2099
59	SC621	2232397	31512	15756	2130	0.7159
60	SC22	69519	627412	627412	2131	0.6854
61	SC991	2875629	137714	68857	2189	0.8125
62	SC1424	1090283	885780	442890	2192	0.5003
63	SC155	2892590	463281	231640	2197	0.8149
64	SC734	5559793	952803	476401	2213	1.1298
65	KS115	4721024	5678228	5678228	2235	1.0831
66	SC411	616487	339356	169678	2253	0.3762
67	BTx643	4904249	2380848	1190424	2253	1.0611
68	RTx2917	1871819	216351	108175	2263	0.6555
69	SC1201	1330	3759445	3759445	2276	0.0948
70	SC949	758100	35924	17962	2286	0.4172
71	SC 58	1912801	1157361	578681	2303	0.6627
72	SC265	2637	856045	428022	2336	0.0246
73	SC671	3224430	499038	249519	2347	0.8604
74	SC145	5475041	172398	86199	2349	1.1211
75	SC305	478737	1137887	568943	2352	0.3315
76	SC323	2434696	703692	351846	2359	0.7476
77	SC525	332689	3325759	1662879	2365	0.2764
78	SC192	387318	489910	244955	2369	0.2982
79	SC473	3352890	1476117	738058	2369	0.8773
80	SC324	1419701	1058631	529316	2381	0.5709
81	SC33	2900960	1022836	511418	2384	0.8161
82	SC748	4336468	98020	49010	2399	0.9978
83	RTx436	4780664	565735	282868	2402	1.0476
84	SC500	5969634	1422838	711419	2409	1.1707
85	SC673	856465	542029	271015	2411	0.4434
86	SC35	5619124	168975	84488	2421	1.1358

87	SC1320	5918398	292958	146479	2422	1.1656
88	SC42	2560093	900840	450420	2425	0.7666
89	SC243	3436177	226405	226405	2436	0.9084
90	SC325	5296802	126800	63400	2444	1.1027
91	SC414	6453845	653479	326739	2460	1.2172
92	SC309	3488277	37717	18859	2466	0.8949
93	SC1033	6429914	3486899	1743450	2467	1.2149
94	SC648	5329758	736525	368262	2470	1.1061
95	SC55	889090	1155382	577691	2494	0.4518
96	SC672	1923633	470194	235097	2495	0.6645
97	SC833	2255937	1173058	586529	2519	0.7196
98	SC566	530066	14671	7335	2564	0.3488
99	SC489	2420789	410318	205159	2571	0.7455
100	SC1246	2156095	172779	86389	2584	0.7035
101	SC1070	3178533	924728	462364	2585	0.8542
102	SC418	6412519	744777	372389	2586	1.2133
103	SC1356	1099966	920982	460491	2587	0.5025
104	BTxARG-1	3842790	1311921	655961	2593	0.9392
105	SC420	533143	1025194	512597	2594	0.3498
106	SC628	1579388	518581	259291	2597	0.6021
107	SC1017	5483125	262560	131280	2604	1.1219
108	SC630	3242074	188173	94087	2609	0.8627
109	SC124	4622373	759143	379572	2613	1.0301
110	SC557	1939	4892110	2446055	2617	0.0211
111	SC1471	4475040	760999	380500	2619	1.0136
112	SC1277	5765164	917749	458875	2631	1.1504
113	SC240	6843496	260524	260524	2641	1.2820
114	SC498	3008011	5228503	5228503	2645	0.8645
115	SC299	3625744	268257	134129	2647	0.9123
116	SC587	1175781	2037011	1018506	2667	0.5195
117	SC855	859429	603222	301611	2671	0.4442
118	RTX2737	1701136	1126398	563199	2681	0.6249
119	SC757	2566179	342996	171498	2686	0.7675
120	SC1203	2298942	3731094	1865547	2691	0.7265
121	SC63	1467526	1024886	512443	2696	0.5804
122	SC574	7750974	2605240	1302620	2704	1.3339
123	SC467	6378397	949239	474620	2717	1.2101
124	SC1154	2150080	245080	122540	2720	0.7026
125	SC929	1469385	199790	99895	2753	0.5808
126	SC639	7743127	212384	106192	2769	1.3333
127	SA5330/Martin	4744012	4535768	2267884	2773	1.0436
128	SC283	8096198	489444	489444	2773	1.3944
129	SC1077	2740857	2610641	1305321	2807	0.7932
130	San Qui Red	8999973	475576	475576	2808	1.4701
131	SC23	8607701	861486	430743	2810	1.4057

