Water use characteristics of selected South African maize (*Zea mays* L.) landraces compared with commercial hybrids

by

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PREFACE

The research contained in this thesis was completed by the candidate while based in the Discipline of Crop Science, School of Agricultural, Earth and Environmental Sciences, in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg Campus, South Africa. The research was financially supported by the Water Research Commission (WRC) of South Africa through WRC Project No. K5/2272//4 'Determining water use of indigenous grain and legume food crops'.

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

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Signed: Professor Albert T. Modi

Date: 30 June, 2014

DECLARATION

I, Farai Mazvimbakupa, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

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a) their words have been re-written but the general information attributed to them has been referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

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ABSTRACT

In South Africa, maize is the staple food, especially in rural areas. The majority of people in these areas rely on rain-fed farming for their agricultural production. Traditional maize landraces are still a feature of the agricultural landscape in rural areas thereby indicating their importance. However, climate change poses a threat to the availability of water, particularly in sub-Saharan Africa where drought is deemed to be prevalent. The aim of the study was, therefore, to compare the water use characteristics of two maize landrace varieties, GQ1 and GQ2 (originating from Gqunge location, Centane Eastern Cape, South Africa) with two popular high yielding commercial hybrids (SC701 and PAN53). Initially, seed quality testing was determined using the standard germination, electrical conductivity and tetrazolium tests. A controlled environment study was then conducted in which the landraces were compared to hybrids across three water regimes [30% crop water requirement (ETc); 50% ETc and 80%ETc]. Separate field studies were conducted to evaluate the growth, development, yield and yield components of these varieties under varying environmental conditions – Ukulinga (irrigated and rain-red) and Swayimani (rain-fed). Results of seed quality tests showed that landrace GQ2 had comparable seed quality to hybrids. However, overall, hybrids had superior seed quality to landraces. Results from the controlled experiment also showed that emergence of landrace GQ2 was at par with hybrids. Subjecting both landraces and hybrids to water stress (50% ETc and 30% ETc) resulted in shorter plants compared to non–stressed plants (80% ETc). Plants also tasselled earlier in response to water stress. The landrace GQ2 continued to perform similarly to hybrid varieties under water stress conditions. In field trials, the dominance of hybrids, attributed to hybrid vigour, was more pronounced under optimum conditions than sub-optimum conditions. Under a low input system (Swayimani), landraces performed at par with hybrids. It can therefore be concluded that landraces of good seed quality may be suitable for cultivation under sub-optimum low input systems where their ability to adapt enables them to produce stable yields and still provide a valuable germplasm resource.

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CHAPTER 1

INTRODUCTION

The water-energy-food security nexus is among the major concerns of the 21st century (Mabhaudhi, 2012). Currently, South Africa's population is approaching the 53 million mark (Statistics South Africa, 2013). This is of major concern, given the pressure this could have on already limited resources. Adding to these concerns is the issue of climate change. Climate change experts have predicted that in Southern Africa, in particular, the frequency and occurrence of drought will increase (Schulze, 2011). Increased temperatures and decreased rainfall caused by expected climate change are likely to result in water becoming an even scarcer resource (Farre´ and Faci, 2009). Much of these adverse effects are expected to affect the rural populace, thus making them more vulnerable to food insecurity. The combination of population growth (increased demand for food) and dwindling water resources will result in increased competition for water between agriculture and other industries (Huang *et al*., 2006). This scenario is of major concern when viewed within the context of current and future food security. Therefore, there is a need to come up with strategies that will encourage sustainable agricultural production and also identify possible crops for future crop improvement. It is in this regard that attention has now been gravitating towards studying traditional and underutilised crops (Modi and Mabhaudhi, 2013).

In South Africa, maize is the main food and feed contributor and is considered as a staple, especially in the rural areas. Only second in production to sugarcane, it is considered to be of great economic importance (DAFF, 2012). However, limited resources like land and water continue to hinder its production. In South Africa, which is generally considered as semi-arid to arid (DWAF, 2006), most people still rely on rainfed agriculture as part of their subsistence farming practices (Barros *et al*., 2007). Most resource–constrained farmers cannot afford to practice conventional agriculture (hybrid seed and fertilizer use) and lack technological advancements such as irrigation (Garcia, 2007). Most farmers in rural South Africa still rely on open–pollinated maize varieties (OPVs) (landraces and certified) (Chimonyo, 2012). Here, traditional maize landraces are still very much a feature of the agricultural landscape.

The term landrace relates to the evolution of crop genetic resources through natural and farmer selected practices (Zeven, 1998). Their advantage of breeding true allows farmers to keep seed to grow the crop in subsequent seasons with low but stable yields under sub-optimum environmental conditions (McCouch, 2004). Evolution of maize landraces through

technological advances has led to the formation of maize hybrids. Maize hybrids can be considered as crop genetic resources that have evolved through plant breeding programmes. Although hybrids boast high yields, these are often only attainable under optimum field conditions with good agronomic practises such as fertilizer, an adequate water supply (Cooper *et al*., 2014). Most farmers in rural areas often lack resources, technical capacity and knowledge that would enable them to realise the yield potential of hybrids. This may explain, in part, why subsistence farmers in rural South Africa still plant maize landraces; they may be adapted to their agro-ecologies, low input systems and produce reasonable yields under such conditions (Zeven, 1998).

The fact that maize landraces are still being cultivated suggests that they still remain an important germplasm resource (Mabhaudhi, 2009). Therefore, there is a need to characterise them for their water use. Previous studies have evaluated their drought tolerance (Mabhaudhi, 2009) and found that drought tolerance existed in certain landraces, especially during the early establishment stage (Mabhaudhi and Modi, 2010). These authors also found that, under water limited conditions, landraces could perform similar to, and in some cases better than conventional hybrids (Mabhaudhi and Modi, 2010). However, the authors did not determine water use characteristics of maize landraces *viz a viz* those of hybrids. In addition, their study did not make use of a known drought tolerant maize hybrid. This suggests that there remains a gap in the information describing water use of local maize landraces compared with hybrids. Such information would be key to identification of maize landraces as possible germplasm resources for continuous crop improvement. Under such conditions, it becomes necessary to employ conventional field experimentation to come up with reliable information that can be used for policy formulation (Mabhaudhi, 2012).

This study will focus on the water use of two maize hybrids (SC701 and PAN53) and two maize landraces (GQ1 and GQ2, from Gqunge location, Centane Eastern Cape, South Africa). The maize hybrid SC701 is a popular white green mealies in South Africa. Being in the medium to late growth class, this variety does well in high rainfall areas. Cultivar SC701 has large cobs, also making it an ideal option for maize silage. At a planting population of 35 000 plants per hectare (Pannar, 2013), this maize variety produces bulk yields and shows good standing (Botswana Agricultural Marketing Board, 2013). Cultivar PAN 53 is a new variety released by Pannar in 2010. This white maize produces good quality, high density flint maize and performs well on a number of different soil types and agro-ecological zones. Being an intermediate maturing variety (105-110 days to maturity), yield potential can reach 10 tonnes per hectare.

The landraces are normally used for both green mealies and dry maize for human and animal feed in the rural areas. They are long-season varieties (~130 -150 days).

The hypothesis of the study is that maize hybrids will perform better than landraces in terms of establishment, growth and yield under conditions of water stress. The aim of the study was to compare the water use characteristics of two maize landrace varieties with two popular high yielding commercial hybrids (SC701 and PAN53). Specific objectives were:

a) to compare seed quality of maize landraces and maize hybrids in terms of viability (germination, imbibition, tetrazolium test) and vigour (electrical conductivity, seedling root to shoot ratio),
b) to determine effect of water stress imposed using varying water regimes under controlled environmental conditions on growth and development of maize landraces and maize hybrids,
c) to compare the maize landraces and maize hybrids with respect to field emergence and early establishment performance under dry conditions (off-season), and
d) to evaluate plant physiology (protein and proline) of maize landraces and hybrids under controlled environment conditions in response to varying water regimes at various locations.

CHAPTER 2

LITERATURE REVIEW

2.1 The Maize Crop

2.1.1 Origins and history

Before the turn of the century, the origin of maize was highly debatable. There were two competing hypotheses postulated in the late 1930's by Beadle (1939) and Mandelsdorf and Reeves (1939). Beadle (1939) proposed the "Teosinte Hypothesis" which stated that maize originated from teosinte. It was believed that through artificial selection by early civilizations, several small mutations with relatively large effects could have transformed teosinte into maize. In contrast, Mangelsdorf and Reeves (1939) suggested that maize was derived from the product of hybridization between an extinct wild maize and Tripsacum, known as the "Tripartite Hypothesis." Although there were strong facts supporting the Tripartite hypothesis, the 1970's witnessed a series of reports in favour of the Teosinte hypothesis. Teosinte is the closest relative of maize and shares the same chromosomal characteristics (length, number and position of centromeres).

According to Vavilov (1931), Weatherwax (1936) and Randolph (1959), variability of wild species of maize is greatest in Mexico (Middle America). On the other hand, Grobman *et al*. (1961) observed vast variability in the Peruvian Andes. Some of the eariest remains of maize specimens (date back 5 600 years ago) can be located in New Mexico. This precedes the earlier finds in Peru dated 2900 years ago. According to Doebley (2004) one could therefore conclude that there were secondary and primary domestication events that occurred. The first being the Middle America and the latter being the Peruvian Andes.

As for its history in Africa, reports suggest that maize was first introduced to Africa by the Portuguese during the 16th century (Miracle, 1966; McCann, 2005). Its spread throughout most of Africa is also attributed to the trade networks of early Portuguese merchants along the eastern and western coasts of Africa. Its introduction into southern Africa may also have happened as a result of migration of indigenous people from east Africa to southern Africa. Another explanation is that it was the Dutch who introduced maize to southern Africa along the southern African coast around 1658 (Miracle, 1966). The fact that maize has been around Africa and southern Africa, in particular, from as early as the 16^{th} century justifies its classification as an indigenised crop of Africa and southern Africa. There currently exists many maize landraces

whose germplasm preservation has occurred at the hands of local subsistence farmers aided also by natural selection.

2.1.2 Botanical description and genetic diversity

Maize (*Zea mays* L.) is an annual plant, which belongs to the Gramineae family and genus *Zea*. Height varies from 0.6m to 5m in some extreme cases. The stem of a maize plant is divided into nodes and internodes which vary between 8 and 21 in number. Tillers have been known to develop from nodes below the soil surface (Du Plessi, 2003). The maize leaves are formed from a blade and sheath. The leaves are where photosynthesis is carried out. New leaves arise from the growing point and may number between 16 and 23 depending on the variety. The stem of the maize plant performs the function of leaf and floral support as well as nutrient and water uptake. Maize is a monocotyledonous plant, meaning each individual plant bears both male and female flowers (Belfield and Brown, 2008). The male flowers occur in a cluster (tassel) on top of end of the stem as a terminal panicle, while the female flowers are borne inside the young cobs which spring from the nodes on the stem usually located about midway on the stalk (Figure 2.1) (Lea, 1991).

Although all maize varieties belong to a single species, *Zea mays*, the number of maize varieties is numerous (Arnon, 1972). In South Africa, there were 490 maize varieties as of 2012 (DAFF, 2012). Table 2.1 lists the various varieties grown in South Africa. Given the limited number of varieties in South Africa, there is a need to consider other genetic variability when it comes to maize production. The use of maize landraces could add genetic diversity (Villa *et al*., 2005), thereby contributing to maize production and improved food security.

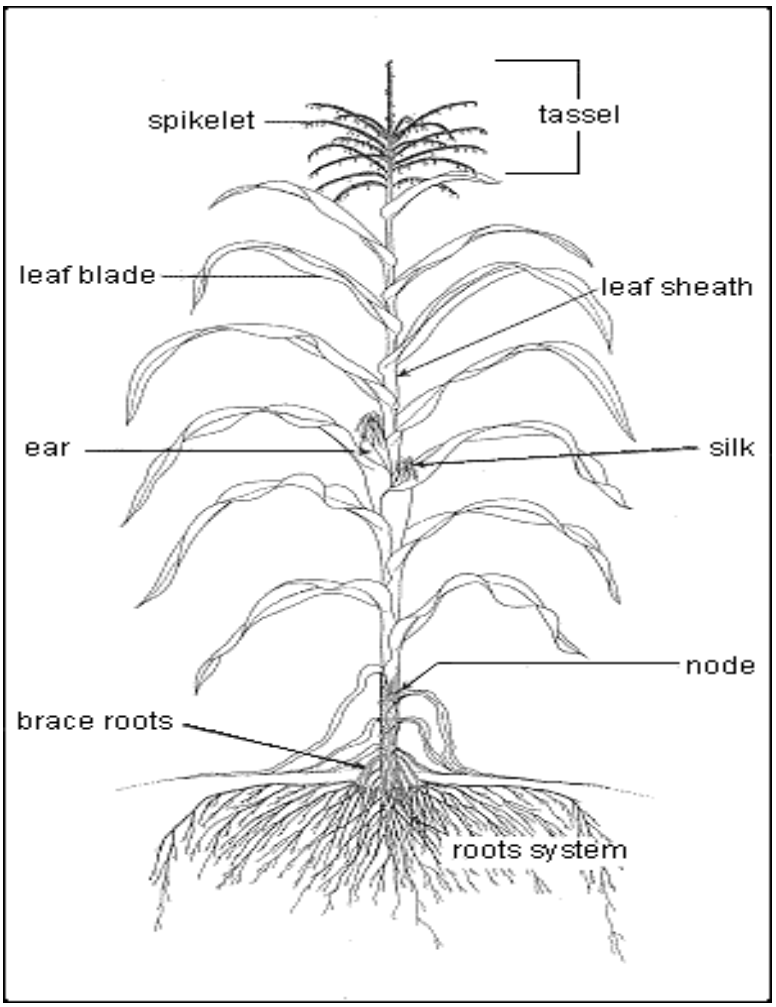

Figure 2.1: Annotated diagrammatic illustration of the maize plant. (Source: http://old.iita.org/cms/details/trn_mat/irg9/irg901.htm; accessed on 21/05/2013)

Table 2.1: List of South African seed variety as of 2012

Type of Seed	Number of Varieties
Yellow Grain Maize: Basters/Hybrids	126
Yellow Grain Maize: Basters/Hybrids (GMO)	92
Yellow Grain Maize: Open Pollinated	3
Yellow Grain Maize: Basters/High Lysine: Hybrids	13
White Grain Maize: Basters/Hybrids	113
White Grain Maize: Basters/Hybrids (GMO)	59
White Grain Maize: Open Pollinated	26
White Grain Maize: Basters/High Lysine: Hybrids	14
White Grain Maize : High Lysine: Open Pollinated	3
Sweet Corn: Basters/Hybrids	39
Sweet Corn: Open Pollinated	2
Total	490

(Source: http://www.daff.gov.za/docs/GenPub/VARIETYseed_032012.pdf ; accessed on 27/05/2013)

Landraces are often known by their local names in the communities that still utilise them. Maize landraces are open-pollinated and remain one of the world's most important natural resources in terms of food security. In Mexico, landraces are cultivated on over 80% of the maize hectarage. Cultivation of maize landraces is mostly done by resource poor farmers in rural areas (Mercer and Wainwright, 2008). They rely on the landraces due to their unique characteristics (phenological, morphological and phenotypic) which make them adaptable to a wide range of environmental conditions as well as resistant and tolerant to diseases and pests (Mabhaudhi, 2009).

2.1.3 Ecology and production

Maize is a crop of subtropical origin (Nafziger, 2009) and is currently grown in a range of agro-ecological environments (IITA, 2009). Preferred growth conditions are warm to hot environments which are frost free (Smith, 2006). Globally, maize grows from 50°N to 40°S (tropics right through to the temperate climates) and from sea level up to 4000 metres above sea level. According to Greaves (1996), cultivars grown outside their original zones of adaptation results in constrained yields. This too was observed by Stone *et al*. (1999). The

average maize yield in high latitudes exceeds that in the tropics by up to 4 times under field conditions. These differences are largely due to variations in their adaptations to climatic factors and genetic makeup. Tropical maize exhibits delayed flowering time, increased plant height, and a greater total leaf number when grown in temperate latitudes with daily dark periods < 11 hrs. (Corral *et al*., 2008) High night temperature reduce maize yields in the tropics by up to 30% (Chang, 1981). For instance, in Uganda (located between latitudes 4.5°N & 1.5°S) average yields of 1.5 tonnes per hectare are produced. The geographic adaptation of maize also brings about issue pertaining to responses of maize to photoperiod.

Maize is a short day plant and has a critical photoperiod of 12.5 hours per day (Belfield and Brown, 2008). Responses to increasing photoperiod observed in maize include delayed tassel initiation and increased leaf number (Mungoma and Pollak, 1991). These responses have been noted to occur at the end of the juvenile stage were floral initiation is about to occur (Birch *et al*., 1998). Research on maize reveals that sensitivity to photoperiod is genotype-dependant (Mungoma and Pollak, 1991). Temperate maize varieties have been observed to be day-length insensitive, whereby tropical maize varieties are sensitive to longer day length (Yang *et al*., 2013). However, the thermal time from emergence to tassel initiation is increased by a constant number of degree days per hour when the photoperiod exceeds 12.5 hours (Birch *et al*., 1998). For plants grown under well-watered conditions, temperature is also important in determining the productivity of the crop (Wilson *et al*., 1995).

Being of subtropical origin, maize responds positively to an increase in temperature up to a given optimum. Low temperatures of less than 7°C may cause physiological damage that may reduce photosynthetic rates resulting in low yields. On the other hand, excessively high temperatures of more than 37°C may be detrimental to plant growth and function as it speeds up plant development, shortening the length of growth periods necessary for optimum plant and grain size. In cooler climates the potential of frost damage is increased when maize is planted outside the optimum planting date and after seed germination and emergence (Mousavi *et al*., 2012). The optimum temperature for normal plant growth and development ranges from 24°C to 30°C (Smith 2006; Birch *et al*., 1998). However, optimum temperatures as high as 34°C have been observed (Birch *et al*., 1998). Heat unit requirements for maize are 750 units to the tasselling stage (Smith, 2006). Hot and dry weather both increases time taken to pollen shed and delays silk emergence. This increases the anthesis silking interval (ASI). Furthermore, the germination of pollen grains on silk greatly reduced (Basra, 2000). The result is fewer kernels produced, and if this persists, low 1000 grain weight and ultimately reducing yields (Herrero and Johnson, 1980). Leaves for maize grown at 23°C photosynthesised faster than leaves from

maize grown between 13°C and 18°C. Those grown at temperatures as low as 13°C reportedly had yellow leaves and photosynthesised at insignificant levels (Bird *et al*., 1977). Although, climatic parameters such as temperature are critical in governing maize development, agronomic practices such as plant density are also of significance (Belfield and Brown, 2008).

Plant density is of particular importance in maize production due the fact that it does not have the tillering capacity to adjust to variation in plant stand. A low planting population per unit area prevents maximum usage of production parameters (land, water and incident radiation) and increase completion for these resources between maize crop and weeds. Adversely, an excessively high planting population can increase the intra-specific competition for growth resources and decrease yield (Mousavi *et al*., 2012). Planting population for maize in South Africa can range from 45 000 plants per hectare to 90 000 plants per hectare depending on genotype, available soil water and nutrients (Department of Agriculture, 2003). In KwaZulu-Natal the recommended planting population based on annual precipitation is 30 000 plants per hectare. This planting population may be increased (with a reduction in-row spacing to 330 mm) to 40 000 plants per hectare. A regular supply of irrigation allows for a planting population of 50 000 plants per hectare (Smith, 2006). However, these recommendations do not take into account the stature (canopy size and structure) of the plant. Therefore, planting density should also take into consideration plant canopy. Maize can be described as having either an erectophile or planophile leaf arrangement. Leaves of maize with erectophile orientation are more upright allowing more incident radiation to be capture. Due to this, more plants per square meter can be grown. On the other hand, maize leaves exhibiting planophile traits allow less incident radiation to be captured by the plant and thus fewer plants are planted per square meter.

Maize is known to grow on a variety of soils, but performs best in well-drained, well-aerated loam and silt loams soils (Smith, 2006). Apart from soil physical characteristics, chemical factors are known to also have an effect on maize yields, particularly soil fertility. Maize has a high nutrient demand. A mature maize plant will have a total nutrient uptake of 8.7 g of nitrogen, 5.1 g of phosphorus, and 4.0 g of potassium. Each ton of grain produced removes 15.0 to 18.0 kg of nitrogen, 2.5 to 3.0 kg of phosphorus and 3.0 to 4.0 kg of potassium from the soil (Du Plessi, 2003). Nitrogen (being an essential macronutrient) is an important component of many structural, genetic and metabolic compounds in plant cells (Saini and Dhawan, 2014). Phosphorus is an important for the development of growing tips and roots, particularly in the early stages of plant development (Postma and Lynch, 2011). Another chemical factor that plays a role in plant growth and development are soil pH.

Soil pH below 4 to 5 reduces growth rates of crops such as maize. Desirable soil pH values for optimum maize growth are in the range of 6.5 to 7 (Sokchea and Preston, 2011). On the other hand Islam *et al.* (1980) showed optimum yields of maize to be obtained at a pH of between 5.5 and 6.5. Acid soils are characteristic of soils that receive high rainfall and those with high levels of aluminium, manganese and iron. It has been observed that such soils are deficient in phosphorus, calcium, magnesium, potassium, sulphur and zinc, all of which are important nutrients for maize growth (Mandiringana *et al*., 2005; Gichangi, 2007). In such cases, aluminium toxicity and phosphorus deficiencies tend to be important factors affecting maize yields. The most easily recognized symptom of aluminium toxicity is the inhibition of root growth leading to low water and nutrient uptake. Soil and water salinity are known to be contributing factors in the reduction of crop yields (Azaizeh and Steudle, 1991). Salinity was observed to reduces root and shoot elongation growth in cotton seedlings (Zidan *et al*., 1990). Apart from salinity, aluminium toxicity is a major factor constraining crop performance, particularly on acid soils such as those commonly found under tropical climatic conditions (Barcelo and Poschenrieder, 2002). Climate and rainfall are also of particular importance in crop production.