132	SC199	10454888	147291	73645	2820	1.5492
133	SC209	3069475	2282936	1141468	2830	0.8394
134	SC6	1272973	3564993	1782496	2844	0.5406
135	SC213	2130600	2018748	1009374	2875	0.6994
136	SC17	7993179	997982	498991	2889	1.3546
137	SC66	2709462	477813	238906	2890	0.7887
138	SC317	3525156	509317	254658	2907	0.8996
139	SC625	4795551	762080	381040	2940	1.0492
140	SC1158	3189662	894904	447452	2952	0.8557
141	SC206	3830800	2316371	1158186	2962	0.9378
142	SC998	7712239	1178892	589446	2965	1.3306
143	SC214	4099817	2602783	1301391	2969	0.9701
144	SC637	5439624	43975	21988	2985	1.1175
145	SC1080	4741350	136206	68103	3001	1.0433
146	SC614	2479005	2546910	1273455	3013	0.7544
147	SC782	4733695	2194117	1097058	3022	1.0424
148	SC241	2894508	320915	160457	3025	0.8152
149	RTAM2566	707027	31	31	3027	0.4121
150	San Chi San	2305561	128445	64223	3032	0.7275
151	Day	3901308	2923516	1461758	3033	0.9464
152	SC330	2351582	187568	187568	3041	3.9862
153	SC295	3466524	2658086	1329043	3052	0.8921
154	SC413	1478759	926933	463466	3064	0.5826
155	SC62	7979026	3153810	1576905	3066	1.3534
156	SC132	7173040	1447645	723822	3072	1.2832
157	SC334	180106	1160249	580124	3078	0.2033
158	SC370	3835237	11051387	5525694	3083	0.9383
159	SC49	2455424	639259	319629	3085	0.7508
160	SC477	613127	191165	191165	3094	2.0354
161	SC1489	8381483	4580512	2290256	3114	1.3871
162	SC319	2755720	76694	38347	3127	0.7954
163	SC423	2529807	489859	244930	3137	0.7621
164	BQL41	4936073	503502	251751	3139	1.0645
165	SC372	2151513	422495	211247	3139	0.7028
166	SC202	7216	1070660	1070660	3141	0.2208
167	SC610	5925459	4584537	2292269	3154	1.1663
168	SC650	3817759	2746796	1373398	3164	0.9362
169	Ajabsido	233419	96802	48401	3179	0.2315
170	BTx3042	7926386	1151375	575688	3185	1.3489
171	SC56	6290527	1312375	656188	3198	1.2017
172	Feterita Gishesh	6295283	2231711	1115856	3198	1.2022
173	SC1205	2127068	305088	152544	3215	0.6988
174	SC1085	796210	161727	80864	3217	0.4275
175	SC1124	2388169	1051794	525897	3223	0.7404
176	SC627	10900042	532892	266446	3238	1.5819

177	SC64	9573411	1052945	526472	3257	1.4825
178	SC888	12931750	572947	286474	3257	1.7230
179	SC1038	9585790	1042292	521146	3262	1.4834
180	SC1429	4120094	456107	228054	3305	0.9725
181	SC1104	6273726	1621686	810843	3307	1.2001
182	SC1271	10669746	732239	366119	3355	1.5651
183	SC979	14301457	767727	383863	3358	1.8119
184	SC1337	633549	473515	236758	3377	0.3814
185	SC52	11522063	2169172	1084586	3382	1.6264
186	SC223	7011073	1756556	878278	3386	1.2687
187	SC170	13236393	4793766	2396883	3391	1.7432
188	P9517	3009279	1094002	1094002	3442	0.8501
189	SC1319	8986086	616335	308167	3456	1.4363
190	SC695	6614361	3154818	1577409	3465	1.2322
191	SC708	143384	667440	333720	3476	0.1814
192	SC465	5911965	163634	81817	3480	1.1650
193	SC441	7201630	478130	239065	3491	1.2858
194	El Mota	6263663	4698439	2349220	3491	1.1991
195	SC1330	7548979	21931	10965	3499	1.3164
196	SC1329	10685690	1836707	918353	3511	1.5662
197	SC284	739812	1372647	1372647	3523	2.2358
198	SC425	7467181	259310	129655	3540	1.3093
199	SC1014	5577520	966234	483117	3550	1.1316
200	SC1416	1002126	231851	115926	3557	0.4796
201	SC115	4585382	434404	217202	3558	1.0260
202	SC987	13226050	497281	248641	3567	1.7425
203	BTx2752	15585018	137340	68670	3568	1.8915
204	SC755	6976137	1751844	875922	3579	1.2655
205	SC659	9024142	1116027	558014	3583	1.4393
206	SC760	779630	937447	468724	3614	0.4231
207	SC1155	4493137	1235064	617532	3631	1.0156
208	Malisor 84-7	2578268	757294	378647	3637	0.7693
209	BOK11	13528758	1150973	575486	3639	1.7623
210	SC1322	10258428	791087	395544	3648	1.5346
211	SC452	1024188	1632263	1632263	3665	2.6307
212	SC13	13718957	194264	97132	3669	1.7747
213	SC725	6664888	3350701	1675351	3686	1.2369
214	SC121	3096952	7167410	3583705	3687	0.8432
215	SC655	8865976	2219278	1109639	3697	1.4266
216	SC971	14102694	3647242	1823621	3713	1.7993
217	SC599	5067442	504591	252296	3715	1.0786
218	SC329	1379031	571108	285554	3717	0.5627
219	SC502	5122493	792508	396254	3720	1.0844
220	SC1212	6401553	95789	47895	3731	1.2123
221	SC738	347301	716592	358296	3731	0.2824