Rainfall requirements for this crop are between 500-700mm over the growing season (which in KwaZulu-Natal is from October to March) (Smith, 2006). When receiving optimum rainfall between 700 mm and 900 mm, yields can reach up to 6 tonnes per hectare. (Mathuva *et al*., 1998) and have been noted to be higher under well watered conditions. As a C4 plant, maize has a high water use efficiency (maize can produce one kg of dry weight using only about 40 kg of water, compared to water use ratios of 60 kg or more in most C3 plants) (Nafziger, 2009). However, management of the crop is also important to attain high yields. Yields as low as 800 kg ha^{-1} have been reported in areas where rainfall is sufficient (550-800 mm/year) but the nutritional status of the soil is low (Mathuva *et al*., 1998).

2.1.4 Uses and importance

Maize is the most important grain crop in South Africa and is produced throughout the country under diverse environments (DuPlessi, 2003). The main grain producing areas are Mafikeng, Barberton and Hobhouse (Smith, 2006). These areas are referred to as the maize triangle. In KwaZulu-Natal, maize is grown extensively under a wide range of environments extending from the dry, hot regions of the thornveld to areas of more favourable rainfall in the midlands and coastal hinterland (Lea, 1991). Maize has a growing cycle ranging from 3 to 13 months

(Meng and Ekboir, 2001). Maize is not only considered as a food source, but is an important component of animal feed and fodder. Is can be used to produce biofuels and has diverse uses in the manufacture of industrial products (Achakzai, 2009). When processed, maize can be used in ethanol and starch production. Starch in turn involves enzymatic conversion into products such as sorbitol, dextrine, sorbic and lactic acid, and appears in household items such as beer, ice cream, ink, batteries and paint (DuPlessi, 2003). Only second in production to sugarcane, maize is the major food and feed contributor in South Africa (DAFF, 2012). Being the major food source, maize influences food security greatly in South Africa.

The annual production of maize in South Africa is approximately 12.5 million tons on 3.1 million ha of land. The average yield per hectare in South Africa is approximately 4.5 tonnes (DAFF, 2011). Half of the production consists of white maize, for human food consumption. About 15 kg of grain are produced for each millimetre of water consumed (Du Plessis, 2003). Drought is the main cause of reduced maize yields in most rural communities of South Africa. Climate change (which largely contributes to drought) is likely to significantly affect the sustainability of water supplies in the coming decades. Changes in precipitation patterns and water availability could have serious consequences for commercial agriculture, thereby affecting food security. It is thus important to consider strategies to mitigate the effects of drought on crop production and aim at conserving water.

2.2 Drought and Water Stress

Drought is one of the most important factors affecting plant survival and crop productivity (Boyer, 1982; Chaves *et al*., 2003). Drought occurs when there is insufficient soil water to meet the demands for crop growth; this can be due to low soil water content or high evaporational demand from the atmosphere (Akinci and Losel, 2012). Drought alone has been known to reduce crop yields by more than 50% and is considered to be a severe threat to sustainable crop production. (Anjum *et al*., 2011).

Water stress triggers a wide variety of plant responses, ranging from changes in cellular metabolism to crop growth rates and yields (Anjum *et al*., 2011). These responses, varying with genotype and intensities of water stress (Chaves *et al*., 2002), have allowed plants to survive and even to maintain some growth under very severe stress conditions (Levitt, 1980). These responses can fall under morphological, biochemical and physiological (Lu *et al*., 2011). These plant responses can also be defined as drought escape, avoidance and tolerance strategies.

However, resistance to drought may be a combination of a range of these responses (Chaves *et al*., 2003).

2.3 Characteristics Associated With Improved Water Use in Plants

Seed germination, seedling emergence and establishment have been identified as key processes in the lifecycle of plants (Hadas, 2004; Rahimi, 2013). The amount of moisture in the growing medium and the wetting duration both influence germination (Gill *et al*., 2002). When a plant is subjected to water stress, the rate of imbibition, germination and seedling growth is markedly reduced (Achakzai, 2009). Willenborb *et al.* (2004) observed that water stress increases mean germination time in maize. It was also observed by Khodarahmpour (2012) that water stress reduced germination percentage (to 92.8%), germination rate (to 69.2%) as well as seedling vigour in maize. The earliest response to water stress in most vascular plants like maize is the inhibition of plant growth (Cominelli *et al*., 2008).

The inhibition of growth allows plants to reduce their transpiration rates and to avoid metabolic and cellular damage caused by low water potentials (Cominelli *et al*., 2008). Reduced plant growth may be accompanied by a reduction in the final size of leaves and internodes (Ritchie *et al*., 1992). Reduction in leaf area expansion is due to reduced cell division and elongation (Serrano *et al*., 1999). As a result, leaves may look smaller in appearance. Leaf reduction further leads to a reduction in canopy photosynthetic capacity and a reduction in intercepted photosynthetically active radiation (PAR) (Craufurd and Wheeler, 1999). Only under extreme conditions of water stress will a plant lose leaves through senescence in order to allow the plant to survive (Yi *et al*., 2010). A study by Dulai *et al*. (2006) showed a decrease in the relative water content of leaves, which consequently resulted in accelerated stomatal closure and a decrease in the net photosynthetic CO_2 fixation. A reduction in leaf size may also be evident of a water stressed plant as it enters the reproductive phase (Ritchie *et al*., 1992).

As a plant enters the reproductive phase, a rapid steady increase occurs in nutrient and dry matter accumulation (Ritchie *et al*., 1992). Maize has been observed to be relatively tolerant to water stress during the vegetative and ripening phases. However, stress during the reproductive phase (particularly the flowering period) causes marked decreases in grain yield (Cakir, 2004). Previous research has also revealed flowering to be very sensitive to water stress, with reduction in biomass, yield and harvest index (Farre and Faci, 2009). A study by Jama and Ottman (1993) concluded that grain yield, dry matter and kernel number are highest under well watered conditions exceeding 80% of the crop water requirements. Other critical stages sensitive to

water deficit include the phenological stages of tasselling, silking and grain filling (reproductive stages). Researched findings by NeSmith and Ritchie (1992) indicate a loss in yield of up to 90% during the tasselling and silking stages alone if a plant is subjected to water stress. It is therefore important to consider the use of more drought tolerant cultivars that reduce the negative impact water stress has on grain yield.

2.4 Effect of Water Stress on Maize Physiology

Plant response to water stress varies depending on the growth stage. Several parameters including chlorophyll content index, accumulation of sugars, antioxidant response and proline accumulation are used to determine these responses.

2.4.1 Chlorophyll content index

Chlorophyll is a key biological component which enables plants to perform photosynthesis (Shibghatallah *et al*., 2013). During the process of photosynthesis, antenna pigments in the leaf chloroplasts absorb solar radiation, and through resonance transfer the resulting excitation is channelled to the reaction centre pigments (chlorophyll a and chlorophyll b being the most important of these pigments).

The leaf colour of a plant can be used to identify stress levels due to its adaptation to the environmental changes (Shibghatallah *et al*., 2013). Photosynthesis is gradually inactivated during senescence in various plants and the loss of activity is accompanied by a large decrease in the chlorophyll content (Sestak 1977). Research conducted on wheat (Camp *et al*., 1982), rice (Uchida *et al*., 1982) and soybean (Sector *et al*., 1984) indicates that a positive correlation exists between photosynthetic activity and chlorophyll content. Chlorophyll content is s direct indicator of plant health and condition (Apogee Instruments Incorporated, 2014). However, growing seasons (Dwyer *et al*., 1995), growth stage, growing conditions and genotype (Peng *et al*., 1993) may cause variation between total chlorophyll and chlorophyll content index (CCI). Advancements in technology over the years have allowed the measurement of the chlorophyll status of plants non-destructively (in situ) (van den Berg and Perkins, 2004) with the use of handheld chlorophyll content meters. Measurement using these meters tend to be instantaneous and can be done under normal lighting conditions in the field (Apogee Instruments incorporated, 2014). Maize (Dwyer *et al*., 1991) and sorghum (Yamamoto *et al*., 2002) are some if the crops where the use of handheld chlorophyll meters has been investigated. Some of the areas where data obtained from chlorophyll content measurements can be applied is nutrient and irrigation management, pest control, environmental stress evaluation and crop breeding.

2.4.2 Accumulation of sugars

Research shows the accumulation of carbohydrates to be a common response to abiotic stress in temperate grasses and cereals. Soluble sugars play a role in protecting plants from stress (Mohammadkhani and Heidari, 2008). In maize, the physiological response to drought appears to be related to the flux of carbohydrates to the young ear around flowering. Concurrent photosynthesis is needed to maintain this flux and evidence suggests that carbohydrate reserves cannot be mobilised to support ear development under drought. Drought has been shown to reduce invertase activity in the ovaries, which may lead to a reduced flux of hexose sugars, depletion of ovary starch and abortion of ovaries (Bänziger *et al*., 2002).

2.4.3 Proline accumulation

Proline accumulation is a common physiological response in many plants occurring at the onset of a wide range of biotic and abiotic stresses. It's considered to be one of the important plant adaptive strategies to cope with the environmental stresses, particularly low water stress (Kavas *et al*., 2013). Some stress factors triggering accumulation of proline include salt, drought, high temperature, low temperature, heavy metal, pathogen infection, nutrient deficiency, atmospheric pollution and UV irradiation (Verbruggen and Hermans, 2008).

Proline plays a multifunctional role in stress defence. (Hare and Cress, 1997). By acting as an osmolyte, a ROS scavenger, and a molecular chaperone stabilizing the structure of proteins, proline protects cells from damage caused by stress (Hare and Cress, 1997; Verbruggen and Hermans, 2008; Mohammadkhani and Heidari, 2008). It can, therefore, accumulate to high concentrations in plant cells without disrupting cellular structure or metabolism (Kavas *et al*., 2013). Proline concentration levels also play a role in primary root elongation. This is particularly so at low water potential where proline concentration is high (Ober and Sharp, 1994).

2.5 Conclusion

The growing concern over increasing populations and the infinite resources of water is becoming a debatable issue among scientists. Increasing occurrence of drought events (largely caused by changes in climate patters) is likely to affect food security worldwide. In South Africa maize is the main staple food. It is estimated that water scarcity could decrease maize production by as much as 15% in the coming decades. Most resource poor farmers living in rural areas still rely due the genetic advantages they possess over hybrids. However, limited knowledge is knows about the water use characteristics of maize landraces.

CHAPTER 3

MATERIALS AND METHODS

3.1 Plant Material

Two maize landraces (GQ1 and GQ2) (Figure 2.1 a, and b) were sourced from local farmers in the Eastern Cape Province, South Africa during 2013. Two hybrids (SC701 and PAN53) (Figure 2.1 c, and d) were used as check varieties to compare with the landraces. SC701 is a popular variety among local farmers who grow it for green mealies given its late maturity and fairly good tolerance to drought. PAN53 is a fairly new and medium maturity variety (refer to Table 3.1).

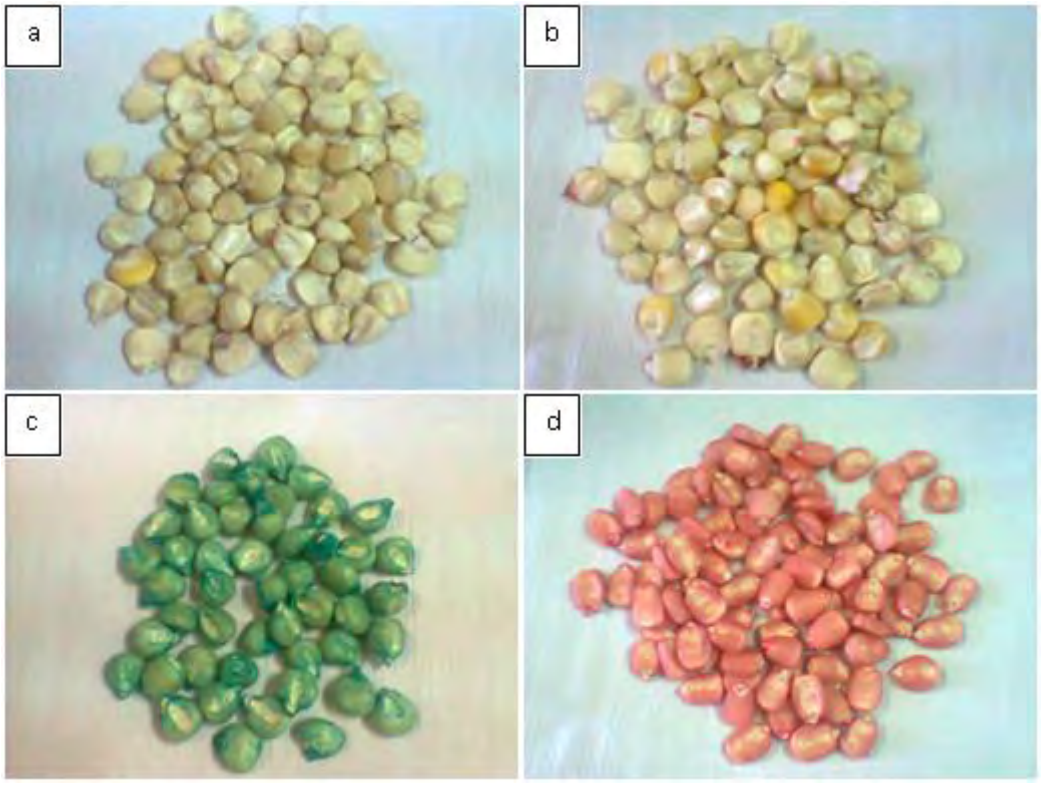

Figure 3.1: Seeds of maize landraces (a) GQ1, (b) GQ2, and commercial hybrid varieties (c) SC701, and (d) PAN53

Table 3. 1: Description of the visual characteristics of the maize varieties

Variety	Colour	Source	100 Seed Weight
GQ1	White	Gqunge, Eastern Cape	44.87
GQ2	White	Gqunge, Eastern Cape	38.35
SC701	White	Pietermaritzburg	57.88
PAN53	White	Greytown	41.55

3.2 Seed Quality Tests

All experiments were laid out in a randomized complete block design at the University of KwaZulu-Natal's (UKZN) seed technology laboratory (29°37'12"S; 30°23'49"E). The number of replicates per experiment as well as the number of seeds used per replicate varied for each experiment. Details of each experiment are given below.

For the standard germination test, four replicates of 8 seeds from each genotype were germinated using the petri dish method. The petri dishes were lined with double sheets of moistened Whatman® filter paper and closed to minimize moisture loss. Petri dishes were incubated in a germination chamber at alternating temperatures of 20°C/30°C (16/8 hours) and at illumination intervals of 16/8 hours, for a period of 8 days (AOSA, 1992) guidelines. The filter paper was re–wetted on a daily basis with deionized water to maintain adequate moisture levels. Daily germination counts were taken based on radicle protrusion of 2 mm or more. On day 8, final germination percentage was calculated according to AOSA (1992) guidelines. This was followed by measuring root and shoot lengths, root: shoot ratio and seedling fresh mass. In addition, the following indices were calculated:

Germination velocity index (GVI), was calculated based Maguire's (1962) formulae:

$$GVI = G_1/N_1 + G_2/N_2 + \ldots + G_n/N_n \qquad \textbf{Equation 3.1}$$

where, GVI = germination velocity index

$G_1, G_2 \ldots G_n$ = number of germinated seeds in first, second… last count.

$N_1, N_2 \ldots N_n$ = number of sowing days at the first, second… last count.

Mean time to germination (MGT) was calculated according to the formulae by Ellis and Roberts (1981):

$$\mathbf{MGT} = \frac{\sum \mathbf{D_n}}{\sum \mathbf{n}} \qquad \textbf{Equation 3.2}$$

where, MGT= mean germination time,

n = the number of seed which were germinated on day D, and

D = number of days counted from the beginning of germination.

Electrical conductivity was measured using the CM100 Model Single Cell Analyser. Twenty (20) seeds per genotype were used due to limited quantities of maize landrace seeds. Seeds from each genotype were individually weighed and placed into wells filled with 2 mℓ distilled water. Electrolyte leakage for each variety was then measured over a 24 hour period.

Seed viability was determined using the Tetrazolium (TZ) test. Four replicates of 20 seeds each were used for the TZ test. The seed was preconditioned for a period of 18 hours by directly soaking in water. After which, a single edge razor blade was used to bisect each seed longitudinally through the midsection of the embryonic axis. Seeds were placed in petri dishes and soaked in a 1% concentration solution of tetrazolium. Petrie dishes were placed in a dark cupboard at room temperature for a period of 6 hours. The number of stained seeds was recorded.

Imbibition was done on a seed testing water bath (Grant Instruments, England). Eight seeds per variety were placed in a completely randomized design experiment with five replicates per variety. Seeds were imbibed for 0, 15, 30, 60, 120, 240, 720, 840, 960, 1440, 2160, 2880, 4320, 5760 and 7200 minutes and the percentage change in seed mass during imbibition was measured at each time interval.

3.3 Controlled Environment Description

A pot trial was conducted in a growth tunnel at the Controlled Environment Facility (CEF) at the University of KwaZulu-Natal, South Africa (29°37'12"S; 30°23'49"E). The environment in the growth tunnels is not fully controlled. However, temperatures (~18/33°C day/night) and relative humidity (60 to 80%) in the tunnels are designed to resemble those of a warm

subtropical climate (Modi, 2007). Temperature, relative humidity and light in the tunnels were monitored using a HOBO® logger (Onset Computer Corporation, USA).

Figure 3.2: Controlled Environment experiment conducted at CERU, University of KwaZulu-Natal.

3.3.1 Experimental design, potting procedure and water stress treatments

The experimental layout was a randomized complete block design (RCBD) with two factors: water stress [three levels – 30% (terminal), 50% (moderate) and 80% (control) of crop water requirement (ETc)] and variety (four levels – GQ1, GQ2, SC701, and PAN53), replicated four times. Forty-eight (48) 20 ℓ pots were each filled with 15 kg of soil whose field capacity had

previously been determined gravimetrically. Three seeds were planted per pot (one in the middle and one on either side), each at a depth of 25 mm. Excess seedlings were thinned soon after emergence to only one plant per pot. The pots were connected to an online drip (2 ℓ $hour^{-1}$) irrigation system. The water applied to the 80%, 50% and 30% ETc treatments amounted to 456.96 mm, 285.6 mm and 171.36 mm for the duration of the study. The amount of irrigation water was based on crop water requirement (ETc), calculated using average monthly reference evapotranspiration (ET_o) and a crop coefficient (Kc) as described by Allen *et al*. (1998):

$$ETc = ET_o * Kc \qquad \textbf{Equation 3.3}$$

where, ETc = crop water requirement,

ET_o = reference evapotranspiration, and

Kc = crop factor.

The Kc values [$Kc_{initial}$ = 0.3 (2 months), Kc_{med} = 1.15 (3 months) and Kc_{end} = 1.05 (1 month)] used in this study were obtained from the FAO Irrigation and Drainage Paper No.56 (Allen *et al*., 1998).

3.3.2 Agronomic practices

Fertilizer application was based on a soil analysis report of the soil used in this study. An organic fertilizer, Gromor® fertilizer (30 g kg^{-1} N, 15 g kg^{-1} P and 15 g kg^{-1} K) was applied at a rate of 80 g per pot. Fertilizer was applied in the early stages of plant growth. Weeding of the pots was conducted weekly. Diseases and pests were monitored weekly.

3.3.3 Data collection

Data collected in the pot trial included seedling emergence, stomatal conductance, chlorophyll content index, soil water content, plant height and leaf number. Emergence was collected from the onset of the trial up to 14 days after planting. The crop was deemed to have established 28 days after sowing when all seedlings had formed their first true leaves. Thereafter, weekly data was collected for stomatal conductance, chlorophyll content index, soil water content, plant height and leaf number. Stomatal conductance (SC) was measured using the steady state leaf porometer (Model SC-1, Decagon Devices, USA). Stomatal conductance readings were taken from the abaxial surface of the second youngest, fully expanded and fully exposed leaf. Chlorophyll content index (CCI) was measured using the CCM-200 (Opti-Sciences, USA) on

the adaxial surface of the second youngest, fully expanded and fully exposed leaf of each plant. The CCM-200 calculates a unitless index (CCI) from the ratio of optical absorbance at 653 nm to that at 931 nm. For both SC and CCI, leaves with signs of visual damage or disease were avoided and measurements were taken during midday (1200-1400hrs) and during periods when the soil was drying. Soil water content was monitored using a Theta Probe (ML-2x) connected to an HH2 handheld moisture meter (Delta–T Devices, UK). Data collection for growth parameters ceased 22 weeks after planting when 100% of the population had reached the tasseling stage. Data collection at harvest included total biomass, ear prolificacy, ear size characteristics, kernel row per ear, kernel number per row and harvest index.

3.3.4 Protein and proline

Total soluble proteins were extracted according to Kanellis and Kalaitzis (1992), with slight modifications. Freeze-dried, milled mesocarp tissue (0.1 g DM) was extracted in 5 mL 50 mM Tris–HCl buffer (pH 7.4) containing 0.2 M NaCl, 20 mM MgSO4, 1 mM EDTA,5 mM -mercaptoethanol, 0.5 mM PMSF, 10 mM leupeptin, and 10% (v/v) glycerol. The samples were then homogenised using the ultrasonic cell disrupter to extract free and membrane-bound proteins. Subsequently, the mixture was allowed to stand on ice for 15 minutes and centrifuged at 20,000×g for 20 min. The supernatant was used for enzyme assays after being filtered through Miracloth®. The protein concentration of the samples was quantified by the Bradford microassay (Bradford, 1976). Bradford dye reagent was prepared by diluting the dye concentrate with distilled water at a ratio of 1:4. The diluted dye (1 mL) was added to test tubes containing 20 uL sample extract; thereafter samples were mixed by three times inversion. Thereafter, samples were incubated at room temperature for 5 min and absorbance read spectrophotometrically at 595 nm. The protein concentration was determined by comparing results with a standard curve constructed using bovine serum albumin (BSA).