222	SC146	259574	102498	102498	3758	1.3244
223	SC798	14661746	1540475	770237	3759	1.8346
224	SC641	8698495	2330402	1165201	3767	1.4131
225	SC367	171440	26583	26583	3771	1.0763
226	BTx3197	7723078	2088072	1044036	3772	1.3315
227	SC118	2221757	480206	240103	3772	0.7142
228	BTx641	6335214	2103443	1051722	3847	1.2060
229	SC1451	5109786	199622	99811	3857	1.0831
230	SC803	18111880	1228147	614074	3860	2.0391
231	SC1494	12195372	254164	127082	3896	1.6732
232	SC328	13292469	372071	186036	3899	1.7469
233	SC337	1194354	520617	520617	3907	2.8408
234	SC1328	2552813	962398	481199	3908	0.7655
235	BTx623	11587643	1754896	877448	3908	1.6310
236	SC805	19594437	1529994	764997	3914	2.1209
237	SC499	1113258	259708	259708	3940	2.7427
238	SC790	9545053	809854	404927	3965	1.4803
239	SC520	272040	5137301	5137301	3976	1.3558
240	SC645	5710917	683823	341911	3981	1.1450
241	SC1056	15516888	1307963	653981	3991	1.8874
242	SC575	860589	3885	3885	4003	2.4114
243	SC1251	1233288	2473255	2473255	4003	2.8868
244	SC749	11748788	678751	339376	4022	1.6423
245	SC564	10158361	10082736	5041368	4048	1.5271
246	SC346	3150599	225282	225282	4056	4.6140
247	SC110	153688	211817	105909	4066	1.5192
248	RTX2536	6343774	128922	128922	4081	1.2343
249	SC373	6366109	836427	418213	4160	1.2089
250	SC1345	12050130	424027	212013	4178	1.6632
251	SC332	7646276	2635161	1317581	4186	1.3249
252	SC1057	21120201	7808857	3904428	4234	2.2019
253	MR732	13954013	1357710	678855	4239	1.7898
254	SC51	5370280	2901317	1450658	4241	1.1103
255	SC301	14917328	812691	406345	4247	1.8505
256	SC1074	3246461	2928402	1464201	4250	0.8633
257	RTx437	6448804	2908618	1454309	4269	1.2167
258	SC623	8193930	216082	108041	4275	1.3715
259	SC391	3704550	3969203	1984602	4294	0.9222
260	BTx645	13313557	3246918	1623459	4295	1.7482
261	SC1211	5006772	426731	213365	4329	1.0721
262	SC60	14829900	2953928	1476964	4347	1.8451
263	RTx430	13608827	349947	174973	4377	1.7675
264	Tx2911	19446242	4111	4111	4380	2.1610
265	SC563	14779792	455425	227712	4390	1.8420
266	(SN149)SA7000 CAPROCK	13145421	722132	361066	4399	1.7372

267	SC1047	15798026	1390272	695136	4401	1.9044
268	SC701	14228978	807288	403644	4422	1.8073
269	SC424	7112443	975744	487872	4437	1.2778
270	Segaolane	7832271	859783	429892	4455	1.3409
271	RTx2783	6645755	218165	109083	4499	1.2352
272	Tx2741	3672814	1299019	1299019	4506	0.9391
273	SC103	13206177	4566591	2283296	4571	1.7412
274	SC1079	11742262	36834	18417	4572	1.6418
275	SC175	20381497	515372	257686	4601	2.1631
276	SC504	3772548	604	604	4610	5.0489
277	SURENO	13111163	478138	478138	4623	1.7744
278	SC964	21812438	2695629	1347814	4696	2.2377
279	SC720	6249718	122083	61041	4716	1.1978
280	BTx399	12905012	79438	39719	4720	1.7212
281	BTx378	17043430	2039834	1019917	4774	1.9780
282	Dorado	12517686	24512	12256	4874	1.6952
283	SC704	15557168	2217085	1108542	4969	1.8898
284	SC333	18250854	24196	12098	5001	2.0469
285	SC702	31375152	565934	282967	5186	2.6838
286	SC471	29536	2515551	2515551	5387	0.4467
287	HEGARI	27576129	4108633	2054316	5611	2.5161
288	SC405	1438536	5920461	5920461	6385	3.1177
289	SC1019	48547969	1140742	570371	6783	3.3384
				Mean	**3004**	**1.096**
				Standard Deviation	**1020.36**	**0.720**

Note: Genotypes that did not record any yield are not included in this analysis. Yield of "zero" (0) was deleted from the list.

Table 5.16: Supplementary Table 3: Flowering time (Ashland 2007) and Yield data (Mean for 2006 and 2007 rainfed- Ashland and Hays).

Genotype	Race/group	Duration to Flowering (Days after Planting – DAP)			Grain weight (g/panicle)	Grain number/ panicle	Harvest Index	Grain Yield (kg/ha)
		Rainfed	Irrigated	Mean				
(SN142)SA386 REDBINE-60	Not Placed	57	67	62	31.5	1021	0.31	3236.3
(SN142)SA7078 COMBINE	Breeding line	57	74	66	38.0	1435	0.38	3024.3
(SN149)SA7000 CAPROCK	Breeding line	60	76	68	33.8	1335	0.26	4398.7
Ajabsido	East & South Africa	58	71	64	40.3	1015	0.24	3179.4
BOK11	Breeding line	62	75	68	31.1	1107	0.23	3638.9
BQL41	Not Placed	59	77	68	23.0	920	0.27	3138.6
BTx2752	Breeding line	62	81	71	37.7	1467	0.33	3568.4
BTx3042	Breeding line	55	65	60	22.8	621	0.23	2786.6
BTx3197	Breeding line	58	66	62	35.3	1251	0.32	3771.7
BTx378	Breeding line	61	72	66	28.8	1030	0.22	4774.3
BTx399	Breeding line	57	74	66	31.3	1025	0.29	4719.7
BTx615	Breeding line	59	76	67	34.6	1103	0.23	1786.9
BTx623	Breeding line	58	73	65	29.5	1233	0.28	3908.4
BTx641	Breeding line	60	73	67	45.2	1775	0.32	3847.0
BTx642	Breeding line	64	78	71	17.8	728	0.18	1846.7
BTx643	Breeding line	62	77	70	23.0	1094	0.18	2253.5
BTx645	Breeding line	59	74	66	41.5	1441	0.28	4294.8
BTxARG-1	Breeding line	59	75	67	47.4	1894	0.32	2592.5
Day	Not Placed	57	66	61	35.2	997	0.34	3033.0
Dorado	Not Placed	60	80	70	52.1	1764	0.29	4873.8
El Mota	West Africa	56	69	63	34.4	1366	0.26	3491.4
Feterita Gishesh	Not Placed	49	65	57	20.9	715	0.28	3197.8
HEGARI	Not Placed	61	75	68	49.8	1763	0.28	5611.5
KS115	Breeding line	57	71	64	28.4	574	0.23	2235.0
KS19	Breeding line	60	71	65	22.0	1018	0.21	1326.8
MR732	Not Placed	66	81	74	43.9	1565	0.25	3563.3
Macia	East & South Africa	60	77	68	46.4	1765	0.30	3637.2
Malisor 84-7	West Africa	61	79	70	44.8	2077	0.43	4239.0
P9517	Breeding line	60	79	69	28.1	1346	0.25	3543.1
RTAM2566	Breeding line	60	75	67	28.0	1113	0.29	3026.9
RTAM428	Breeding line	66	78	72	23.3	778	0.23	1521.5
RTX2536	Breeding line	61	78	69	36.8	1369	0.33	4080.7
RTX2737	Breeding line	60	77	69	17.7	800	0.14	2681.2
RTx2783	Breeding line	63	79	71	33.0	1345	0.28	3936.6