Proline colorimetric determination proceeded according to Bates *et al*. (1973). For proline colorimetric determinations, a 1:1:1 solution of proline, ninhydrin acid and glacial acetic acid was incubated at 100ºC for 1 hour. The reaction was terminated in ice and the chromosphere was extracted with 4 ml toluene and its absorbance read at 520 nm using a Shimadzu UV-VIS spectrophotometer (Shimadzu Scientific Instruments, USA). The proline concentration was determined from a standard curve and calculated on a dry weight basis as follows:

[(µg proline/ mℓ x mℓ toluene)/ (115µg/µmole)]/ [(g sample)/5] = µmoles proline/g of dry weight material. **Equation 3.4**

3.4 Field Trials

3.4.1 Site description

A field trial was planted at the University of KwaZulu-Natal Research Farm (Ukulinga) in Pietermaritzburg (29°37'S; 30°16' E; 805 m a.s.l) under rain-fed and irrigated conditions. A separate field trial was planted under rain-fed conditions in Swayimani (29°25'S; 30°41'E). For both locations, weather data for the duration of the experiments were obtained courtesy of the Agricultural Research Council – Institute for Soil, Climate and Water (ARC–ISCW) network of automatic weather stations.

3.4.2 Experimental designs

At Ukulinga the experimental design was a split-plot design arranged in a randomized complete block design (RCBD) with irrigation (full irrigation versus rain-fed) as a main factor and maize variety (GQ1, GQ2, SC701 and PAN53) as sub-factors. The experiment was replicated four times. The plant population was 26 667 plants per hectare (0.75 m x 0.5 m). The individual plot size was 6 m^2 (3 m x 2 m) while the main plot size was 165 m^2 (15 m x 11 m) per treatment. In order to allow for maximum plant stand, all treatments were established under full irrigation. After crop establishment, irrigation was withdrawn from rain-fed plots. Irrigation scheduling in the irrigated plots was scheduled weekly to meet 100% of crop water requirement (100% ETc). Irrigation was applied using sprinklers that were designed to have a radius of 6 m; the irrigated and rain-fed plots were spaced 10 m apart to prevent water from irrigated plots reaching rain-fed plots.

At Swayimani, the experimental design was a RCBD with a single factor: variety (four levels – GQ1, GQ2, SC701 and PAN53), replicated four times. Similar to Ukulinga, the plant population was 26 667 plants per hectare (0.75 m x 0.5 m). The individual plot size was 6.75 m^2 (2.25 m x 3 m) while the main plot size was 180 m^2 (12 m x 15 m).

3.4.3 Agronomic practices

Fertilizer application was based on a soil analysis report of the soil used in this study. An organic fertilizer, Gromor® fertilizer (30 g kg^{-1} N, 15 g kg^{-1} P and 15 g kg^{-1} K) was applied at a rate of 410 g per plant. Fertilizer was applied in the early stages of plant growth. Weeding was done using hand hoes. Scouting for pests and diseases was done weekly at Ukulinga and every fortnight at Swayimani.

3.4.4 Data collection

Data collection in field trials included seedling emergence, chlorophyll content index, plant height and leaf number. Data was collected weekly at Ukulinga and fortnightly at Swayimani. Emergence was collected from the onset of the trial up to 28 days after planting (DAP). The crop was deemed to have established 28 days after sowing when all seedlings had formed their first true leaves. Thereafter, data collection for plant growth and physiology commenced. At Ukulinga, chlorophyll content index (CCI) was measured using the CCM-200 (Opti-Sciences, USA) on the adaxial surface of the second youngest, fully expanded and fully exposed leaf of each plant. The CCM-200 calculates a unit less index (CCI) from the ratio of optical absorbance at 653 nm to that at 931 nm. At Swayimani, chlorophyll content index (CCI) was measured using the SPAD 502*Plus* chlorophyll meter (Konica Minolta, USA) on the adaxial surface of the second youngest, fully expanded and fully exposed leaf. The SPAD 502*Plus* calculates a unit-less index (CCI) from the ratio of optical absorbance at 651 nm to that at 940 nm. Leaves with signs of visual damage or disease were avoided and measurements were taken during midday (1200-1400 hrs.) and during periods when the soil was drying. Soil water content was monitored using a PR2/6 profile probe connected to an HH2 handheld moisture meter (Delta–T Devices, UK). Data collection for growth parameters at Ukulinga ceased 20 weeks after planting when 100% of the population had tasselled. Data collection at Swayimani ceased 15 weeks after planting due to deemed failure of the trial. Data collection at harvest included total biomass, ear prolificacy, ear size characteristics, kernel row per ear, kernel number per row, grain mass and harvest index.

3.5 Statistical Analyses

All data were subjected to analysis of variance (ANOVA) using GenStat® (Version 14, VSN International, UK). Means of significantly different variables were separated using least significant differences (LSD) at a probability level of 0.05.

CHAPTER 4

GERMINATION AND SEED QUALITY TESTS OF LOCAL LANDRACE AND HYBRID MAIZE VARIETIES

4.1 Introduction

Good seed quality is important in any cropping system as it plays an important role in the early growth stages of agricultural crops (Goggi *et al*., 2008). According to Santos (2010), quality seed can be defined as varietally pure, with high germination percentage, free from disease and disease organisms and with a proper moisture content and weight. Having good quality seed will enable better field performance in terms of germination, rapid emergence and vigorous seedling growth (Santos, 2010). A high percentage of seedling emergence and good crop stand encourages optimum planting population density to be obtained (Ghassemi-Golezani, 1992) thereby improving crop yields. It is an established fact that good quality seed is a pre-requisite for optimum return of the crop (FAO, 2006). Maize is the main staple food of South Africa (DAFF, 2012). With water being a scarce resource (Farre and Faci, 2009; Barros *et al*., 2007), improved maize yield would greatly contribute to food security. According to Chimonyo (2012), most rural farmers in South Africa rely on open pollinated maize varieties. However, traditional varieties that resource poor farmers are familiar with tend to produce relatively low yields despite their adaptability to low-input farming systems (Manzanilla *et al*., 2011). Low yield could be the result of low quality seed from farmer's prior harvest or improper storage of the seed (Manzanilla *et al*., 2011). Understanding the value of good quality seed, particularly among traditional varieties, can greatly contribute to food security and sustainable livelihoods. The planting value of a seed lot can be determined through seed quality testing. The quality is the measure of the potential performance of a seed lot under optimal conditions (Schmidt, 2000).

Seed testing can be used as a means of providing information on parameters of seed quality such as the physiological, physical, phytosanitary and genetic qualities (FAO, 2010). Of importance to this study are the physiological parameters. Physiological parameters of seed quality relate to viability and vigour. Influences on viability have been well documented over the years (Scharpf, 1970). The term viability refers to the ability of a seed to germinate under ideal conditions (Bradbeer, 1988). According to Linington *et al*. (1996), a germination test is the most useful method to determine the viability of a seed sample. ISTA (1985) defines germination of a seed lot in a laboratory as the emergence and development of the seedling to

a stage where the aspect of its essential structures indicate whether or not it is able to develop further into a satisfactory plant under favourable conditions. Seed quality testing under field conditions is often problematic due to the inability to replicate conditions reliably. The use of laboratory testing allows for the control of external factors to give the most uniform, rapid and complete germination (Kurdikeri *et al*., 1996). There are chemical tests that have also been used to determine viability. These tests detect chemical reactions that usually but not always occur in living systems (Scharpf, 1970). Such a test is the tetrazolium test, which is the most widely applied biochemical method to examine seed viability.

As an important primary seed evaluation parameter, seed vigour should be used to supplement viability testing so as to understand how the seed lot will perform under normal conditions (Gupta, 1986). According to AOSA (1983), seed vigour comprises those seed properties which determine the potential for rapid, uniform emergence, and development of normal seedlings under a wide range of field conditions. Vigour testing involves direct tests (for example, a cold test) where an environmental stress is reproduced in the laboratory and the percentage and or rate of seedling emergence are recorded. In indirect tests, like electrical conductivity, measure other characteristics of the seed that have proved to be associated with some aspect of seedling performance (ISTA, 2006). Some seed quality tests have been shown to correlate well to seedling emergence under average or good field conditions (DeVries *et al*., 2007). For instance, research by TeKrony *et al*. (1989) showed low vigour seed lots to have lower emergence compared to high vigour seed lots. Although research has been conducted on the influence of seed quality on maize (Lovato and Balboni, 1997; Noli *et al*., 2008; Matthews and Khajeh-Hosseni, 2006; Matthews and Khajeh-Hosseni, 2007), limited research had been done on the seed quality of landraces. The aim of this study, therefore, is to compare viability (germination, imbibition, tetrazolium test) and vigour (electrical conductivity, seedling root to shoot ratio) of two maize landraces with those of two hybrids.

4.2 Results

4.2.1 Final germination percentage

Final germination percentage showed that there were highly significant differences ($P < 0.001$) among maize varieties. High final germination percentages (100%, each) were observed for GQ 2 and PAN53 (Figure 4.1). The landrace GQ 1 had the lowest final germination 67.5% (Figure 4.1).

4.2.2 Germination vigour characteristics

The results indicated that there were highly significant differences ($P < 0.001$) among varieties in terms of GVI and MGT (Table 4.1). GQ2 germinated at a fastest rate and had the lowest MGT (3.57). PAN53 had high GVI (35.69), followed by GQ 2. In terms of GVI, GQ1 and SC701 were similar although SC701 had the highest MGT (4.82) (Table 4.1 and Figure 4.1).

4.2.3 Electrolyte conductivity

Results obtained of EC showed that there were highly significant differences ($P < 0.001$) among varieties. SC701 recorded the highest EC (220.1 µS/g), followed by GQ1 (187.5 µS/g). On the other hand, GQ2 and PAN 53 had the lowest EC values of 33.5 µS/g and 38.5 µS/g, respectively.

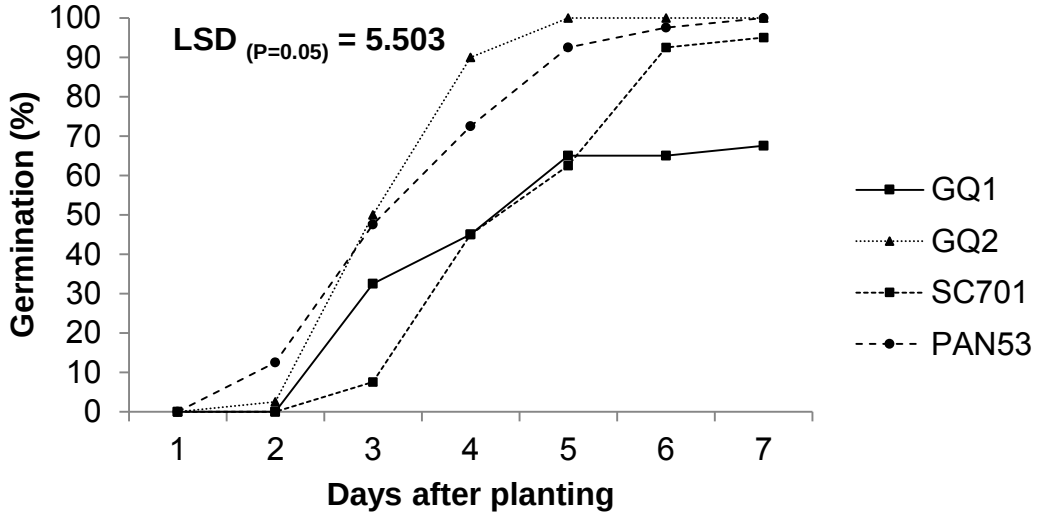

Figure 4.1: Daily germination percentages of Landraces (GQ 1 and GQ 2) and hybrids (SC701 and PAN53) measured during a standard germination test

Table 4.1: Performance of Landraces (GQ 1 and GQ 2) and hybrids (SC701 and PAN53) during a standard germination test.

Variety	GVI	MGT (days)	Root Length (mm)	Shoot Length (mm)	Root: Shoot	Dry Mass (g)
GQ 1	22.20c	3.96b	22.50a	9.43b	2.61a	2.97b
GQ 2	36.55a	3.57b	34.20a	12.60ab	2.81a	2.77b
SC701	22.10c	4.82a	25.50a	12.70ab	2.11a	4.14a
PAN53	35.69b	3.78b	33.40a	17.70a	1.87a	2.85b
LSD$_{(P=0.05)}$	0.319	0.5232	1.351	0.5447	1.004	0.247
F pr.	<0.001	0.001	0.211	0.038	0.211	<0.001
SED	0.161	0.240	0.62	0.257	0.473	0.117
% cv	26.8	4.2	33.9	31.1	31.9	5.8

Note that values sharing the same letter within the same column are statistically similar at LSD (P=0.05). Means were sorted in descending order

4.2.4 Tetrazolium (TZ) Test

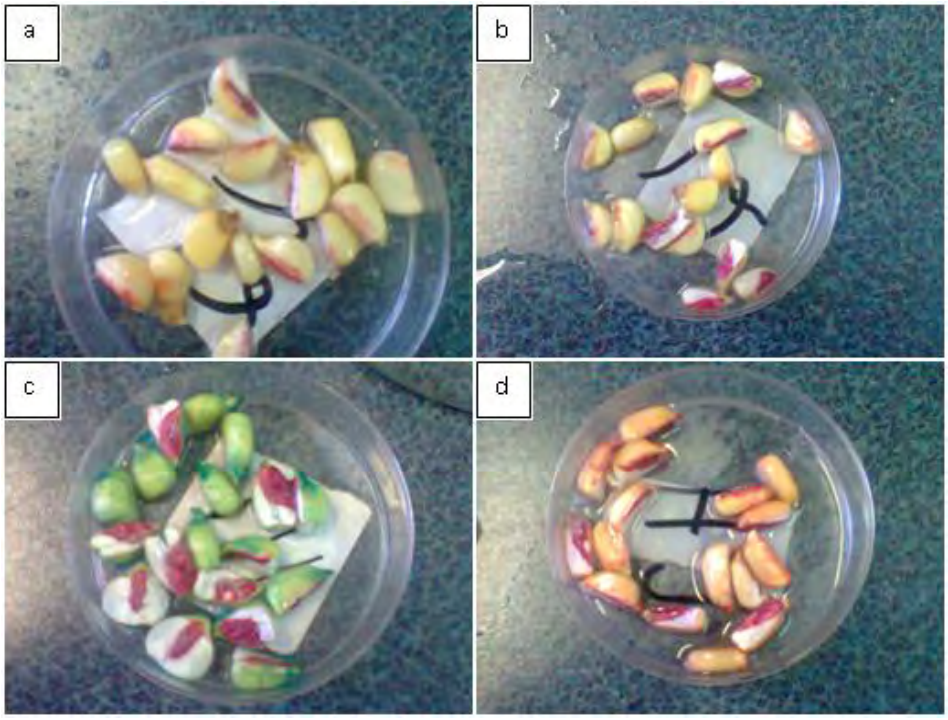

Figure 4.2: Results obtained from the TZ test showing positively stained seeds; a) GQ1, b) GQ2, c) SC701, and d) PAN53

All seeds (8 seeds per variety) tested positive for the tetrazolium test (Figure 4.2).

4.2.5 Imbibition

Highly significant differences ($P < 0.001$) were observed between varieties in terms of percentage weight increase (Figure 4.3). The highest weight gain was observed for GQ2 (44.4%), followed by PAN53 (39.6%), while low values were observed for SC701 (37.6%) and GQ1 (34.4%).

A positive correlation observed between final germination percentage and imbibition points out to imbibition being a better indicator of seed viability for the maze varieties. Results observed on seed imbibition showed the parameter to be a good indicator of seed quality as it differentiates seed varieties. GQ2 which had the highest and most rapid percentage weight increase performs at as high a standard in terms of viability with hybrids SC701 and PAN53. This shows a potentially high quality seed.

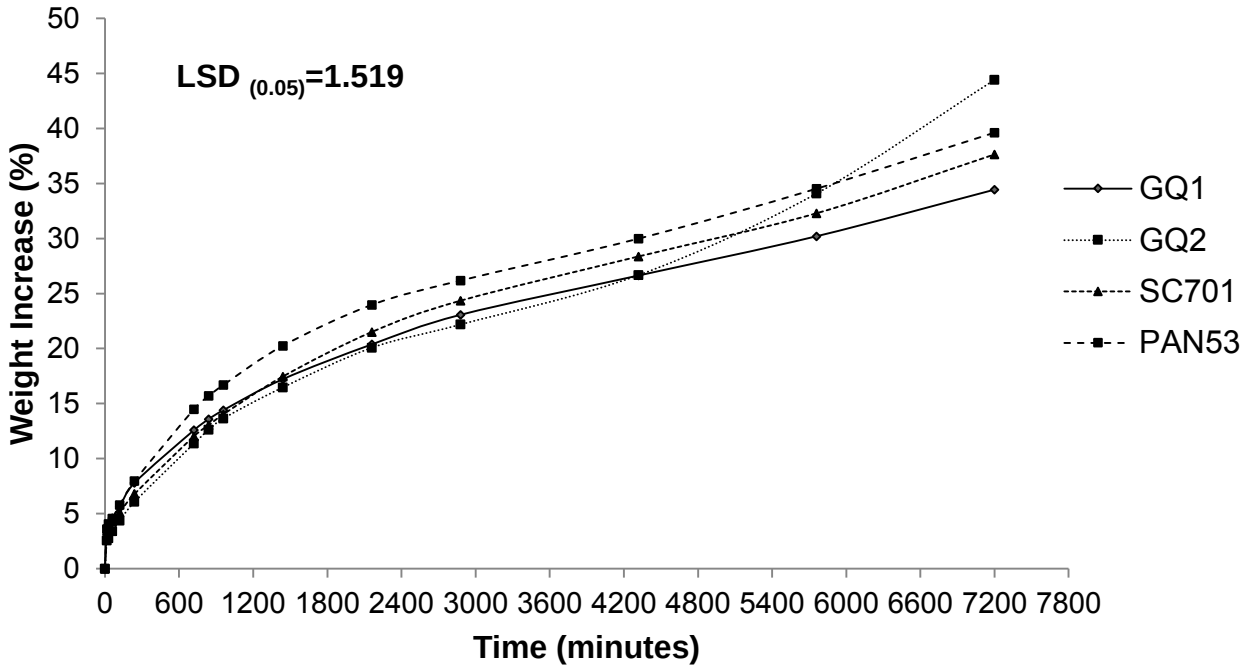

Figure 4.3: Percentage weight increments of Landraces (GQ1 and GQ2) and hybrids (SC701 and PAN53) measured at hourly intervals during an imbibition test.

4.2.6 Relationships between seed quality parameters

A strong positive significant correlation was observed between the following variables: fresh mass and dry mass (r = 0.98; P = 0.02); MGT and dry mass (r = 0.99; P = 0.01); root length and GVI (r = 0.98; P = 0.02). Although not statistically significant, strong positive correlations were also observed between the following variables: MGT and fresh mass (r = 0.93); root length and percentage weight increase during imbibition (r = 0.90); MGT and EC (r = 0.82); percentage mass increase during imbibition and final germination percentage (r = 0.80); shoot length and final germination percentage (r = 0.79); shoot length and root length (0.74).

A strong negative significant correlation can be observed between GVI and EC (r = -0.99; P = 0.01). Although no significant differences were observed, a strong negative correlation exists between the following variables: root length and EC (r = -0.95); shoot length and R: S ratio (r = -0.84); percentage weight increase during imbibition and EC (r = -0.79); MGT and GVI (r = -0.76).

4.3 Discussion

The results of the study show clearly that there is variation between the hybrids and the landraces in terms of the standard germination test. Variety differences observed in these results for final germination are inconsistent with most findings in literature that dictate that landrace seed lots are of inferior quality when compared with hybrid seeds. Similar results were obtained by Mabhaudhi and Modi (2010) where landraces performed at par with hybrids in terms of final germination percentage. However, it cannot be concluded that the planting potential of landraces is always equal to that of hybrids given the low performance of GQ1. It should, however, be assumed that genetic variability of GQ1 potentially caused poor germination contrary to results obtained from the TZ test.

The tetrazolium test is a biochemical test which measures certain metabolic events in seeds associated with germination. The test is essentially a measurement of dehydrogenase enzyme activity. These enzymes reduce the colourless tetrazolium chloride salt to form a water soluble red compound which stains living cells a red colour while dead cells remain colourless. Research supports the notion that results on the TZ test generally concur with those of germination closely (Department of Agriculture, Food and the Marine, 2013). Poor correlation between TZ and germination percentage is often attributed to embryo damage. According to Naderidarbaghshahi and Bahari (2012) there is a disagreement between TZ test and the SG test. It had also been noted by the Department of Agriculture, Food and the Marine (2013) that TZ

test is not suitable for carry over seed, which is the likely case with landraces. On the other hand, a positive correlation observed between final germination percentage and imbibition points out to imbibition being a better indicator of seed viability for the maze varieties. Results observed on seed imbibition showed the parameter to be a good indicator of seed quality as it differentiates seed varieties. GQ2 which had the highest and most rapid percentage weight increase performs at as high a standard in terms of viability with hybrids SC701 and PAN53. This shows a potentially high quality seed.

Although seed lots may have similar performance under theoretically ideal laboratory conditions, performance may differ in the field under adverse conditions (AOSA, 1983). Seed vigour is also considered as an important component in determining the physiological quality of seeds as it provides an indication of seed deterioration. Vigour testing is likely to identify seed lots which may not perform well under sub-optimal conditions despite acceptable germination results (van de Venter, 2000). Parameters considered under seed vigour testing include mean germination time (MGT), germination velocity index (GVI), seedling length tests and electrolyte leakage (EC).

MGT can be defined as the length of the lag period from the start of imbibition to radicle protrusion (Mavi *et al*., 2010) and is considered as a good measure of the vigour of viable seeds (Shen and Oden, 2000). Ordinarily hybrid vigour would cause the strength of a given seed lot to be limited to hybrids (Mabhaudhi, 2009), Observations by Matthews and Khajeh-Hosseni (2006) and Demir *et al*., (2008) support the notion that MGT is associated with the performance of a seed lot in the field in terms of seedling emergence. In an experiment conducted by Demir *et al*., (2008) it was observed that seedling with higher MGT produced smaller seedlings both under optimal conditions in the laboratory and under sub-optimal conditions in the soil. Mavi *et al*. (2010) suggested that MGT is critical in determining emergence performance. Seeds with a low MGT emerge faster in the field, thereby achieving rapid crop stand and setting up the plant canopy structure. A strong negative correlation exists between MGT and GVI. According to Mabhaudhi (2009), high GVI can be attributed to hybrid vigour as MGT depicts the strength of the seed lot. From the data obtained, GQ2 indicates high seed vigour having obtained the highest GVI, showing again the ability of a landrace to perform at par with a hybrid.

During the early stages of seed imbibition, exudates leak out of the cell membrane due to an ineffective barrier. In the conducted experiment, SC701 showed higher conductivity than all other seed varieties. However, high conductivity values displayed by GQ1 also point to high electrolyte leakage. Research by Pandey (1992) and Hampton and TeKrony (1995) show

conductivity to be correlated to field emergence. It can therefore be concluded that those seed varieties that perform poorly during the conductivity test for vigour will exhibit poor emergence under field conditions. That said, it must be noted that the negative correlation observed between conductivity and germination percentage was not strong.

Seed quality of hybrids remains superior to that of landraces although some landraces (GQ2) may have similar seed quality. However, it cannot be concluded that the planting potential of landraces would be equal to that of hybrids. It is therefore suggested that farmers should do germination tests before they plant in the field. For seed quality, it has been suggested that using one parameter to quantify seed quality is misleading. Other seed quality tests which have not been previously conducted in this study such as the cold test and the accelerated aging test should be considered.

CHAPTER 5

EFFECT OF WATER STRESS ON THE GROWTH AND DEVELOPMENT OF LOCAL MAIZE LANDRACES IN COMPARISON TO HYBRIDS UNDER CONTROLLED ENVIRONMENTAL CONDITIONS

5.1 Introduction

Maize is the most dominant staple food in Southern Africa (Mugo *et al*., 2002). In South Africa it is considered to be the main staple crop. Resource poor farmers in South Africa still cultivate maize landraces; landraces are known for their adaptability to harsh environmental conditions while producing reasonable yields (Zeven, 1998). This indicates their importance (Mabhaudhi, 2009), particularly to rural communities, and their potential ability to contribute to food security. However, the increasing threat of climate change threatens food security. A major concern, particularly in sub-Saharan Africa, is the occurrence of drought. Drought has now been considered as the single most critical threat to food security (Farooq *et al*., 2009). Low and erratic rainfall distribution (Mabhaudhi and Modi, 2011), coupled with altered soil water availability (Earl and Davis, 2003), contribute to severe yield loss in most crops (Karunaratne *et al*., 2011) from water stress. It has been predicted that climate change will contribute to the decrease in food crop yields over the next 50 years (Leakey *et al*., 2006). With water becoming a scare resource in the 21st century (Barros, 2007), the challenge remains on the ability of existing food crops to feed and sustain an ever increasing population.

The availability of water during different stages of crop growth influences its ability to survive. The early stages in the development of a plant (seed germination, seedling emergence and establishment) are key processes that are sensitive to water availability (Hadas, 2004). Factors such as the amount of available water in the growing medium and the duration of wetting have an influence on germination. Studies looking at the response of these early stages to water stress have shown water stress to contribute to reduced seed germination (Willenborg *et al.*, 2004) and early seedling growth (Mabhaudhi and Modi, 2010). Water stress has also been observed to cause marked decreases in germination rate and seedling vigour (Khodarahmpour, 2011; Mabhaudhi and Modi, 2010).

The most sensitive stage to water stress for the maize plant is the reproductive phase (Cakir 2004; Farre and Faci, 2009; NeSmith and Ritchie, 1992; Jama and Ottman, 1993), particularly at flowering. Some of the adverse effects of water stress during this period include reduced

biomass production, yield and harvest index (Farre and Faci, 2009). This ultimately leads to a reduction in grain yield (Cakir, 2004). Research on the effects of water stress on maize growth show grain yield, dry matter and kernel number to be the main components affected by water stress. Jama and Ottman (1993) observed a marked difference in water stressed plants and those receiving water in excess of 80% crop water requirement in terms of the above mentioned traits. NeSmith and Ritchie (1992) observed yield losses of up to 90% due to water stress imposed during the reproductive stages of tasseling and silking.

Although the importance of water has been quantified for many crops, little attention has been given to underutilised crops (landraces) (Karunaratne *et al*., 2011). A better understanding of the effects of drought on these landraces is important for improving agricultural systems and their management (Chaves *et al*., 2003), and thus improving food security. The first objective of this study, therefore was to observe the effect of water stress, under controlled environment conditions, on growth and photosynthetic parameters of two landraces (GQ1 and GQ2) in comparison to two hybrids (SC701 and PAN53). The second objective was to observe the effect of water stress on yield and yield components of the two landraces in comparison to the two hybrids under controlled environment conditions.

5.2 Results

5.2.1 Soil water content

The trend for soil water content shows the 80% ETc to have higher values compared with the 50% ETc and the 30% ETc. The lowest values can be observed for the 30% ETc treatment where values consistently remain below both 50% and 80% ETc treatments (with the exception of week 11). This trend is visible throughout the growth period of the crop. Soil water content does however remain below the permanent wilting point of the soil for all treatments with the exception of 6, 8, 9 and 10 weeks after planting for the 80% ETc treatment (Figure 5.1).

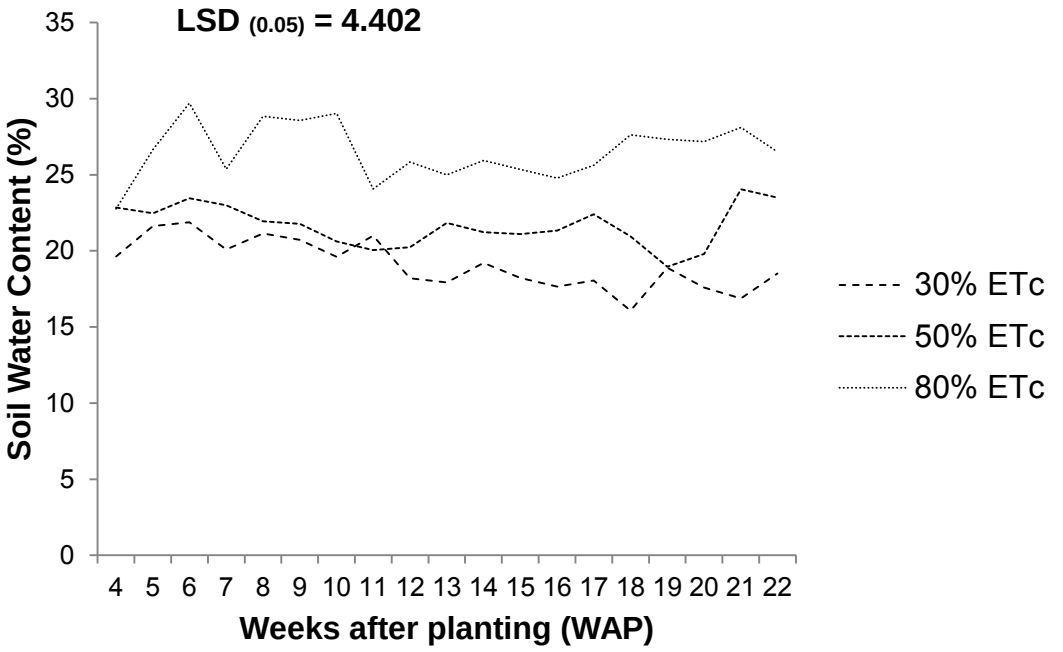

Figure 5.1: Soil water content comparing water treatments 30% ETc, 50% ETc, 80% ETc

5.2.2 Emergence

Results of seedling emergence showed differences between varieties as all treatments were established under optimum conditions. Daily emergence showed highly significant differences ($P < 0.001$) among varieties. The hybrids (SC701 and PAN53) showed faster and more uniform emergence throughout seedling emergence and establishment compared with both GQ1 and GQ2 (Figure 5.2). This trend contributed to higher final emergence values for the hybrids (SC701 and PAN53) compared to the landraces (GQ2 and GQ1). Mean separation revealed that all means were statistically different in terms of final emergence. SC701 had the highest final emergence (100%) followed by PAN53 (94.44%). Final emergence of the landraces was low; 86.11% and 61.11% for GQ2 and GQ1, respectively.

5.2.3 Crop physiology

Statistically, no differences were observed in terms of stomatal conductance. Results of SC showed no significant interaction ($P > 0.05$) between varieties and water regimes (Figure 5.3). There were also no significant differences ($P > 0.05$) recorded between water regimes as well as among varieties (Figure 5.3). However, stomatal conductance tended to fluctuate throughout

the duration of crop growth. This was a recurring trend across water regimes. Based on mean values of varieties across water regimes and time, landraces had a higher SC than hybrids. GQ2 had the highest SC (58.1 mmol m^{-2} s^{-1}) followed by GQ1 (54.6 mmol m^{-2} s^{-1}). The hybrids PAN53 and SC701 had lower values (53.6 mmol m^{-2} s^{-1} and 52.2 mmol m^{-2} s^{-1}, respectively). Mean values of water regimes across varieties showed the 80% ETc water regime to have the highest SC (55.3 mmol m^{-2} s^{-1}). Interestingly, the 30% ETc water regime had slightly higher SC (54.3 mmol m^{-2} s^{-1}) than the 50% ETc water regime (54.2 mmol m^{-2} s^{-1}).

Results obtained from chlorophyll content index showed highly significant interaction ($P < 0.001$) between water treatment and variety. There were significant differences ($P < 0.05$) between water treatments. Chlorophyll content index (CCI) was highest at 30% ETc and 80% ETc respectively, although these values differed by a small margin (0.05). Highly significant differences were observed among varieties ($P < 0.001$). PAN53 had the highest CCI (10.52), followed by both GQ2 and GQ1 with 10.09 and 10.05 respectively. SC701 has the lowest CCI at a value of 8.53. Although fluctuations were visible throughout the growth period, the general trend for CCI showed a decrease in CCI for all treatments (30%, 50% and 80% ETc) as plant growth progressed towards maturity (Figure 5.4).

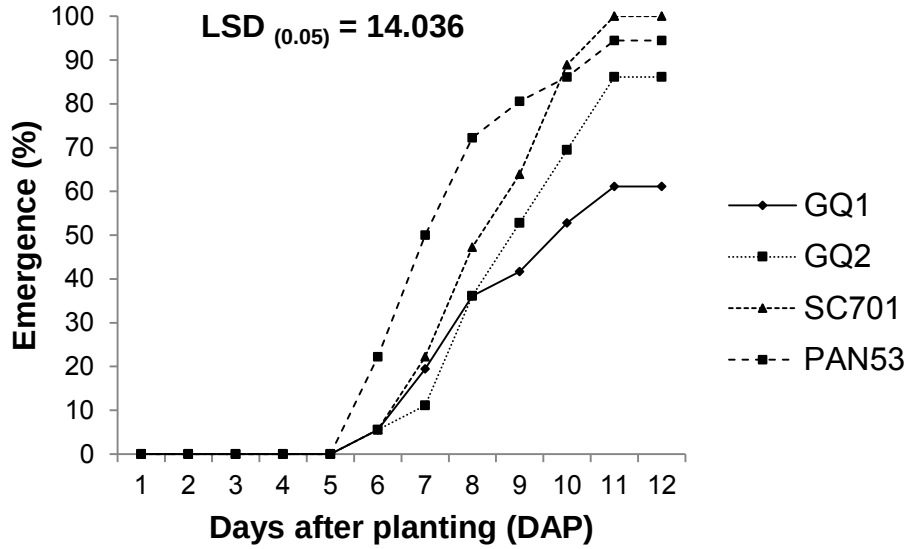

Figure 5.2: Daily emergence percentage of landraces (GQ1 and GQ2) and hybrids (SC701 and PAN53) over a 12 day period.

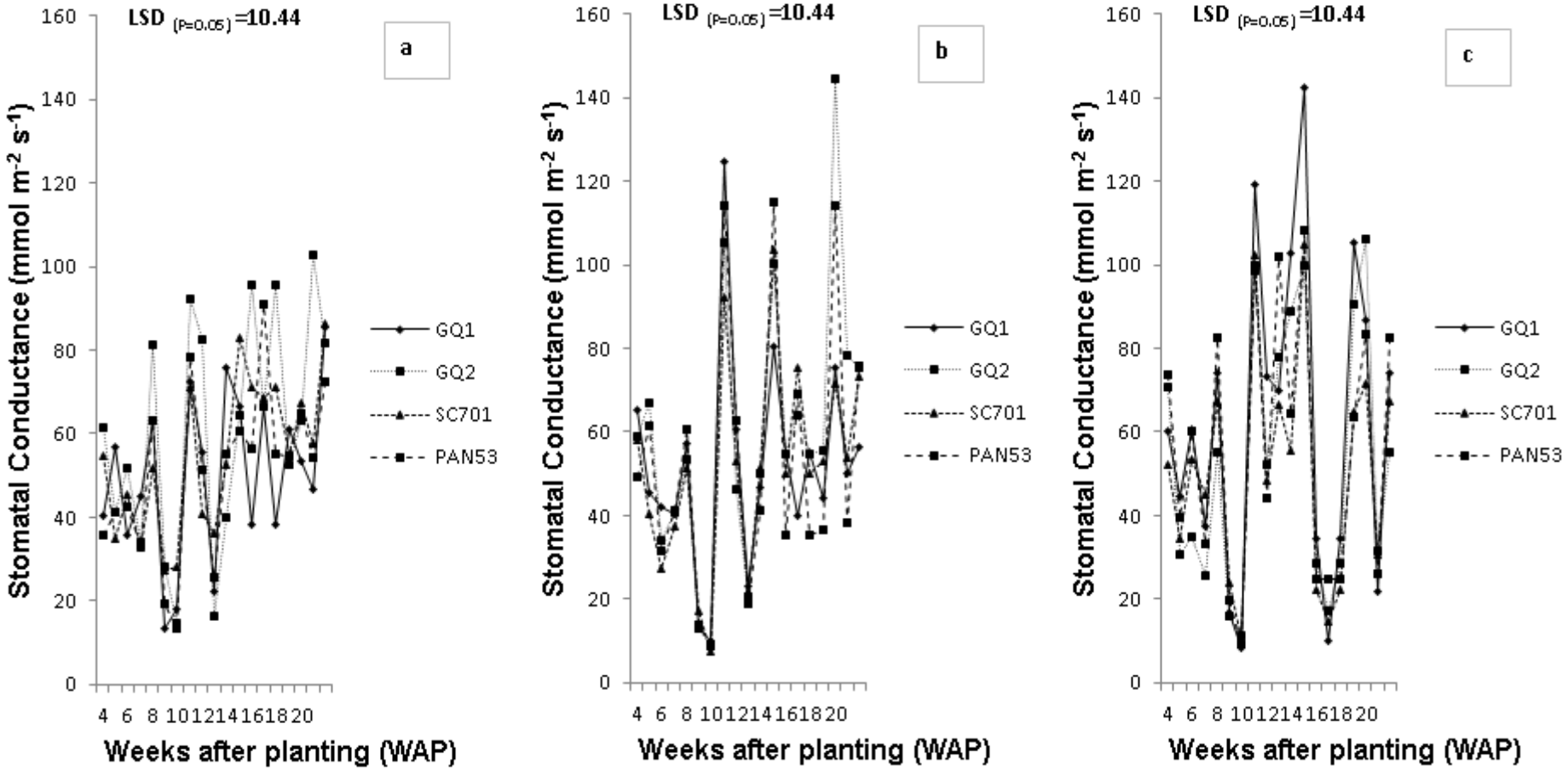

Figure 5.3: Stomatal Conductance of landraces GQ1 and GQ2 in comparison to hybrids SC701 and PAN53 across water treatments a) 30% ETc b) 50% ETc and c) 80% ETc

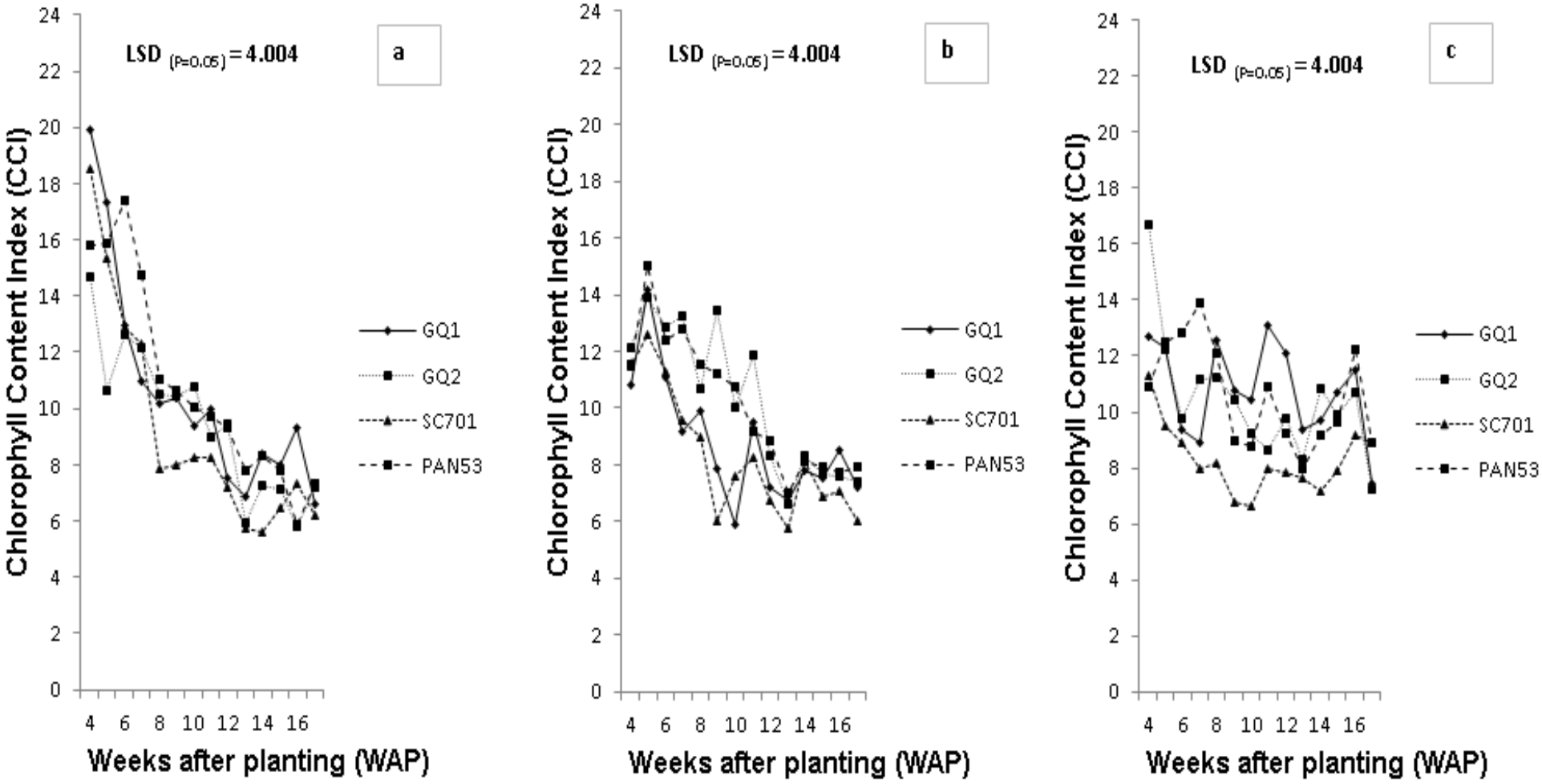

Figure 5.4: Comparison of Chlorophyll content index (CCI) between water treatments: a) 30% ETc b) 50% ETc c) 80% ETc

Results obtained from leaf and seed proline showed that there was highly significant interaction ($P < 0.001$) between water treatment and variety. There were also highly significant differences ($P < 0.001$) between water regimes and between varieties. Terminally water stressed plants has the highest seed proline concentration (11.142 μmoles/gDW) compared to the 50% ETc water treatment (1.025 μmoles/gDW) and the 80% ETc water treatment (2.932 μmoles/gDW). Landraces had higher seed proline concentrations than the hybrids. GQ2 had the highest proline concentration (8.924 μmoles/gDW) while GQ1 had a proline concentration of 6.944 μmoles/gDW. In terms of leaf proline, again the 30% ETc water treatment had the highest concentration (19.246 μmoles/gDW) compared to the 50% ETc water treamtment (0.057 μmoles/gDW) and the 80% ETc water treatment (0.077 μmoles/gDW). PAN53 (0.518 μmoles/gDW) and GQ1 (0.610 μmoles/gDW) had relatively low concentrations of proline in the leaf compared to SC701 (7.376 μmoles/gDW) and GQ2 (17.366 μmoles/gDW)

Results from leaf protein showed that there was highly significant interaction ($P < 0.001$) between water treatment and variety. There were also highly significant differences ($P < 0.001$) between water regimes and between varieties. The 80% ETc water treatment had a higher concentration of protein (83.44 mg/gDW) compared to the 50% ETc water treatment (80.41 mg/gDW) and the 30% ETc water treatment (80.15 mg/gDW) which had slightly lower values than the 50% ETc water treatment. GQ2 had the highest protein concentration (83.43 mg/gDW) of all varieties. The lowest protein concentration was attained from GQ1 (79.81 mg/gDW), with values for PAN53 (81.41 mg/gDW) and SC701 (80.69 mg/gDW) falling between the two landraces.