RTx2917	Breeding line	61	78	69	36.0	1559	0.23	2262.9
RTx430	Breeding line	61	75	68	31.3	1113	0.24	4377.5
RTx436	Breeding line	67	80	74	41.2	1932	0.27	2401.7
RTx437	Breeding line	60	76	68	37.8	1483	0.33	4269.3
SA5330/Martin	Not Placed	64	75	69	36.3	1454	0.29	2772.5
SC1014	durra	64	76	70	36.5	1093	0.26	3550.3
SC1017	durra	60	74	67	27.2	942	0.21	2603.6
SC1019	caudatum	63	76	70	44.9	1967	0.36	5935.2
SC103	caudatum	58	69	64	30.2	1138	0.29	4571.3
SC1033	durra	67	80	73	37.8	1216	0.25	2466.6
SC1038	durra	59	74	67	33.7	1198	0.32	3261.9
SC1047	durra	64	74	69	47.7	1590	0.26	3850.7
SC1055	caudatum	58	74	66	25.4	991	0.31	2724.6
SC1056	East & South Africa	54	65	60	30.6	1442	0.30	3990.5
SC1057	caudatum	62	76	69	29.3	1084	0.24	4234.1
SC1070	West Africa	56	66	61	18.6	553	0.25	2584.7
SC1074	kafir	53	71	62	19.9	523	0.16	4249.7
SC1076	caudatum	60	71	66	20.4	596	0.19	589.7
SC1077	caudatum	55	67	61	26.0	1284	0.34	2807.4
SC1079	caudatum	57	73	65	30.6	1140	0.29	4572.0
SC108	caudatum	61	75	68	22.0	937	0.23	1972.8
SC1080	kafir	63	69	66	27.5	1272	0.24	3000.6
SC1085	durra	65	76	70	40.0	1377	0.25	2815.2
SC110	caudatum	58	75	66	33.6	1244	0.32	4065.8
SC1103	kafir	52	65	59	16.5	743	0.14	851.9
SC1104	kafir	59	74	67	23.5	1285	0.28	3306.8
SC1124	guinea	59	70	65	34.1	1217	0.37	3223.2
SC115	caudatum	60	75	67	22.8	1051	0.29	3113.0
SC1154	durra	58	70	64	23.5	980	0.29	2720.4
SC1155	durra	63	74	68	29.5	1277	0.26	3630.9
SC1158	durra	60	74	67	27.5	1227	0.28	2951.9
SC118	caudatum	55	67	61	25.2	1055	0.31	3772.1
SC1201	guinea	65	80	73	22.6	718	0.27	1707.3
SC1203	Central America	60	71	66	16.5	827	0.13	2690.6
SC1205	Not Placed	55	66	61	24.5	916	0.29	2812.7
SC121	caudatum	56	66	61	31.5	1290	0.33	3686.8
SC1211	kafir	59	73	66	32.9	1364	0.29	4329.2
SC1212	caudatum	59	70	64	24.7	903	0.19	3731.1
SC1214	guinea	53	67	60	18.7	870	0.19	2025.3
SC1215	Not Placed	60	66	63	17.0	647	0.26	1702.6

SC1218	guinea	59	65	62	21.0	774	0.23	1292.8
SC124	durra	61	75	68	24.3	1127	0.26	2613.3
SC1246	kafir	54	65	59	17.4	670	0.19	2583.8
SC1251	caudatum	61	74	67	27.5	1199	0.27	3002.4
SC1271	caudatum	60	75	68	23.0	810	0.22	3355.2
SC1277	Not Placed	57	69	63	25.3	819	0.24	2630.7
SC13	durra	55	66	60	25.0	1241	0.21	3668.7
SC1319	caudatum	59	75	67	25.5	727	0.17	3456.3
SC132	Not Placed	61	76	68	28.9	862	0.19	3072.3
SC1320	caudatum	58	74	66	32.3	964	0.22	2422.2
SC1322	guinea	57	67	62	26.1	1142	0.25	3648.3
SC1328	caudatum	56	67	62	29.0	1083	0.30	3907.5
SC1329	Not Placed	56	66	61	25.1	760	0.22	3510.9
SC1330	durra	61	75	68	36.5	1072	0.24	3499.2
SC1337	guinea	56	68	62	19.7	743	0.20	3377.1
SC134	Not Placed	58	74	66	20.0	699	0.16	1552.3
SC1345	caudatum	52	66	59	28.8	1135	0.30	4177.5
SC135	durra	72	82	77	25.1	551	0.15	1331.2
SC1356	caudatum	52	64	58	15.7	492	0.24	2587.4
SC1416	durra	53	64	59	16.7	626	0.36	3556.8
SC1424	Not Placed	59	67	63	16.3	817	0.19	2191.6
SC1426	kafir	58	70	64	14.9	595	0.12	1685.0
SC1429	guinea	57	68	63	19.5	634	0.25	3305.0
SC1439	guinea	54	66	60	9.3	480	0.08	897.2
SC1440	Not Placed	55	66	60	13.1	524	0.21	1082.8
SC145	bicolor	63	76	69	15.9	951	0.14	2055.6
SC1451	caudatum	55	67	61	37.0	1009	0.31	3857.2
SC146	Not Placed	66	78	72	30.0	1124	0.24	3757.5
SC1471	durra	62	73	67	33.4	943	0.27	2619.0
SC1484	guinea	57	74	66	19.5	926	0.24	1850.6
SC1489	durra	55	68	62	30.2	988	0.25	3113.5
SC1494	guinea	58	72	65	26.5	1009	0.26	3896.2
SC15	guinea	60	77	68	11.5	538	0.10	606.5
SC155	durra	65	79	72	25.7	955	0.17	1922.4
SC17	bicolor	63	71	67	24.5	1148	0.22	2888.8
SC170	caudatum	62	78	70	27.4	1227	0.24	3391.5
SC172	Not Placed	59	80	70	42.1	1261	0.22	492.0
SC173	Not Placed	60	74	67	25.2	924	0.25	1803.2
SC175	caudatum	61	75	68	32.7	1050	0.21	4600.6
SC192	durra	57	70	64	20.9	708	0.19	2368.7