5.2.4 Crop growth

The interaction between water regimes and varieties was not significant ($P > 0.05$) with regards to plant height. There were also no significant differences ($P > 0.05$) between water treatments. There were, however, significant differences ($P < 0.05$) among varieties (Table 5.1). At 30% ETc, SC701 had the tallest plants followed by GQ2, GQ1 and PAN53, respectively. At 50% ETc, PAN53 had the tallest plants followed by SC701, GQ2 and GQ1, respectively. Under optimum conditions (80% ETc), SC701 had the tallest plants while GQ1 had the shortest plants. Mean values of variety across water treatments showed that the 80% ETc water treatment had the tallest plants as expected. This was followed by the 50% ETc water treatment at 164.4 cm and the 30% ETc water treatment at 156.1 cm.

Table 5.1: Plant growth and photosynthetic parameters of landraces (GQ1 and GQ2) in comparison to hybrids (SC701 and PAN53)

Water Treatment	Variety	Height at Tasseling (cm)	Leaf number at Tasseling	Time to Tasseling (Days)
	GQ1	144.50bcd	10.25a	115.90ab
	GQ2	146.00bcd	9.25ab	124.20ab
	SC701	193.80ab	10.25a	94.50b
30% ETc	**PAN53**	140.20cd	9.25ab	87.50b
Mean		**156.10**	**9.81**	**105.40**
	GQ1	126.00d	9.71ab	105.00ab
	GQ2	159.50abcd	9.00ab	120.00ab
	SC701	184.00abc	10.00ab	214.20ab
50% ETc	**PAN53**	188.00abc	9.25ab	115.50ab
Mean		**164.40**	**9.50**	**116.40**
	GQ1	154.20abcd	8.75	120.80ab
	GQ2	174.00abcd	9.75b	117.30ab
	SC701	198.20a	9.25ab	138.20a
80% ETc	**PAN53**	176.50abcd	9.50ab	141.80a
Mean		**175.80**	**9.31**	**129.50**
LSD (P=0.05)		10.44	1.08	34.84
F pr.		0.17	0.13	0.162
S.E.D		0.53	0.53	17.13
% cv		4.70	3.20	12.1

Note that values sharing the same letter within the same column are statistically similar at LSD (P=0.05). Means were sorted in descending order.

Mean values for water treatments across varieties showed a trend where hybrids SC701 and PAN53 dominated over GQ1 and GQ2. SC701 had the highest plant height at 192 cm followed by PAN53 at 168.2 cm. Values for GQ2 and GQ1 were 159.8 cm and 141.7cm respectively.

With regards to leaf number, there was no significant interaction ($P > 0.05$) between water regimes and varieties. There were also no significant differences (($P > 0.05$) observed between

water treatments and varieties (Table 5.1). Both SC701 and GQ1 had increments in leaf number with decreasing field capacity, while PAN53 and GQ2 remained consistent in terms of leaf number. Although statistically there were no differences, separation of means revealed differences between GQ1 which had the lowest number of leaves (8.75) and SC701 which had the highest number of leaves (10.25). Mean values for varieties recorded across water treatment showed that the hybrids had more leaves than the landraces (mean values for hybrids were 9.58 and mean values for the landraces were 9.5 respectively). In terms of water treatments across varieties, the 30% ETc water treatment had the most leaves (9.81). Although differences are slight, the 80% ETc water treatment had the least number of leaves (9.31).

5.2.5 Crop phenology

There are no significant interactions ($P > 0.05$) between water treatments and varieties in regards to days to tasselling (Table 5.1). There are, however, significant differences ($P < 0.05$) between water treatments. The 30% ETc water treatment had plants which tasselled faster than the 50% ETc water treatment and the 80% ETc water treatment. The corresponding valued were 105, 116 and 130 days respectively. Statistically there are no significant differences ($P > 0.05$) between varieties. However, mean values of varieties across water treatments show that GQ1 had plants which tasselled fastest (114 days) followed by PAN 53 (115 days). GQ2 plants took the longest time to tassel (121 days) followed by SC701 plants (119).

5.2.6 Yield and yield components

Results on total biomass showed no significant interactions ($P > 0.05$) between varieties and water treatments (Table 5.2). There were significant differences ($P < 0.05$) between water treatments but not between varieties. A trend can be observed in which the 80% ETc water treatment has the highest total biomass (334 g). There were, however, no large differences between the 50% ETc water treatment (252 g) and the 30% ETc water treatment (240 g). Observation of mean values for varieties across water treatment show that the landraces had higher total biomass values than the hybrids. GQ1 and GQ2 had values of 316 g and 270 g respectively, whereas SC701 and PAN53 had values of 0.259 and 0.255 respectively.

Table 5.2: Yield components of Landraces (GQ1 and GQ2) and commercial hybrids (SC701 and PAN53) subjected to three water treatments (30% ETc, 50% ETc and 80% ETc).

Water Treatment	Variety	Total biomass (g)	Ear No. plant^{-1}	Ear mass plant^{-1} (g)	Ear length (mm)	Kernel rows ear^{-1}	Kernel No. row^{-1}
	GQ 1	253b	1.00a	51ab	66.80bc	1.75bc	3.08ab
	GQ 2	241b	0.75a	52ab	46.80cd	0.00a	0b
	SC701	266b	1.50a	56ab	61.00bcd	4.25abc	3.25ab
30% ETc	**PAN53**	199b	0.75a	32b	26.20d	4.00abc	4.25ab
Mean		**240**	**1.0**	**48**	**50.2**	**2.5**	**2.65**
	GQ 1	224b	1.50a	60ab	67.00bc	5.25abc	4.17ab
	GQ 2	265b	1.50a	50ab	73.80bc	4.25abc	2.33ab
	SC701	223b	1.25a	45ab	79.50bc	4.50abc	6.46ab
50% ETc	**PAN53**	295b	1.00a	70ab	74.00bc	10.75a	9.67a
Mean		**225**	**1.312**	**56**	**73.6**	**6.19**	**5.66**
	GQ 1	332ab	1.25a	81ab	86.00ab	3.00bc	3.17ab
	GQ 2	441a	1.25a	206a	74.50bc	2.25bc	3.33ab
	SC701	289b	1.00a	68ab	96.20a	4.25abc	4.83ab
80% ETc	**PAN53**	273b	1.00a	88ab	93.00a	8.00ab	9.25a
Mean		**334**	**1.125**	**111**	**87.4**	**4.38**	**5.15**
LSD (P=0.05)		0.139	0.6868	138.400	29.500	6.281	6.946
F pr.		0.368	0.368	0.680	0.236	0.879	0.951
S.E.D.		0.064	0.338	68	14.500	3.087	3.414
%cv		19.3	16.1	48.7	12.3	25.2	41.6

Note that values sharing the same letter within the same column are statistically similar at LSD (P=0.05). Means were sorted in descending order. Mean values were rounded off to two decimal places

Ear prolificacy results showed no significant interactions (P > 0.05) between varieties and water treatments (Table 5.2). Statistically there were no differences between water treatments or varieties. Separation of means also alludes to the fact that there are no differences. However, mean values of variety across water treatments showed higher means among GQ2 and GQ1 (1.67 and 1.25 respectively) compared to SC701 and PAN53 (1.25 and 0.917). This trend is similar to that observed for total biomass above.

For ear size characteristics (ear mass per plant and ear length per plant) there were no significant interactions (P > 0.05) between varieties and water treatments (Table 5.2). The general trend through observation of mean values attained for water treatments across varieties show that the 80% ETc water treatment > 50% ETc water treatment > 30% ETc water treatment. For varieties, GQ2 and GQ1 perform better than PAN53 and SC701 in terms of ear mass. This trend does not transcend to ear length. SC701 had the longest plant ears (78.9 mm) while PAN53 had the shortest plant ears (64.4 mm). Both GQ1 and GQ2 have values between these hybrids (73.2 mm and 65 mm respectively).

Figure 5.5: Quality of ears obtained from the controlled environment study a) PAN53 b) GQ1.

Harvest index (HI) results obtained showed no significant interaction ($P > 0.05$) between variety and water regimes. There were also no significant differences ($P > 0.05$) between water treatments or varieties. PAN53 attained the highest harvest index under optimum conditions. This was followed by GQ2, GQ1 and SC701, respectively. HI under water stress conditions was considerably lower for all varieties, with PAN53 having the lowest HI. Adversely, SC701 had the highest HI under stress conditions (30% ETc). Trend observation showed the 80% ETc water treatment to have higher HI compared to the 50% ETc water treatment and the 30% ETc water treatment. Mean values for varieties across water treatments show GQ1 and GQ2 (0.238 and 0.224, respectively) to have a higher HI than PAN53 and SC701 (0.225 and 0.216, respectively).

5.3 Discussion

Research by Modi and Mabhaudhi (2010) concluded that landraces may adhere to the same level of viability as hybrids in the early stages of crop establishment. Significant differences occurring between varieties could be the result of poor seed quality, particularly in regards to GQ1. As with results obtained from section 4.2, it can be suggested that genetic characteristics of GQ1 contribute to poor seed germination and ultimately emergence. It should also be remembered that literature points out hybrids to have better seed quality than landraces. Mabhaudhi (2009) attributed hybrid vigour to be limited to hybrid seed. Given results on MGT in (Table 4.1) where hybrids had a lower MGT, the above statement is in line with research by Mavi *et al*. (2010) that suggests that MGT is a critical component in determining emergence performance of a seedlot. However, changes in morphological characteristics (Jaleel *et al*., 2009) are the ultimate determinants of stress effect in plants.

Closure of stomata has been identified to be an early response to water stress (Khoshvaghti *et al*., 2013) through a reduction in transpiration rates. This ultimately leads to a reduction in the net photosynthetic CO_2 fixation (Ritchie *et al*., 1992). Results showed no significant interactions between varieties and water treatments, thereby supporting evidence presented by Chavez (1991) and Cornic and Massacci (1996) that suggests that closure of stomata is more common under field conditions as opposed to controlled environment conditions as with this study. Farooq *et al*. (2009) also suggests that an interaction of both intrinsic and extrinsic factors govern stomatal oscillations, and not just soil water availability.

Plants adapt to low water stress through the accumulation of proline (Kavas *et al*., 2013). The terminally water stressed treatment (30% ETc) had considerably higher proline concentration than the moderate (50% ETc) and control (80% ETc) water stress treatments in both the seed and the leaf. Research by Delauney and Verma (1993) has shown proline to accumulate under water stress conditions. However, results attained by landraces contradict the notion that landraces are more tolerant to water stress. Protein results do, however, show higher concentrations of protein for landraces particularly GQ2. This points to landraces as being a valuable source of nutrition and an important consideration in improving the livelihoods of rural communities without compromising the quality of food nutritionally.

In the early stages of vegetative growth, plants are more susceptible to water stress than at mid stages of vegetative growth. That said, water stress during the vegetative stages of crop growth can lead to reduced plant growth (Cominelli *et al*., 2008). Although differences were not statistically significant, results show plant height to be lower under stress imposed water treatment. With increased water application, increments in plant height occur. Research by Dunford and Vasquez (2005) supports these findings, where plants that received more water accumulated more plant material and therefore increased in height. Similar results were attained by Khoshvaghti *et al*. (2013) and Pandey *et al*. (2000). Results show that SC701 (being a late maturing hybrid) had taller plants. This alluded to the fact that genotypes with long growth periods are on average taller than other genotypes (Bert *et al*., 2003). Although landraces are late maturing (Mabhaudhi, 2009), it must be remembered that hybrid vigour gives hybrids a growth advantage due to their genetic potential. Shorter plant height among the landraces supports reduced loss of water through transpiration, thereby potentially improving water use efficiency within those cultivars.

Results attained on leaf number show no significant differences between varieties or water treatments. However, plant leaves respond to water stress through decreased cell division and elongation (Serrano *et al*., 1999), to give reduced leaf area expansion. The results obtained in this study do not follow this trend. Hajibabaee *et al.* (2012) suggested that leaf number is not affected by environmental conditions and will therefore not be affected by irrigation treatments (also considering the experiment was conducted under controlled environment conditions).

The reproductive phase of maize plant growth is considered to be sensitive to water stress (Cakir, 2004) causing marked reduction in yield (Bolaños and Edmeades, 1996). The general trend showing increments in yield and yield components (ear length, ear mass, kernel rows per ear,

kernels per row and harvest index) with increased water application support the notion that plant growth is particularly sensitive to water stress. These reductions in yield and yield components are likely associated with lower evapotranspiration and radiation interception (Stone *et al*., 2001). Schussler and Westgate (1991) indicated that reduced photosynthetic activity leads to poor seed set in plants grown in pots. This possibly supports low kernel number per row and reduced kernel numbers per ear. That said, it must be remembered that water stress may be due to rapid development of water deficit occurring in pots as opposed to crops grown under field conditions (Otegui *et al*., 1995). Performance of landraces being at par with hybrids under such tunnel conditions indicates that they could potentially be a viable source of improving food security provided the given yield similarities.

Results from the controlled environment experiment show again that landraces can perform at par with hybrids despite reduced of plant growth parameters. Even under high water stress, yield components reveal that landraces GQ2 and GQ1 compensate in terms of yield. This supports the notion that landraces are tolerant to drought. Under high water stress conditions the hybrids did not perform as well as the landraces given their advantage in vegetative growth. This consideration should be given when considering the impact on food security as landraces have the potential to produce as high a yield as hybrids. However these results were obtained under optimum conditions where water regimes were varied. An experiment under field conditions would aid in further decision making in regards to the impact that landraces could have on food security.

CHAPTER 6

COMPARISON OF GROWTH, DEVELOPMENT AND YIELD COMPONENTS OF LOCAL MAIZE LANDRACES TO HYBRIDS UNDER IRRIGATED AND RAIN-FED FIELD CONDITIONS

6.1 Introduction

Maize, being the main staple food in South Africa (Du Plessis, 2003; DAFF, 2012) is of great importance, especially in rural areas. Local maize landraces are still cultivated widely by subsistence farmers (Mabhaudhi and Modi, 2010) due to their affordability (Mabhaudhi, 2009) and their ability to produce low but stable yields under fluctuating environmental conditions (McCouch, 2004). These varieties remain an important germplasm resource to subsistence farmers in South Africa (Mabhaudhi and Modi, 2010). Mostly grown under rain fed conditions (Mabhaudhi and Modi, 2010), water plays a limiting factor. Predicted increases in the frequency and severity of drought (Schulze, 2011) pose a threat to current and future food security. Of primary concern in sub–Saharan Africa is drought which is predicted to increase in both frequency and intensity. It has previously been suggested that maize landraces may be able to contribute to food security under these conditions (Mabhaudhi and Modi, 2013).

Drought is a global problem seriously influencing grain production and quality through impaired crop growth, altered water relations and reduced water use efficiency (Farooq *et al*., 2012). Understanding how crops respond to drought stress can aid in crop management under such environmental conditions (Chaves *et al*., 2009). The effects of drought range from morphological to molecular and are evident at all phenological stages of plant growth (Farooq *et al*., 2009). Plant water deficit occurs when transpirational loss exceeds water absorption through the roots (Patterson, 1995). Maize yields are reduced when evapotranspiration exceeds water supply from the soil at any given time during maize growth. Yield losses due to water stress vary depending on crop growth stage at which water stress occurs. Water stress during vegetative growth stages will lead to an overall reduction in crop productivity (Castiglioni *et al*., 2008). It will reduce stem and leaf cell expansion as well as dry matter accumulation due to lower water and CO_2 uptake. This results in reduced plant height and leaf area, and lower yield potential (Ritchie *et al*., 1992). Leaf area reduction contributes to a reduction in canopy photosynthetic capacity and a reduction in intercepted photosynthetically active radiation (PAR) (Craufurd and Wheeler, 1999).

The reproductive stage is particularly sensitive to water stress (Cakir, 2004; Farre and Faci, 2009; NeSmith and Richie, 1992; Jama and Ottman, 1993). Maize is most sensitive to water stress during the flowering stage, particularly at pollination (Cakir, 2004; Ali and Talukder, 2008). This is due to a reduction in pollen grain availability (Trueman and Wallace, 1999), increased pollen grain sterility (Al-Ghzawi *et al*., 2009) and decreased pollen grain germination as well as pollen tube growth (Lee, 1988). In addition, water stress can cause a reduction in synchronisation between silking and pollination (Thelen, 2007; Ngugi *et al*., 2013). Stress occurring one week before to one week after flowering may delay silking until after most of the pollen is shed. This results in poor pollination (Bolaños and Edmeades, 1996), especially on the tips of the ears (Thelen, 2007; Ali and Talukder, 2008); this will result in poorly developed ears (Ali and Talukder, 2008). Water stress during this period of ear size determination may seriously contribute to incomplete kernel set (Nielson, 2013). Early maturing hybrids will advance through these stages in a shorter time, which usually results in smaller ears than late maturing hybrids (Ali and Talukder, 2008). Grain filling occurs between pollination and maturity and it is the stage where about 40–50% of total biomass is translocated to the grains. Drought stress during grain filling reduces the duration of grain filling (Barnabas *et al*., 2008). This results in unfilled kernels, reduced kernel weight, and light, chaffy ears (Ali and Talukder, 2008). Drought stress during grain filling may also lead to grain abortion (Coffman, 1998). Water stress occurring after grain has reached physiological maturity will have no effect on final yield (Ngugi *et al*., 2013).

Although maize landraces have been suggested as a possible future crop under water limited conditions (Mabhaudhi and Modi, 2013), there is need for research to determine their water use characteristics as has been done for hybrids. The objective of this study was to determine growth, development and yield responses of maize landraces *viz* hybrids to irrigated and rain-fed conditions.

6.2 Results

6.2.1 Weather and soil water content

Temperatures were consistently low at both Ukulinga (Figure 6.1a) and Swayimani (Figure 6.1b) at the times of planting (July at Ukulinga and August at Swayimani). Temperatures remained consistently below 25°C until December when temperatures increased above the 25°C point, which is ideal for maize growth. Rainfall during these periods was also low, with increasing rainfall amounts recorded in October at both locations. Soil water content generally fluctuated throughout the duration of the study (Figure 6.2). The top 100 cm consistently had the lowest soil water content. The general trend at Ukulinga (Figure 6.2) showed that soil water content was higher at lower depths, particularly at 1 m. This trend corresponded with that observed at Swayimani (Figure 6.3). There was a marked difference between the irrigated (Figure 6.2a) and the rain-fed (Figure 6.2b) treatments at Ukulinga, with the irrigated treatment having higher soil water content.

6.2.2 Emergence

Results of emergence from Ukulinga showed that there were significant differences ($P < 0.05$) between varieties. On average, hybrids SC701 and PAN53 had higher rates of emergence than landraces GQ1 and GQ2. SC701 had the highest rate (76.5%), followed by PAN53 (60.5%). The landrace GQ1 had the lowest emergence (38%) (Figure 6.4).

At Swayimani results showed highly significant differences ($P < 0.001$) among varieties with respect to emergence. Similar to results obtained at Ukulinga, the hybrids had higher final emergence (SC701 at 76.8% and PAN53 at 83%) than landraces (GQ2 at 61.6% and GQ1 at 35.7%) (Figure 6.5).

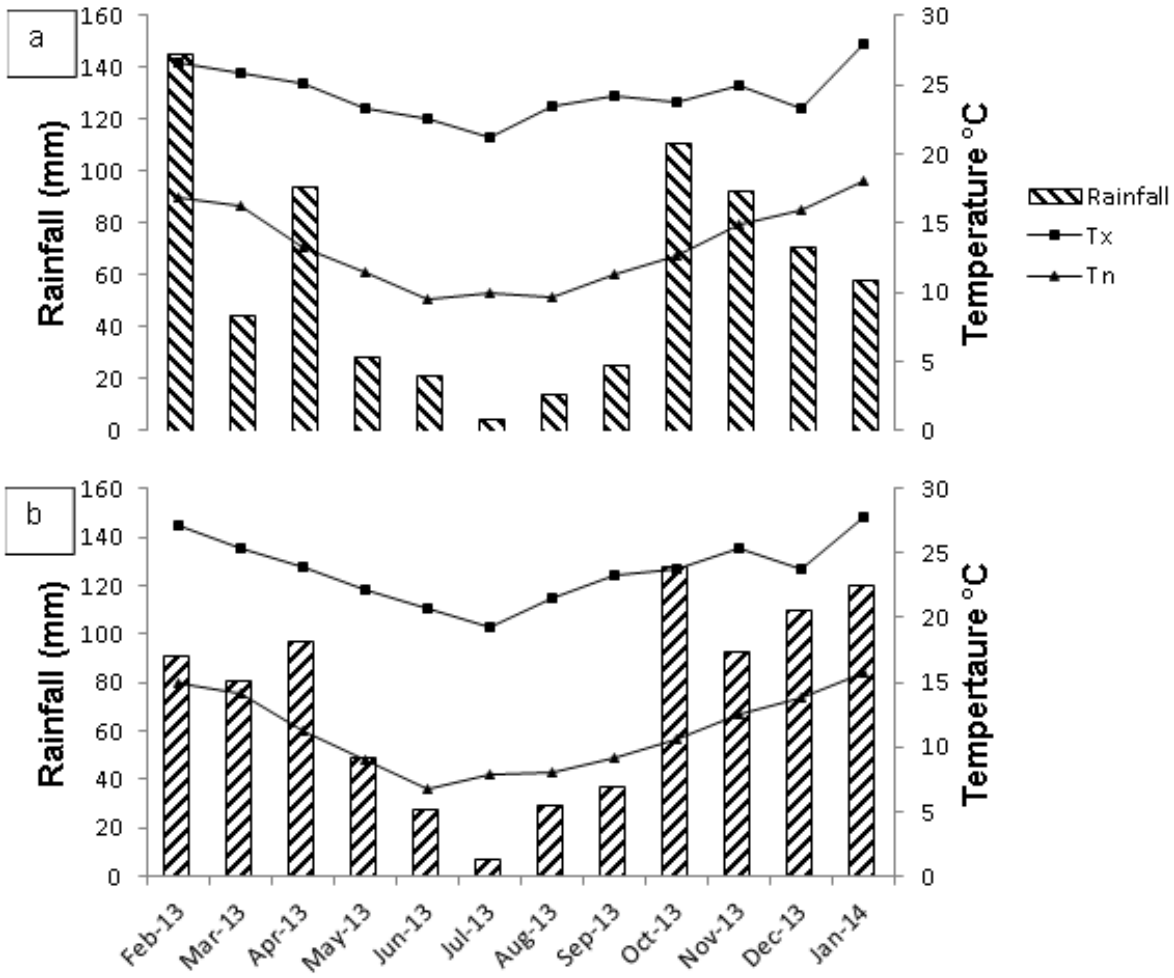

Figure 6.1: Monthly rainfall and maximum and minimum temperatures (°C) recorded at a) Ukulinga and b) Swayimani from February 2013 to January 2014.

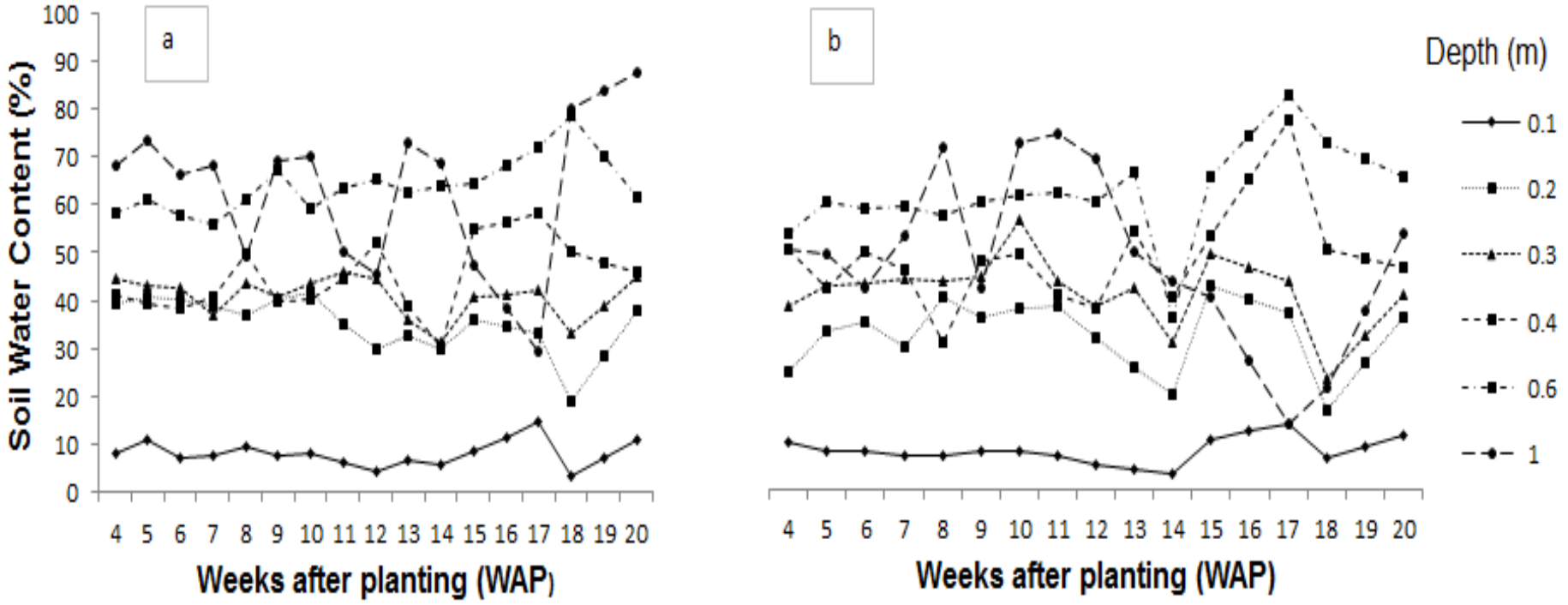

Figure 6.2: Soil water content recorded at Ukulinga at six depths (0.1, 0.2, 0.3, 0.4, 0.6 and 1.0 m) over the duration of the trials under a) irrigated, and b) rain-fed conditions.

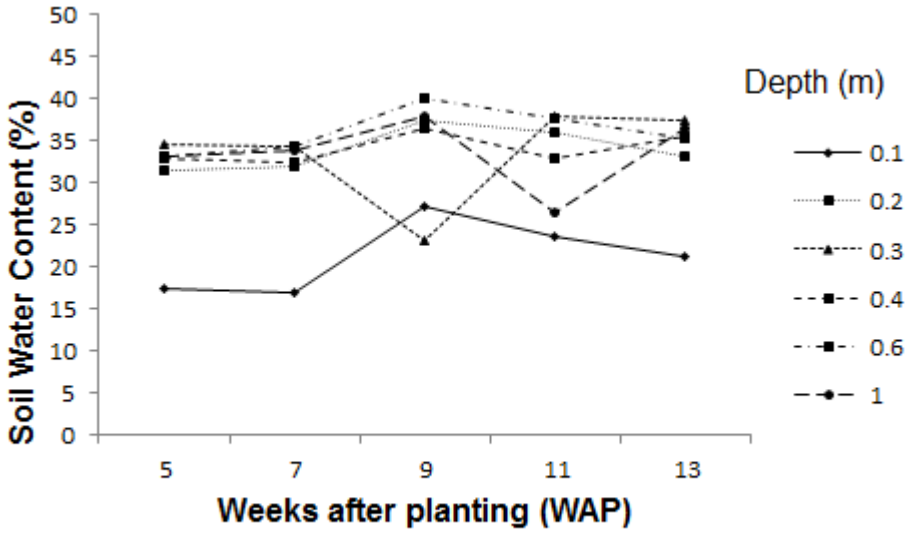

Figure 6.3: Soil water content observed at Swayimani at six depths (0.1, 0.2, 0.3, 0.4, 0.6 and 1.0 m) over the duration of the trial.

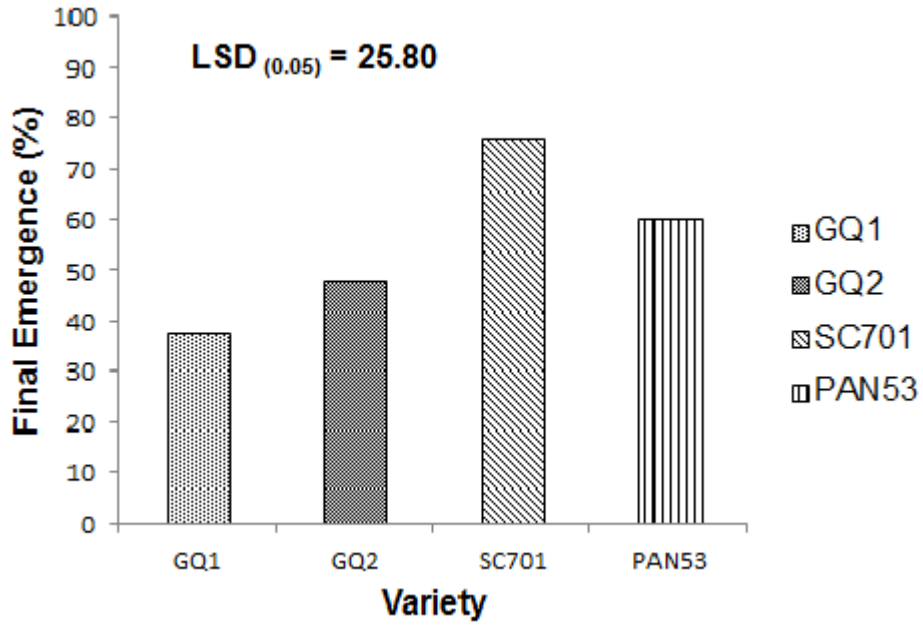

Figure 6.4: Final emergence of landraces (GQ1 and GQ2) and hybrids (SC701 and PAN53) at Ukulinga.

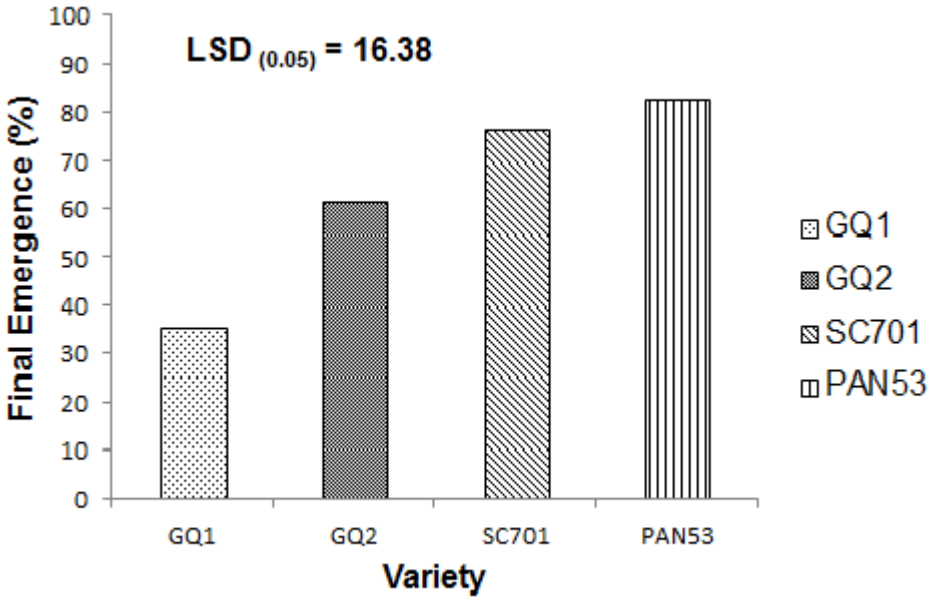

Figure 6.5: Final emergence of landraces (GQ1 and GQ2) and hybrids (SC701 and PAN53) at Swayimani.

6.2.3 Crop physiology

At Ukulinga, results obtained for chlorophyll content index (CCI) showed a highly significant interaction ($P < 0.001$) between water regimes and variety. There were no significant differences ($P > 0.05$) between water regimes. Chlorophyll content index was slightly higher under rain-fed relative to irrigated conditions (20.41 and 20.17, respectively). There were, however, highly significant differences ($P < 0.001$) among varieties. Based on mean values of varieties across water regimes, PAN53 had the highest CCI (22.83), followed by GQ1 (20.86), GQ2 (19.86) and SC701 (17.6). Although CCI fluctuated throughout the growth period, a sharp decline was observed 14 weeks after planting for both water regimes (Figure 6.6).

At Swayimani, CCI showed no significant differences ($P > 0.05$) among varieties. Mean separation of varieties over time indicated that hybrids had higher CCI than the landraces. PAN53 had the highest CCI at 33.25 followed by SC701 at 31.76. The landraces GQ2 and GQ1 had values of 31.01 and 30.60 respectively (Figure 6.7).

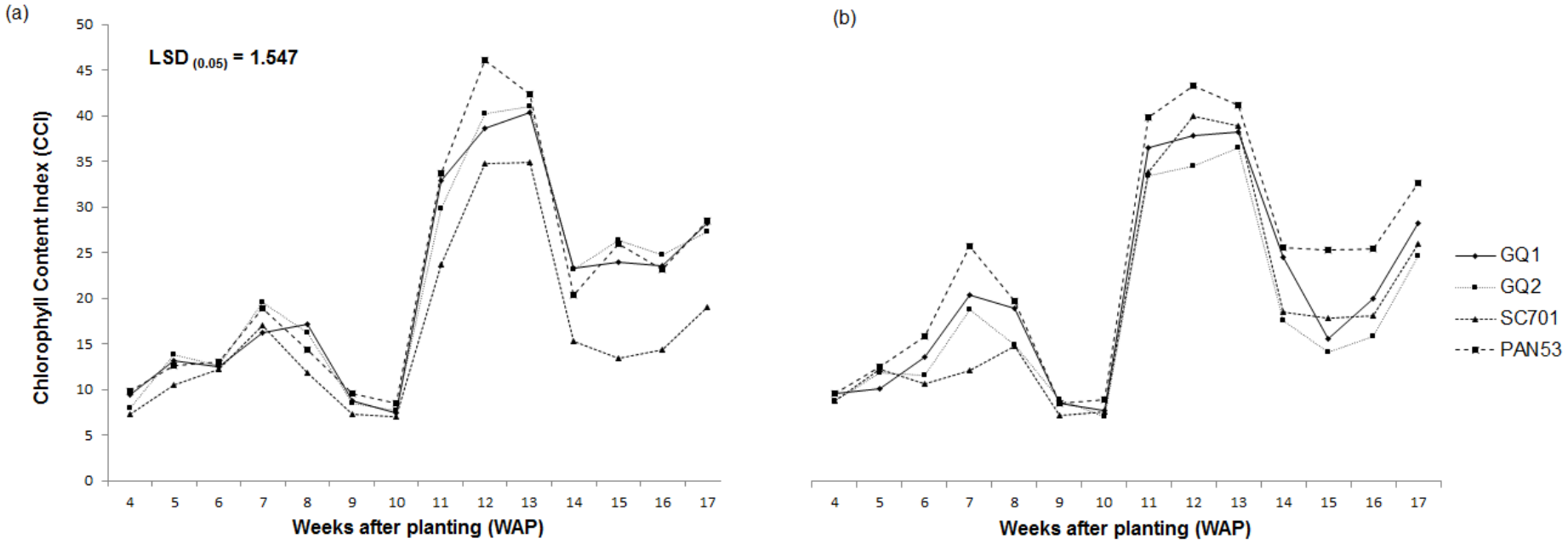

Figure 6.6: Comparison of chlorophyll content index (CCI) of hybrids (SC701 and PAN53) and landraces (GQ1 and GQ2) under a) irrigated, and b) rain-fed conditions.

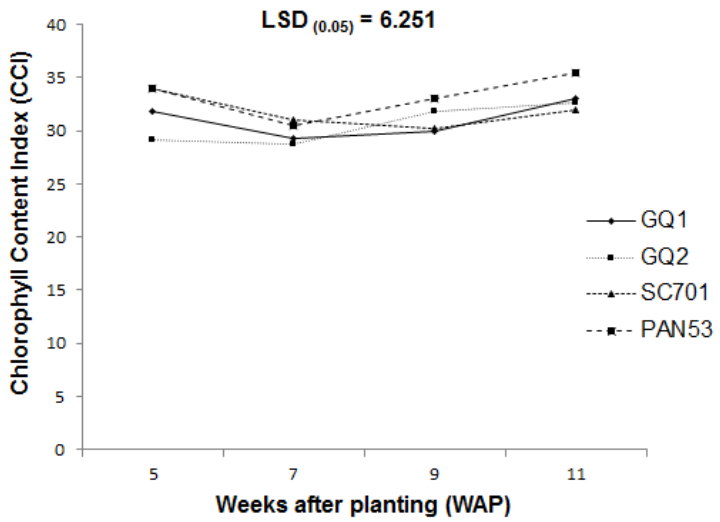

Figure 6.7: Chlorophyll content index (CCI) of hybrids (SC701 and PAN53) and landraces (GQ1 and GQ2) recorded at Swayimani.

6.2.4 Crop growth

The interaction between water regimes and varieties was not significant ($P > 0.05$) with regards to plant height. There were also no significant differences ($P > 0.05$) between water regimes. There were, however, significant differences ($P < 0.05$) among varieties. Hybrids had taller plants than landraces. This trend was consistent with the one observed in chapter 4 where hybrids were taller than landraces. GQ1 had the shortest plants (149.9 cm). Mean values of water regimes across varieties showed that the irrigated plants were taller than the rain-fed water treatment (Table 6.1).

With regards to leaf number at Ukulinga, there was no significant interaction ($P > 0.05$) between water regimes and varieties. There were also no significant differences ($P > 0.05$) observed between water regimes or varieties (Table 6.1). Although differences were not statistically significant, the irrigated water regime had more leaves than under rain-fed conditions. Mean values of varieties across water regimes showed that GQ1 had the most leaves (13.84). This contradicted results of plant height whereby GQ1 had the shortest plants.

Table 6.1: Plant growth (plant height and leaf number) of landraces (GQ1 and GQ2) and hybrids (SC701 and PAN53) measured at tasseling under irrigated and rain-fed conditions.

Water Treatment	Variety	Height at tasseling (cm)	Leaf number at tasseling
Irrigated	**GQ1**	159.52abc	14.06a
	GQ2	170.20abc	12.81a
	SC701	193.40a	13.31a
	PAN53	175.15abc	13.00a
Mean		**174.60^{a}**	**13.29^{a}**
Rain-fed	**GQ1**	140.32c	12.62a
	GQ2	146.90bc	13.27a
	SC701	190.36ab	13.32a
	PAN53	177.40abc	13.21a
Mean		**163.80^{ab}**	**13.11^{a}**
LDS (P=0.05)		28.41	1.225
F pr.		0.495	0.143
S.E.D		13.57	0.60
%cv		5.90	5.6

Note that values sharing the same letter within the same column are statistically similar at LSD (P=0.05). Means were sorted in descending order. Mean values were rounded off to two decimal places

Plant height at Swayimani showed no statistical differences among the varieties ($P > 0.05$). Unlike the plants at Ukulinga, the tallest plants at the end of data collection were recorded among GQ1 (60.96 cm). The difference in plant height between the hybrids was very slight (PAN53 at 57.10 cm and SC701 at 55.55 cm). GQ2 had the lowest recorded plant height at 54.33 cm (Figure 6.8).

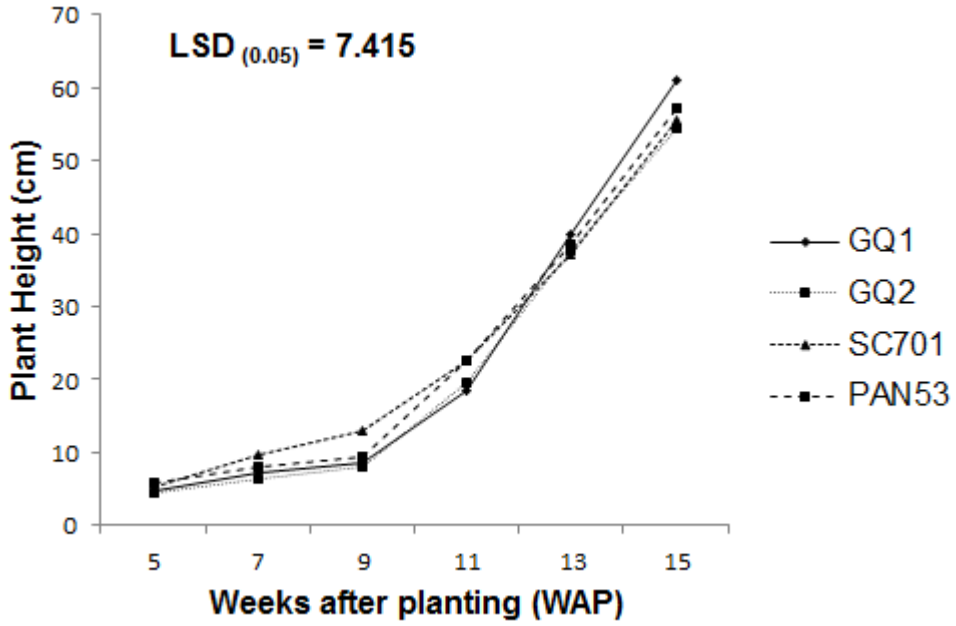

Figure 6.8: Plant height of landraces (GQ1 and GQ2) and hybrids (SC701 and PAN53) measured at Swayimani.

Leaf number at Swayimani also showed no significant differences ($P > 0.05$) between varieties. However, at the cease of data collection, the landraces had on average, more leaves than the hybrids (10.08 for GQ2and 9.51 for GQ1). Not far behind were hybrids SC701 (9.90) and PAN53 (8.80) (Figure 6.9).

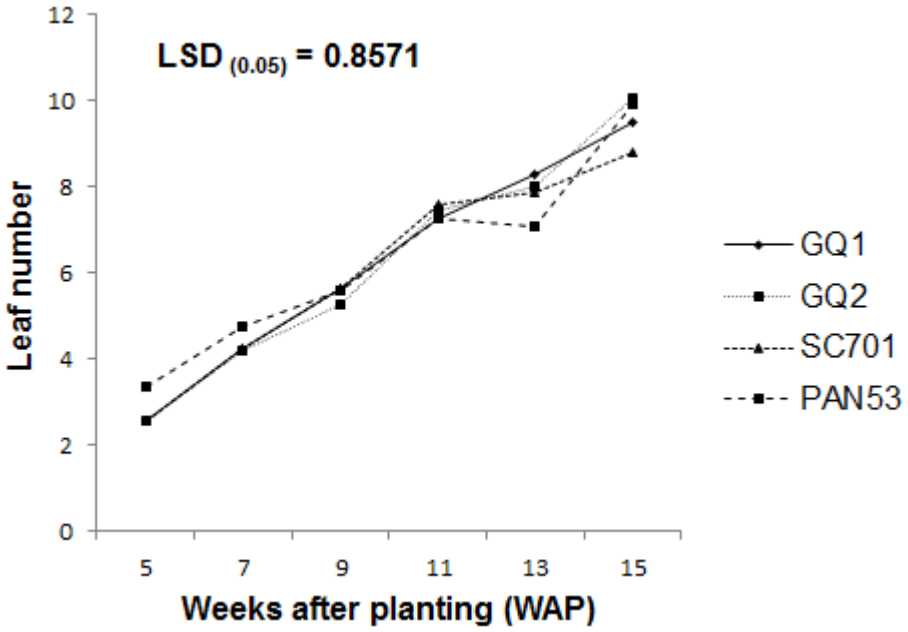

Figure 6.9: Leaf number of landraces (GQ1 and GQ2) and hybrids (SC701 and PAN53) measured at Swayimani.