SC199	durra	66	82	74	23.7	746	0.17	2820.0
SC202	Not Placed	55	66	61	29.1	946	0.34	3141.1
SC206	durra	66	80	73	21.9	1044	0.21	2962.4
SC209	durra	60	74	67	27.3	973	0.19	2830.4
SC21	kafir	60	71	65	15.2	775	0.19	2015.1
SC213	bicolor	59	74	67	26.0	976	0.24	2874.5
SC214	bicolor	57	68	63	31.0	803	0.25	2968.8
SC22	durra	65	85	75	22.3	921	0.18	1598.6
SC223	kafir	56	73	64	35.0	1505	0.35	3386.0
SC224	bicolor	62	73	67	16.7	466	0.11	1443.1
SC23	durra	63	77	70	25.8	954	0.16	2810.3
SC240	durra	68	81	74	28.3	1430	0.24	2641.4
SC241	Not Placed	56	76	66	23.1	881	0.30	3024.9
SC243	Not Placed	61	80	70	22.3	1413	0.22	2436.1
SC25	durra	70	83	77	24.3	502	0.12	1329.2
SC261	Not Placed	59	70	65	19.9	878	0.29	2975.2
SC265	guinea	57	71	64	19.1	963	0.34	2335.8
SC279	guinea	52	73	62	22.7	855	0.29	2030.1
SC283	guinea	62	76	69	19.4	709	0.25	2772.7
SC284	Not Placed	58	66	62	28.8	986	0.39	3523.1
SC295	guinea	59	75	67	27.8	1139	0.37	3052.1
SC299	guinea	55	66	61	21.3	831	0.50	2647.1
SC301	guinea	57	71	64	20.3	767	0.20	4247.4
SC303	guinea	60	71	65	8.7	491	0.19	1383.2
SC305	guinea	59	71	65	12.8	1684	0.25	2352.2
SC309	bicolor	57	67	62	20.5	904	0.29	2465.6
SC317	guinea	61	75	68	23.1	1067	0.25	2907.2
SC319	caudatum	55	67	61	24.2	1193	0.30	3127.4
SC322	caudatum	60	71	65	35.8	1450	0.34	2117.9
SC323	caudatum	56	67	61	15.6	584	0.21	2359.3
SC324	caudatum	56	74	65	21.8	1155	0.22	2381.1
SC325	caudatum	58	65	61	15.8	648	0.18	2138.5
SC328	caudatum	61	75	68	31.7	1339	0.27	3411.3
SC329	Not Placed	58	66	62	20.9	696	0.23	3716.8
SC33	durra	63	73	68	33.0	1171	0.26	2384.4
SC330	Not Placed	57	73	65	21.7	1220	0.22	3040.6
SC331	Not Placed	64	77	70	13.8	636	0.16	1833.4
SC332	Not Placed	62	71	66	40.4	1038	0.32	4185.7
SC333	caudatum	57	67	62	31.0	1139	0.37	5000.8
SC334	caudatum	55	64	59	33.9	932	0.45	2638.3