Figure 6.10 shows the plant growth cycle for each variety. For GQ1, GQ2 and SC701, the irrigated water treatment consistently performs better than the rain-fed water treatment. The trend is slightly different with regards to PAN53. The irrigated and rain-fed regimes grow at par with little marked difference between the two except in the mid-stages of vegetative growth. It must be noted that final plant heights for both hybrids (SC701 and PAN53) were similar in terms of water treatment.

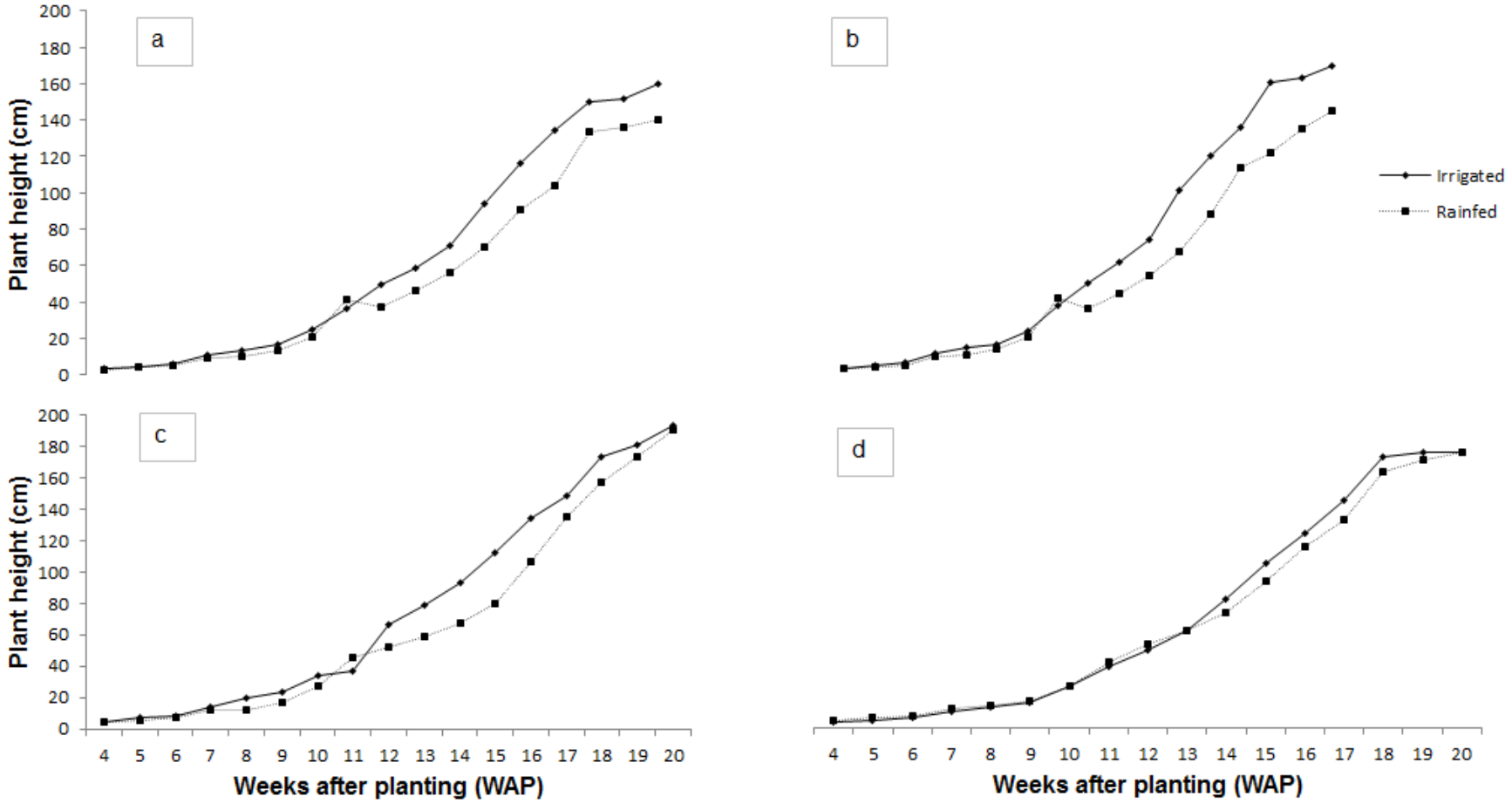

Figure 6.10: Plant growth curves of landraces (a) GQ1 and (b) GQ2, in comparison to hybrids (c) SC701 and (d) PAN53 recorded over the duration of the trials.

6.2.5 Crop phenology

Time to tasselling showed a significant interaction ($P < 0.05$) between water regimes and varieties (Table 6.2). There were significant differences ($P < 0.05$) between water regimes, and highly significant differences ($P < 0.001$) among varieties. On average, the irrigated water regime had plants that tasselled faster than under rain-fed conditions. Under irrigated and rain-fed conditions, plants tasselled at ≈120.31 and ≈124.69 days after planting (DAP). Hybrids SC701 and PAN53 both tasselled at 126 days after planting while landraces GQ2 and GQ1 tasselled at ≈121.63 days and ≈116.38 DAP (Table 4.2).

Results for time to silking showed no significant interaction ($P > 0.05$) between water regimes and varieties (Table 6.2). There were, however, highly significant differences ($P < 0.001$) between water regimes. Statistically, there were no differences among varieties ($P > 0.05$). Silking occurred earlier under irrigated (≈128.62 DAP) than rain-fed (≈138.25 DAP) conditions. Based on mean values of varieties across water regimes, landraces took more days after planting for silks to appear than the hybrid.

Anthesis-silking interval (ASI) results showed no significant interaction ($P > 0.05$) between water regimes and varieties (Table 6.2). There were, however, highly significant differences ($P < 0.001$) between both water regimes and varieties. On average, ASI was longer under rain-fed (13.56 days) than irrigated (7.44 days) conditions.

6.2.6 Yield and yield components

Results of total biomass from Ukulinga showed no significant interaction ($P > 0.05$) between water regimes and varieties (Table 6.3). There were no significant differences ($P > 0.05$) between water regimes or varieties. Although no statistical differences were observed between water regimes, the irrigated water treatment had a higher total biomass than the rain-fed water treatment. This trend was consistent for all yield components. Mean values of varieties across water regimes showed that hybrids had, on average, higher biomass than landraces (Table 6.3).

Table 6.2: Plant phenology observed at Ukulinga for landraces (GQ1 and GQ2) and hybrids (SC701 and PAN53) under irrigated and rain-fed conditions.

Water treatment	Variety	Time to Tasselling (days)	Time to Silking (days)	Anthesis-Silking Interval (Days)
Irrigated	**GQ1**	113.75c	129.50bc	15.75a
	GQ2	115.50bc	126.00c	10.50ab
	SC701	126.00ab	129.50bc	0.00c
	PAN53	126.00ab	129.50bc	3.50bc
Mean		**120.31^{b}**	**128.62^{cd}**	**7.44^{cd}**
Rain-fed	**GQ1**	119.00abc	136.50abc	17.50a
	GQ2	127.75a	143.15a	15.40a
	SC701	126.00ab	138.25ab	12.25ab
	PAN53	126.00ab	135.10abc	9.10abc
Mean		**124.69^{a}**	**138.25^{a}**	**13.56^{a}**
LDS (P=0.05)		6.509	6.996	5.674
F pr		0.036	0.121	0.078
S.E.D		3.110	3.3342	2.711
% cv		1.2	1.3	27.1

Note that values sharing the same letter within the same column are statistically similar at LSD (P=0.05). Means were sorted in descending order. Mean values were rounded off to two decimal place

Total biomass at Swayimani showed no significant differences ($P > 0.05$) among varieties. These results were consistent with those observed at Ukulinga. Although not statistically different, landraces had higher total biomass than hybrids. Landraces GQ1 and GQ2 had total biomass values of 579 g and 407 g, respectively while PAN53 and SC701 had values of 411 g and 374 g, respectively (Table 6.4).

Ear prolificacy results observed at Ukulinga showed no significant interaction ($P > 0.05$) between water regimes and varieties (Table 6.3). There were no significant differences ($P > 0.05$) between water regimes or varieties. Mean values of water regimes across varieties showed that ear prolificacy was higher under irrigated (1.24 ears per plant) than the rain-fed (0.69 ears per plant) conditions. Although statistically not significant, the margin between the two was almost 100%.

Based on mean values of varieties across water regimes, SC701 and PAN53 had higher ear prolificacy than GQ1 and GQ2 (Table 6.3).

The trend was similar at Swayimani for ear prolificacy. There were no significant differences ($P > 0.05$) among varieties (Table 6.4). However, on average, hybrids had higher ear prolificacy than landraces. SC701 had the highest ear prolificacy (1.11 ears per plant) while GQ1 had the lowest ear prolificacy (0.95 ears per plant). As with the Ukulinga trial, GQ1 had the lowest ear prolificacy (Table 6.4).

For ear size characteristics at Ukulinga (ear mass and ear length per plant) there was no significant interaction ($P > 0.05$) between water regimes and varieties (Table 4.3). There were also no significant differences ($P > 0.05$) between water regimes or varieties. SC701 had a high ear mass (209 g) followed by GQ2 (177 g), PAN53 (147 g) and GQ1 (123 g). A comparison of irrigated and rain-fed means showed that ear mass was higher under irrigated (191 g) relative to rain-fed (137 g) conditions. This trend translated well to ear length where irrigated plants had longer ears (192.1 mm) than the rain-fed plants (191.6 mm) (Table 6.3).

Results for ear size characteristics at Swayimani followed a similar trend as that observed at Ukulinga. There were no significant differences ($P > 0.05$) between varieties (Table 4.4). However, landraces had higher mass than hybrids with GQ2 having a value of 214 g and SC701 having a value of 172 g. In terms of ear length, landraces had longer ears than hybrids. As with ear mass, GQ2 had the longest ears (181.4 mm) while SC701 had the smallest ears (168.9 mm) (Table 6.4).

Results of kernel rows per ear showed no significant interactions ($P > 0.05$) between water regimes and varieties (Table 4.3). There were no differences ($P > 0.05$) between water regimes or varieties at Ukulinga. There were also no significant differences ($P > 0.05$) obtained for kernel number per row. However, mean values of water regimes across varieties showed that the irrigated water regime had more kernel rows per ear and kernel number per row compared to the rain-fed regime. Although hybrids had, on average, more kernel rows per ear (5.81 and 5.45 for SC701 and PAN53, respectively) than landraces (2.71 and 6.23 for GQ1and GQ2 respectively) this trend did not translate to kernel number per row. GQ2 had the most kernel number per row (15.0) while GQ1 had the lowest (8.6) (Table 6.3).

Table 6.3: Yield and yield components of landraces (GQ1 and GQ2) and commercial hybrids (SC701 and PAN53) under irrigated and rain-fed conditions at Ukulinga.

Water Treatment	Variety	Total biomass (g)	Ear No. plant^{-1}	Ear mass plant^{-1} (g)	Ear length (mm)	Kernel rows ear^{-1}	Kernel No. row^{-1}	Harvest Index (HI)	100 grain mass (g)	Yield (kg ha^{-1})
	GQ1	766.00a	0.92a	173.00a	224.60a	4.00a	12.00a	0.25a	69.50a	4.61a
	GQ2	594.00a	1.25a	180.00a	178.00a	6.58a	16.10a	0.28a	61.50a	4.80a
	SC701	491.00a	1.04a	240.00a	191.20a	5.42a	13.90a	0.33a	62.00a	9.05a
Irrigated	**PAN53**	699.00a	1.77a	170.00a	174.70a	6.83a	13.00a	0.22a	58.30a	4.54a
Mean		**638.00^{a}**	**1.24^{a}**	**191.00^{a}**	**192.10^{a}**	**5.71^{a}**	**13.70^{a}**	**0.269^{a}**	**62.80^{a}**	**5.75^{a}**
	GQ1	388.00a	0.38a	74.00a	180.60a	1.42a	5.10a	0.19a	56.80a	1.74a
	GQ2	593.00a	0.79a	174.00a	190.60a	5.88a	14a	0.30a	57.60a	4.64a
	SC701	656.00a	0.79a	178.00a	206.00a	6.25a	12.70a	0.28a	66.30a	4.74a
Rain-fed	**PAN53**	522.00a	0.79a	123.00a	189.00a	4.06a	7.90a	0.16a	51.00a	5.14a
Mean		**540.00^{a}**	**0.69^{a}**	**137.00^{a}**	**191.60^{a}**	**4.40^{a}**	**9.90^{a}**	**0.23^{a}**	**57.90^{a}**	**4.07^{a}**
LDS (P=0.05)		392.7	1.373	205	67.43	5.438	12.73	0.2495	20.41	4.63
F pr.		0.237	0.884	0.928	0.503	0.737	0.906	0.938	0.658	0.380
S.E.D		188.8	0.660	98.6	32.18	2.615	6.12	0.1200	9.75	2.204
%cv		18.0	57.8	39.5	5.7	32.4	25	23.6	3.2	48.00

Note that values sharing the same letter within the same column are statistically similar at LSD (P=0.05). Means were sorted in descending order. Mean values were rounded off to two decimal place

Table 6. 4: Yield and yield components of landraces (GQ1 and GQ2) and commercial hybrids (SC701 and PAN53) at Swayimani under rain-fed conditions.

Variety	Total biomass (g)	Ear No. plant^{-1}	Ear mass plant^{-1} (g)	Ear length (mm)	Kernel rows ear^{-1}	Kernel No. row^{-1}	Harvest Index (HI)	100 grain mass (g)	Yield (kg ha^{-1})
GQ1	579a	0.95a	207a	167.90a	7.60a	17.8a	0.36b	46.11a	5.52a
GQ2	407a	1.04a	214a	181.80a	10.10a	23.7a	0.53ab	46.38a	5.70a
SC701	374a	1.11a	172a	202.60a	9.64a	21.8a	0.46ab	46.24a	4.59a
PAN53	411a	1.05a	261a	184.50a	11.72a	24.2a	0.64a	43.47a	6.96a
LSD (P=0.05)	157.7	0.1339	73.70	30.6	4.234	10.07	0.137	14.24	1.946
F pr.	0.063	0.120	0.125	0.734	0.246	0.500	0.008	0.960	0.125
S.E.D	69.7	0.0592	32.60	13.29	1.872	4.45	0.061	6.29	0.868
%cv	22.5	7.3	21.0	12.7	5.1	7.7	18.0	15	21.7

Note that values sharing the same letter within the same column are statistically similar at LSD (P=0.05). Means were sorted in descending order. Mean values were rounded off to two decimal places

For Swayimani, there were no significant differences ($P > 0.05$) among varieties for either kernel rows per ear or kernel number per row (Table 6.4). These results were consistent with those observed at Ukulinga. On average, hybrids PAN53 (11.72) and SC701 (9.64) had more kernel rows per ear compared with GQ2 (10.10) and GQ1 (7.60), although GQ2 had more kernel rows per ear than PAN53. This trend was similar to that of kernel number per row where PAN53 (24.2) and SC701 (21.8) had, on average, more kernel number per row than GQ2 (23.7) and GQ1 (17.8).

At Ukulinga, results from 100 grain mass (GM) showed that there was no significant interaction ($P > 0.05$) between water regimes and varieties (Table 6.3). These results were consistent with all yield components. Again, mean values of water regimes across varieties showed the irrigated water regime to have had higher 100 GM (62.8 g) than the rain-fed regime (57.9 g). On average, SC701 had the highest 100 GM (64.2 g) while PAN53 had the lowest 100 GM (54.6 g) (Table 6.3).

Results of 100 GM obtained from Swayimani also followed the same trend as Ukulinga. There were no significant differences ($P > 0.05$) among varieties (Table 6.4). The landraces had, on average, higher 100 GM (46.38 g for GQ2 and 46.11 g for GQ1) compared with SC701 (46.24 g) and PAN53 (43.47 g) (Table 6.4).

Harvest index (HI) results obtained at Ukulinga showed no significant interaction ($P > 0.05$) between water regimes and varieties (Table 6.3). There were also no significant differences ($P > 0.05$) between water regimes or varieties. Mean values of water regimes across varieties showed very little differences in between the irrigated (0.269) and the rain-fed (0.231) conditions. SC701 had the highest HI (0.302), followed by GQ2 (0.290), GQ1 (0.216) and PAN53 (0.191) (Table 6.3).

At Swayimani, results of HI showed significant differences ($P < 0.05$) among varieties (Table 6.4). The hybrids had a higher HI than the landraces. PAN53 had the highest HI value of 0.64, followed by GQ2 at 0.534. GQ1 had the lowest harvest index of 0.36 (Table 6.4).

For Ukulinga, results of yield showed no significant interaction ($P > 0.05$) between water regimes and varieties. There were also no significant differences ($P > 0.05$) between water regimes as well as varieties. Mean values of water regimes across varieties showed that plants yielded higher under irrigated than rain-fed conditions. Yield of SC701 was ≈100% that of other varieties under the irrigated conditions. Under rain-fed conditions, GQ1 had the lowest yield

(1.74 t ha^{-1}). Mean values of varieties across water regimes showed that hybrids yielded better than landraces (Table 6.3).

At Swayimani, there were no significant differences (P > 0.05) among varieties with respect to final yield. Both GQ1 and GQ2 performed better than SC701. Hybrid SC701, which had previously performed well under rain-fed conditions at Ukulinga, attained the lowest yield in this environment (4.59 t ha^{-1}). This highest yielding variety was PAN53 (6.95 t ha^{-1}) (Table 6.4).

6.3 Discussion

An understanding of the processes involved in crop growth is essential to understanding plant responses to environmental stresses. Under stress conditions it is important for the crop to achieve rapid emergence and stand establishment (Rahimi, 2013). Good stand establishment aids in the maximization of available water, particularly in arid environments (Cisse and Ejeta, 2003). For this reason it is important to have varieties with good crop establishment. Early establishment is also an important consideration in areas where low soil temperatures prevail at planting (Cisse and Ejeta, 2003). Research by Mabhaudhi (2009) showed early planting of maize to have high emergence results above 75% for all varieties, particularly landraces. That said, it must be remembered that the planting dates for maize in South Africa range from October to December (DAFF, 2008). Planting for this trial was conducted in July when temperatures were low. Optimum growth temperatures for normal plant growth and development ranges from 24°C to 30°C (Birch *et al*., 1998; Smith 2006). Average maximum temperatures for the month of July when planting was done were 21.3°C. Low daily temperatures could reduce soil temperatures, thereby reducing the emergence potential of seeds at both Ukulinga and Swayimani. Early planting has been associated with poor emergence (Mwale *et al*., 2003; Beiragi *et al*., 2011). It must be remembered that the early stages of plant growth can have an impact on performance of the crop. Legwaila *et al*. (2013) reported low performance of Bambara groundnut landraces following poor emergence and seedling establishment. This could also explain the relatively low performance of GQ1 compared with other varieties throughout the study. Good crop establishment aids rapid canopy development. Poor establishment results in sparse canopy formation which increases soil evaporation (Yunusa *et al*. 1997).

Effects of drought on plants include closure of stomata and decrease in cell enlargement and growth (Jaleel *et al*., 2009). Reduction in photosynthesis is also a major effect of water

stress (Farooq *et al*., 2009). Only under severe water stress will photosynthesis cease, causing a destruction in plant metabolism, and ultimately causing plant death (Jaleel *et al*., 2008). Water stress also causes changes in chlorophyll content (Nayyar and Gupta, 2006). Chlorophyll content has been known as an indicator of photosynthetic capacity of plant tissue (Wright *et al*., 1994). Cate and Perkins (2003) and Dwyer *et al*. (1995) concluded that CCI values were strongly correlated with chlorophyll concentration as determined by absorbance of extracted pigments. The current study showed no statistical variation between water regimes. These results are similar to findings by Schlemmer *et al*. (2005) where acute water stress did not have an impact on chlorophyll content. Research shows that the relationship between CCI and total chlorophyll must be quantified for each species (Van den Berg and Perkins, 2004) as variations may occur during growing seasons (Dwyer *et al*., 1995), at different temperatures (Dwyer *et al*., 1991) and at different physiological stages (Dwyer *et al*., 1991; Schlemmer *et al*., 2005). With regards to variety, varieties with high chlorophyll content (particularly under drought conditions) are more likely to yield better (Hassanzadeh *et al*., 2009). At both Ukulinga and Swayimani, hybrid PAN53 had the highest CCI value possibly indicating its potential as a high yielding variety. However, it must be reiterated that CCI varies with physiological growth stage (Dwyer *et al*., 1991).