SC336	Not Placed	57	65	61	21.7	769	0.35	1663.0
SC337	Not Placed	56	68	62	31.4	1520	0.34	3906.5
SC346	Not Placed	65	79	72	46.2	1775	0.42	4055.9
SC348	caudatum	56	66	61	22.9	918	0.23	1882.4
SC35	durra	65	79	72	22.7	730	0.12	2118.1
SC367	Not Placed	55	66	60	42.5	1254	0.44	3771.0
SC370	Not Placed	52	66	59	30.0	730	0.32	2698.1
SC372	Not Placed	58	71	65	35.5	1124	0.28	3138.7
SC373	caudatum	57	66	61	48.6	1457	0.41	4159.7
SC38	durra	71	84	78	25.4	820	0.18	1737.5
SC382	caudatum	51	66	58	21.3	641	0.34	1159.0
SC386	Not Placed	57	67	62	24.4	663	0.34	1271.0
SC391	caudatum	55	67	61	28.7	674	0.24	4294.0
SC396	caudatum	54	70	62	16.6	609	0.37	1929.4
SC405	Not Placed	57	76	66	42.7	1770	0.60	6384.6
SC411	caudatum	56	67	61	16.0	616	0.28	2253.3
SC413	caudatum	57	66	61	32.9	1162	0.27	3064.1
SC414	kafir	63	80	72	24.9	767	0.24	2108.7
SC418	kafir	59	75	67	20.2	834	0.22	2585.8
SC42	caudatum	60	77	68	18.3	632	0.22	2121.5
SC420	kafir	57	70	64	26.1	973	0.32	2594.0
SC423	caudatum	58	71	65	18.6	879	0.18	3137.4
SC424	caudatum	59	69	64	23.8	824	0.29	4437.3
SC425	durra	57	75	66	23.9	681	0.41	3539.7
SC441	durra	68	81	74	29.2	1162	0.20	3054.4
SC449	guinea	54	66	60	27.1	1278	0.31	2019.7
SC450	Not Placed	61	78	69	15.1	808	0.22	1176.7
SC452	Not Placed	60	75	68	31.5	1296	0.27	3665.4
SC465	guinea	55	70	62	24.6	792	0.35	3479.8
SC467	durra	61	76	68	27.0	1199	0.24	2717.4
SC471	Not Placed	63	79	71	44.7	2524	0.34	5387.0
SC473	durra	62	76	69	25.4	1078	0.19	2369.5
SC477	Not Placed	62	75	68	35.9	1619	0.27	3094.0
SC480	durra	69	86	77	23.5	739	0.10	979.6
SC489	durra	68	81	74	23.4	1026	0.16	2570.6
SC49	guinea	53	67	60	28.8	885	0.40	3084.8
SC498	durra	67	88	77	57.3	1230	0.13	2645.4
SC499	Not Placed	64	77	71	30.6	1560	0.41	3940.2
SC500	durra	69	80	74	29.4	1216	0.25	2409.0
SC502	durra	58	67	62	23.4	877	0.31	3719.8

SC504	Not Placed	53	72	62	20.8	1080	0.37	4609.9
SC51	caudatum	60	71	65	28.6	1244	0.35	4240.6
SC52	caudatum	70	85	75	25.3	1141	0.13	2959.4
SC520	Not Placed	59	71	65	39.6	966	0.35	3976.1
SC525	guinea	52	59	55	19.1	656	0.18	2365.5
SC53	durra	56	68	62	12.3	490	0.20	1574.4
SC532	guinea	60	71	65	24.4	1060	0.34	1401.5
SC55	caudatum	54	66	60	14.6	476	0.26	2494.0
SC553	Not Placed	59	77	68	10.4	176	0.09	825.9
SC557	caudatum	58	71	64	22.0	1114	0.28	2617.1
SC558	caudatum	58	74	66	24.7	1125	0.22	1931.9
SC56	caudatum	58	67	63	20.7	739	0.30	3197.8
SC562	caudatum	59	73	66	17.5	837	0.19	1404.4
SC563	caudatum	55	65	60	24.5	751	0.34	3840.9
SC564	caudatum	61	76	68	23.1	945	0.29	4048.3
SC566	caudatum	54	66	60	14.3	597	0.20	2563.7
SC57	guinea	64	76	70	42.1	1195	0.32	1305.6
SC574	caudatum	61	76	68	17.0	866	0.20	2703.9
SC575	Not Placed	60	78	69	48.7	1117	0.43	4003.1
SC58	caudatum	57	67	62	21.3	653	0.24	2302.7
SC587	durra	70	82	76	30.7	1380	0.22	2333.3
SC59	caudatum	57	67	62	12.3	805	0.19	1905.2
SC599	caudatum	63	77	70	26.6	1072	0.23	3715.3
SC6	durra	65	78	71	25.3	1338	0.24	2843.6
SC60	caudatum	60	75	67	24.6	1005	0.26	3803.7
SC605	guinea	55	65	60	13.8	610	0.26	1928.4
SC606	guinea	50	66	58	16.4	483	0.20	1575.4
SC609	bicolor	54	67	60	22.6	930	0.26	1680.5
SC610	bicolor	57	69	63	36.4	1342	0.42	3153.6
SC614	bicolor	60	75	68	20.6	948	0.21	3013.0
SC62	Not Placed	60	66	63	18.8	926	0.44	3066.5
SC621	bicolor	56	70	63	12.6	671	0.17	1863.6
SC623	durra	59	69	64	25.7	1336	0.26	4274.8
SC624	durra	56	69	62	15.9	744	0.24	1453.2
SC625	kafir	60	68	64	26.8	1213	0.23	2940.0
SC627	kafir	62	73	68	28.1	1142	0.24	3238.4
SC628	kafir	58	68	63	26.5	1077	0.25	2596.6
SC63	caudatum	49	60	55	23.8	744	0.32	2695.5
SC630	kafir	58	67	63	20.6	756	0.22	2608.8
SC637	kafir	60	71	65	18.6	845	0.26	2985.3

SC639	kafir	59	70	64	25.7	1115	0.30	2769.2
SC64	kafir	60	76	68	21.5	848	0.23	3257.1
SC641	kafir	56	72	64	20.6	1002	0.25	3767.3
SC645	kafir	56	66	61	32.6	1480	0.27	3981.5
SC648	kafir	58	66	62	13.6	625	0.19	2470.3
SC650	kafir	62	73	67	30.4	1201	0.25	3163.8
SC655	kafir	58	71	64	25.6	1232	0.26	3696.8
SC659	guinea	60	73	67	27.9	1358	0.28	3582.7
SC66	guinea	57	71	64	18.6	880	0.26	2890.2
SC663	guinea	58	67	62	21.8	695	0.20	2075.6
SC67	guinea	53	65	59	18.6	994	0.22	2094.2
SC671	kafir	61	74	67	26.3	849	0.23	2347.4
SC672	kafir	60	67	64	19.7	811	0.19	2494.7
SC673	kafir	56	66	61	26.5	1067	0.28	2410.9
SC679	guinea	56	70	63	13.7	406	0.18	1763.1
SC695	caudatum	56	71	63	19.8	825	0.18	3464.8
SC701	caudatum	58	73	66	26.4	1021	0.30	4421.8
SC702	caudatum	59	74	67	38.4	1220	0.30	5186.4
SC704	caudatum	57	74	65	31.8	1694	0.34	4968.6
SC708	caudatum	59	72	65	29.0	1191	0.29	3475.7
SC720	caudatum	56	73	65	35.3	1581	0.31	4715.5
SC725	caudatum	56	75	65	28.6	786	0.25	3686.2
SC734	caudatum	59	72	65	20.9	973	0.21	2213.4
SC738	caudatum	58	69	63	23.0	757	0.27	3731.5
SC748	guinea	56	69	62	25.2	939	0.33	2398.8
SC749	caudatum	58	74	66	26.3	988	0.22	4021.7
SC755	Not Placed	58	67	63	26.4	927	0.24	3131.9
SC757	kafir	58	75	67	20.5	795	0.23	2685.8
SC760	kafir	52	66	59	21.9	578	0.27	3613.9
SC782	caudatum	56	67	61	17.5	884	0.24	3022.1
SC79	Not Placed	56	66	61	11.6	495	0.15	1988.0
SC790	Breeding line	55	68	61	34.6	1135	0.32	3469.1
SC798	caudatum	58	71	64	30.9	1125	0.26	3758.5
SC803	caudatum	61	75	68	37.6	1224	0.29	3860.3
SC805	caudatum	60	77	69	27.4	1099	0.26	3914.2
SC833	durra	57	70	64	18.3	651	0.13	2518.5
SC84	durra	58	66	62	9.0	490	0.10	1393.9
SC855	durra	56	66	61	29.1	886	0.23	2670.5
SC888	durra	63	78	70	33.3	1018	0.18	3257.1
SC91	bicolor	58	66	62	11.5	413	0.21	1703.5

SC929	durra	63	77	70	36.1	993	0.24	2753.3
SC937	bicolor	63	74	68	16.1	940	0.18	1801.0
SC941	bicolor	57	66	61	11.1	653	0.16	1860.0
SC942	bicolor	66	75	70	8.1	427	0.08	1248.2
SC947	Not Placed	54	65	59	29.5	1336	0.34	3344.5
SC949	bicolor	60	68	64	10.6	516	0.12	2285.8
SC964	caudatum	64	80	72	33.4	1081	0.24	4695.9
SC968	durra	60	71	65	12.9	520	0.15	1818.3
SC970	Not Placed	65	82	73	17.9	713	0.20	1281.6
SC971	kafir	62	76	69	25.5	966	0.22	3712.9
SC979	caudatum	62	75	68	31.8	963	0.22	3357.6
SC982	caudatum	63	77	70	27.6	771	0.18	1838.7
SC987	durra	58	67	63	28.5	1097	0.22	3121.2
SC991	bicolor	58	65	62	20.5	784	0.20	2189.5
SC998	Not Placed	60	72	66	33.5	1267	0.33	2965.5
SRN39	Not Placed	66	81	73	27.2	865	0.16	2112.6
SU629	Not Placed	54	66	60	42.3	1144	0.26	4315.2
SURENO	Central America	63	78	71	43.3	1789	0.25	4303.1
San Chi San	China	55	67	61	42.3	1010	0.34	3031.8
Segaolane	Not Placed	58	71	65	35.5	1305	0.27	4454.9
Shan Qui Red	China	56	67	61	32.9	906	0.29	2751.8
Tx2741	Breeding line	58	71	64	35.0	1464	0.39	4285.7
Tx2911	Breeding line	58	76	67	29.8	943	0.28	3473.3