Under field conditions, crops are usually exposed to episodes of abiotic stresses during their growth cycles which affect their productivity (Loomis and Connor, 1992). Water deficit has a negative impact on the quality and quantity of plant growth. At the whole plant level, the effect of drought is usually observed as a decrease in plant growth and development (Zlatev and Ledon, 2012). Results obtained showed reduced plant height and leaf number in plants where there was no irrigation. These findings are consistent with those of Dunford and Vasquez (2005), Khoshvaghti *et al*. (2013) and Pandey *et al*. (2000), where plants receiving more water were taller than those receiving less water. These finding are also consistent with the controlled environment experiment where the plants under the 80% ETc water treatment were taller. Reduced plant height and leaf number under water limited conditions is a strategy to reduce leaf transpiration and thus improve water use efficiency of the plant. Both SC701 and PAN53 benefited from hybrid vigour as they had the tallest varieties at Ukulinga. Plant growth and development at Swayimani was restricted due to low temperatures throughout the growing period. According to Smith (2006) and Birch *et al*. (1998), the optimum growth temperatures for normal plant growth and development ranges from 24°C to 30°C. Maximum temperatures at Swayimani rarely exceeded 25°C throughout the growing period of the crop. This resulted in

stunted plant growth throughout the experiment. An increase in temperatures in December did, however, promote plant growth (Figure 6.1b).

Plants respond to water stress through decreased cell division and elongation (Serrano *et al*., 1999). However, under favourable conditions, plants with a high leaf area have a greater rate of photosynthesis, and thus, higher growth rate (Zlatev and Ledon, 2012). The formation of a good canopy will aid in the reduction of soil evaporation (Yunusa *et al*., 1997) while maximising transpiration and thus improve crop water use (Mabhaudhi *et al*., 2013). Minor differences in leaf number between water regimes and among varieties in both locations points to the possible fact that water treatment has no effect on leaf number, as observed by Hajibabaee *et al*. (2012) and Akkas-Ali *et al*. (1999). That said, it must be remembered that plants with low leaf area but a high photosynthetic rate may assimilate as much as those with a high leaf area but low photosynthetic rate. Therefore, leaf size can be compensated by a high photosynthetic rate in plants.

The magnitude of plant responses to environmental stresses can be analysed in terms of the physiological determinants of grain yield (Juan *et al*., 2012). Maize is highly sensitive to water stress and visible symptoms of water stress include reduction in growth, delayed maturity, reduced biomass and reduced crop grain yield (Farre and Faci, 2009). Results of phenology showed statistical differences between water treatments. In maize, water stress has been shown to affect yield through delayed silking, which thus increases the anthesis to silking interval (Cattivelli *et al*., 2008). This explains the higher ASI observed under rain-fed conditions in the current study. Observations of differences between varieties showed that landraces generally tassel earlier than hybrids. Ngugi *et al*. (2013) observed open pollinated varieties to flower earlier and to have a longer ASI. This is consistent with results obtained in the study. Research by Crauford and Peackock (1993) showed delayed flower initiation due to water stress in *Pennisetum* and *Sorghum*. It was also observed by Bolanos and Edmeases (1996) showed that short ASI is associated with drought tolerance. From the results of the experiment, it can therefore be said that landraces appear to be relatively more drought tolerant than the hybrids.

The most sensitive stage to water stress in maize is the reproductive stage, particularly flowering (Ali and Talukder, 2008). Stress during this stage causes marked decrease in grain yield (Caki, 2004). Results of yield and yield components from the current study showed that there were no differences across all yield components at both locations (with the exception of HI results at Swayimani). This contradicts findings by Jama and Otterman (1993) who concluded that grain yield and kernel number were highest under well watered conditions. In

this study, the irrigated and rain-fed water regimes differed only slightly. This could indicate that landraces compensate through increased rates of photosynthesis. According to Zlatev and Ledon (2012), a plant with low leaf area but a high rate of photosynthesis may assimilate as much as a plant with a high leaf area but low rate of photosynthesis. Results of CCI show both GQ1 and GQ2 to have, on average, values as high as the hybrids, thereby potentially indicating the ability of landraces to accumulate biomass as well as the hybrids under drought stress conditions. Landraces are known to produce low stable yields under unstable environmental conditions (McCouch, 2004). This is well indicated by yields of GQ2 and GQ1. Yields increase slightly in a low input system (Swayimani) from yields under irrigated conditions. However, it must be remembered that poor performance of GQ1 under rain-fed conditions at Ukulinga could be due to poor emergence and establishment in the field (Legwaila *et al*., 2013).

Seed quality plays a role in determining the field performance of a variety. GQ1 had low emergence and ultimately low yields under both optimum field conditions and a low input sub-optimum farming system. Growth and development was slower for landraces compared to hybrids. The advantages of hybrids under optimum irrigated conditions can be attributed to hybrid vigour. This is also observed at Swayimani where PAN53 had higher yields than the landraces. Under sub-optimum low input conditions, both GQ2 and GQ1 performed well. It can therefore be concluded that the dominance of hybrids is clearer under optimum than sub-optimum conditions, as SC701 failed to perform as well under sub-optimum conditions. On the other hand, under sub-optimum conditions, landraces have the potential to perform as well as hybrids as observed in Swayimani. It is important to consider the quality of the seed through seed testing before planting the landrace as high germinating landraces do have the potential to perform at par with hybrids. Strategies of improving seed emergence and establishment of landraces will aid in better crop performance and will contribute to increased return on the crop. Such strategies could include seed priming techniques and seed sterilization before planting.

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSION

7.1 Introduction

Maize is the main staple food in South Africa (DAFF, 2012) and is of particular importance to people residing in rural areas whose diets are predominantly starch-based. Increased pressure on resources, coupled with increasing population growth, shifts the focus of agriculture to the provision of food security for this growing population. Drought has been identified as the single most critical threat to food security (Farooq *et al*., 2009). Increase in the severity and frequency of drought (Schulze, 2011) calls for innovative techniques to be adapted into farming so as to improve the water use efficiency of crops. Local farmers in South Africa still cultivate local maize landraces as a source of staple food. These landraces are mainly cultivated under rainfed conditions. Although they are reported to be well–adapted to harsh environmental conditions, yields are relatively low (Manzanilla *et al*., 2011; Modi and Mabhaudhi, 2013). An understanding of the water use characteristics of these landraces could aid in identifying them for future crop improvement. In order to do this, this study took an approach that initially evaluated seed quality of the landraces before conducting controlled and field experiments.

7.2 Aims and objectives

The aim of the study was to compare the water use characteristics of two maize landrace varieties with two popular high yielding commercial hybrids (SC701 and PAN53). Specific objectives were:

i. to compare seed quality of maize landraces and maize hybrids in terms of viability (germination, imbibition, tetrazolium test) and vigour (electrical conductivity, seedling root to shoot ratio),
ii. to determine effect of water stress imposed using varying water regimes under controlled environmental conditions on growth and development of maize landraces and maize hybrids,
iii. to compare the maize landraces and maize hybrids with respect to field emergence and early establishment performance under dry conditions (off-season),

iv. to evaluate plant physiology (protein and proline) of maize landraces and hybrids under controlled environment conditions in response to varying water regimes at various locations

7.3 Challenges

The following challenges occurred during the study;

- Wild attacks by animals resulted in the termination of a first trial at Ukulinga research farm. In the same site, animal attacks were experienced toward maize maturity. However, these did not affect the plants severely.
- Growth of plants in Swayimani was slow due to low temperatures. Plants were stunted and height increments were only observed when temperatures increased after a period of four months.
- Poor weeding of trials prevented potentially beneficial data (LAI) from being collected as part of the data collection plan.

7.4 Future teaching, learning and research possibilities

The following recommendations may be made, based on observations made during the study;

- Leaf area measurements may prove to be vital in grasping a better understanding in the relationship between plant growth and photosynthesis. These measurements may also be useful for crop modelling.
- Crop modelling is becoming a useful tool to determine the performance of agricultural systems through input of variables collected throughout the experiment. It would also be a beneficial tool in aiding decision making. Developing a crop model for maize landraces will help determine the usefulness of landraces in contributing to food security under a range of environments suitable for rain-fed farming.
- Extension officers should be encouraged to obtain seed from farmers who cultivate landraces and submit it for seed quality testing. Better selection of material to be used for seed in the next season should also be provided to farmers. The use of good quality seeds may result in improved yields for farmers who still cultivate these landraces.
- The issue of seed quality is key to turning around the performance of landraces. Therefore, a study evaluating seed systems of these landrace should be initiated. Such a

study could even be used as a future case study for similar interventions on other underutilised, indigenous and traditional crops that are still cultivated using landraces

- The practice of sound agronomic practices such as planting date selection will allow for better performance in terms of yield. In this regard, the development of crop models to advise farmers on suitable planting dates will prove useful.

7.5 Final comments and summary conclusions

Seed quality has been identified as one of the most important factors determining crop performance (Santos, 2010), particularly under field conditions. Poor seed quality will affect the ability of the seed to germinate under normal conditions, thus having a deleterious effect on final yield (Mabhaudhi and Modi, 2011). In the initial study (Chapter 4) we evaluated the seed quality of the landraces and compared it with that of commercial hybrids. Results of seed quality tests conducted showed that hybrids have an advantage over landraces due to hybrid vigour. The study also revealed that landraces have the potential to perform at par with hybrids. However, it cannot be assumed that all landraces that perform well during viability testing will have good vigour and will perform well under field conditions. According to Van der Venter (2000), vigour testing can give an indicator of those seed lots that may not perform well under sub-optimum conditions despite good germination results. This is of particular importance as most landraces are cultivated under sub-optimum conditions. GQ1, possibly due to genetic variability, performed poorly during vigour testing, having high electrical conductivity and a high mean germination time. Consequently, GQ1 performed poorly under field conditions. Total emergence for this variety at both Ukulinga and Swayimani was low and this affected the overall yield of the variety. The interaction between seed quality and water stress was then evaluated under controlled environment conditions. Studies on the effect of water stress on plant growth, photosynthesis and yield components revealed that water stress does play an important role in determining the overall performance of a seed lot and its water use characteristics.

The early stages of plant growth (seed germination, seedling emergence and establishment) are particularly sensitive to water stress (Hadas, 2004), as a maize plant is susceptible to water stress during different stages of crop growth. The vegetative stage of maize plant growth has been observed to be less sensitive than the reproductive stage. However, water stress during this stage has been known to cause a reduction in plant growth, leaf area and reduced photosynthesis (Mabhaudhi, 2009). Chapter 5 results showed that plants subjected to terminal stress were shorter than those subjected to moderate and no stress. There were, however, no

differences in terms of leaf number. This result is in line with research by Hajibabaee *et al*. (2012) that showed no reduction in leaf number due to environmental stress, and therefore irrigation would not affect leaf number. Research has shown severe water stress not to have an impact on chlorophyll content, as observed by Schlemmer *et al*. (2005). The terminally stressed water treatment had the highest CCI, although differences between varieties were minimal. Water stress did, however, affect time to tasselling between the different water regimes. Terminally stressed plants tasselled faster than plants in the controlled water treatment. This could be defined as a drought tolerance strategy where plants mature earlier due to water stress. Although growth and development of the landraces were slower compared to the hybrids, results on HI show that the landraces had higher HI than the hybrids. According to Zlatev and Ledon (2012), plants with a high photosynthetic rate but smaller leaf area are capable of assimilating as much biomass as plants with a high leaf area but low photosynthetic rate. Results on CCI show that landraces had higher CCI than hybrids, thereby potentially contributing to higher harvest index values.

Although controlled environment conditions are ideal for determining the effect of water stress on growth, photosynthesis and yield parameters, extrapolation of such results to field performance is often difficult. Under field conditions plants are exposed to environmental stresses which alter the expression of genetic potential (G x E interactions). Landraces in South Africa are mostly cultivated under sub-optimum environmental conditions where rainfall is low and erratic (Modi and Mabhaudhi, 2013). Thus, an experiment was conducted to determine the growth, photosynthesis, yield and yield components of maize landraces compared to hybrids under field conditions (Chapter 6). Planting time played a significant role in the final emergence of plants as temperatures were too low. Maize requires temperatures between 24°C and 30°C (Birch *et al*., 1998; Smith 2006) for normal growth to occur. Temperatures at both locations were below 22°C at the time of planting, thereby influencing seed germination and ultimately seedling emergence. Good crop establishment is important under field conditions as it allows for quicker canopy development, which reduces loss of water from the soil surface (Mabhaudhi and Modi, 2013). Therefore hybrids would be at an advantage having higher emergence rates. Growth of plants at Ukulinga, following the imposition of an irrigation treatment *viz.* a rain-fed treatment, showed a similar trend to that of the controlled environment experiment where hybrids were taller than landraces. Poor crop emergence could contribute to reduced plant height for landraces. Again water stress did not have an effect on leaf number. Landraces are considered to be relatively drought tolerant. The ability to maintain leaf number under both irrigated and rain-fed conditions points to a well–developed canopy which could be a

mechanism to reduce water loss from the soil. This suggests that landraces may have water use characteristics that allow for efficient use of water (Blum, 2012).

The reproductive stage of maize plants has been deemed as the most sensitive to water stress (Cakir, 2004; Farre and Faci, 2009; NeSmith and Ritchie, 1992; Jama and Ottman, 1993). Observations of plant phenology showed the irrigated water regime to tassel and produce silks faster, thereby reducing the ASI. Water stress has been observed to cause delayed silking in maize plants and therefore a higher ASI (Cattivelli *et al*., 2008). Research shows that early maturing varieties have shorter anthesis-silking intervals than late maturing varieties, and landraces have previously been reported to be late maturing (Mabhaudhi, 2009). Water stress during flowering affects ear development. This is evident as rain-fed plants had fewer ears per plant and less ear mass per plant than irrigated plants. Water stress during the reproductive phase can be observed to cause incomplete kernel set, as seen by reduced kernel rows per ear and kernel number per row for plants under rain-fed conditions for both Ukulinga and Swayimani. The performance of GQ2 under rain-fed conditions showed that landraces, with reasonably good seed quality, do have the ability to perform as well as hybrids under optimum and sub-optimum conditions. This was evident at both Ukulinga and Swayimani with stable production of yields. The landrace GQ1, having poor seed quality, did not perform as well under sub-optimum conditions at Ukulinga. Under low input conditions at Swayimani performance of landraces improved but remained relatively the same for hybrids, indicating that landraces were well adapted to sub-optimum conditions.

In conclusion, seed quality is an important component in determining the overall performance of landraces under both controlled environment and field conditions. Based on this study it can be concluded that when landraces are of good seed quality, as was the case with GQ2, they may perform at par with hybrids. Under field conditions, poor seed quality negatively affects crop establishment and water use characteristics and ultimately reduces overall yield. Therefore, the issue of providing high quality seed remains key to successful crop production and strategies to improve seed quality of landraces should be explored. Final yield and yield components showed GQ2 to perform at par with hybrids SC701 and PAN53.. The good performance of landraces under rain-fed conditions can be attributed to a smaller canopy size and ability to maintain high levels of chlorophyll content. This suggests presence of drought avoidance mechanism in landraces. This implies that landraces may be suitable for cultivation under sub-optimum low input systems where these advantages enable them to produce stable yields.

REFERENCES

ACHAKZAI, A.K.K. (2009). Effect of water stress on imbibition, germination and seedling growth of maize cultivars. Sarhad J. Agric. 25(2): 165-172.

AKINCI, S. & LÖSEL, D. M. (2012). Plant water-stress response mechanisms. In I. Md. M. Rahman, & H. Hasegawa (Eds.), Water Stress (pp. 15-42). Rijeka, Croatia. In Tech.

AKKAS ALI, M., GOLAM SARWAR, A.K.M. & AZAD-UDUDOULA PRODHAN, A.K.M. (1999). Effect of water stress on the growth features of different maize (Zea mays L.) cultivars. Pak. J. Bot. 31(2): 455-460.

AL-GHZAWI, A.A., ZAITOUN. S., GOSHEH, H.Z. & ALQUDAH, A.M. (2009). The impacts of drought stress on bee attractively and flower pollination of *Trigonella moabitica* (fabaceae). Arch. Agron. Soil Sci. 55(6): 683–692.

ALI, M.H. & TALUKDER, M.S.U. (2008). Increasing water productivity in crop production – A synthesis. Agric. Water Manage. 95: 1201-1213.

ANJUM, S.A., XIE, X., WANG, L., SALEEM, M.F., MA, C.& LEI, W. (2011). Morphological, physiological and biochemical responses of plants to drought stress. Afr. J. Agric. Res. 6(9): 2026-2032.

AOSA (1983). Seed vigor testing handbook. Contribution no. 32 to the handbook on seed testing. Association of Official Seed Analysts. USA.

AOSA. (1992). Association of Official Seed Analysts: Seed Evaluation Handbook. Contribution No.35.

APOGEE INSTRUMENTS INCORPORATED, 2014. http://www.apogeeinstruments.com/content/CCM_webmanual.pdf (accessed 10/01/2014)

ARNON, I. (1972). Economic Importance of Maize. Crop production in dry regions. Leonard Hill London. 2: 146-156.

AZAIZEH, H. & STEUDLE, E. (1991). Effects of salinity on water transport of excised maize (*Zea mays* L.) roots. J. Plant Physiol. 97: 1136-1145.

BÄNZIGER, M., DE MEYER, J., MWALA, M.S., PHIRI, M.A.R., VIVEK, B. &. PIXLEY, K.V. (2002). Progress in delivering stress tolerant maize varieties to farmers in southern Africa. p. 67–71. *In* J. DeVries et al. (ed.) Biotechnology, breeding and crop systems for African crops:

Research and product development that reaches farmers: Proc. of an Int. Workshop, Los Baños, Philippines.

BARCELO´, J. & POSCHENRIEDER, C. (2002). Fast root growth responses, root exudates, and internal detoxification as clues to the mechanisms of aluminium toxicity and resistance: a review. Environ. Exp. Bot. 48: 75–92.

BARNABÁS, B., JÄGER, K. & FEHÉR, A. (2008).The effect of drought and heat stress on reproductive processes in cereals. Plant. Cell. Environ. 31: 11–38.

BARROS, V. (2007). Adaptation to Climate Trends: Lessons From the Argentine Experience. In: *Climate change and Adaptation.* [Leary, N., J. Adejuwon, V. Barros, I. Burton, J. Kulkarm, and R. Lasco(eds.)]. Earthscan, London, UK.

BASRA, A.S. (2000). Crop responses and adaptations to temperature stress. Food Products Press, New York, USA.

BATES, L.S., WALDREN, R.P. & TEARI, D. (1973). Rapid determination of free proline for water stress studies. Plant Soil 39: 205-207.

BEADLE, G. (1939). Teosinte and the origins of Maize. J. Here. 30: 245-247.

BEIRAGI, M.A., KHORASANI, S.K., SHOJAEI, S.H., DADRESAN, M., MOSTAFAVI, K. & GOLBASHY, M. (2011). A Study on Effects of Planting Dates on Growth and Yield of 18 Corn Hybrids (*Zea mays* L.).Am. J. Exp. Agric. 1(3): 110-120.

BELFIELD, S. & BROWN, C. (2008). Field crop manual: maize. A guide to upland production in Cambodia NSW Department of Primary Industries. Cambodia.

BERT, P.F., JOUAN, I., TOURVIEILLE DE LABROUHE, I., SERRE, F., PHILIPPON, J., NICOLAS, P. & F. VEAR. (2003). Comparative genetic analysis of quantitative traits in sunflower (*Helianthus annus* L.). 2. Characterization of QTL involved in developmental and agronomic traits. Theor. Appl. Genet. 107: 181-189.

BIRCH, C.J., HAMMER, G.L. & RICKERT, K.G. (1998).Temperature and photoperiod sensitivity of development in five cultivars of maize (*Zea mays* L.) from emergence to tassel initiation. Field Crop Res. 55: 93 - 107.

BIRD, I. F., CORNELIUS, M. J. & KEYS, A. J. (1977). Effects of temperature on photosynthesis by maize and wheat. J. Exp. Bot. 28: 519-24.

BOLAÑOS, J. & EDMEADES, G.O. (1996). The importance of the anthesis-silking interval in breeding for drought tolerance in tropical maize. Field Crop Res. 48: 65–80.

BOTSWANA AGRICLUTURAL MARKETING BOARD (2013).www.bamb.co.bw (accessed 24/06/2013).

BOYER, J.S. (1982). Plant productivity and environmental potential for increasing crop plant productivity, genotypic selection. Science 218: 443-448.

BRADBEER, J.W. (1988). Seed dormancy and germination: seed viability and vigour. Pp95-109.Springer, USA.

BRADFORD, M.M. (1976) A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein dye binding. Anal. Biochem. 72: 248-254.

ÇAKIR, R. (2004). Effect of water stress at different development stages on vegetative and reproductive growth of corn. Field Crop Res. 89: 1-16.

CAMP, P. J., HUBER, S.C., BURKE, J. J. & MORELAND, D. E. (1982). Biochemical changes that occur during senescence of wheat leaves. I. Basis for the reduction of photosynthesis. Plant Physiol. 70: 1641-164.

CASTIGLIONI, P., WARNER, D., BENSEN, R.J., ANSTROM, D.C., HARRISON, J., STOECKER, M., ABAD, M., KUMAR, G., SALVADOR, S., D'ORDINE, R., NAVARRO, S., BACK, S., FERNANDES, M., DASGUPTA, J.T.S., BONIN, C., LUETHY, M.H. & HEARD, J.E. (2008). Bacterial RNA Chaperones Confer Abiotic Stress Tolerance in Plants and Improved Grain Yield in Maize under Water-Limited Conditions. Plant Physiol. 147: 446–455.

CATE, T.M. & PERKINS, T.D. (2003).Chlorophyll content monitoring in sugar maple (*Acer saccharum*). Tree Physiol.23: 1077–1079.

CATTIVELLI, L., RIZZA, F., BADECK, F.W., MAZZUCOTELLI, E.., MASTRANGELO, A.N., FRANCIA, E., MARÈ, C., TONDELLI, A. & STANCA, A.M. (2008). Drought tolerance improvement in crop plants: An integrated view from breeding to genomics. Field Crop Res. 105: 1-14.

CHANG, J. (1981). Corn yield in relation to photoperiod, night temperature, and solar radiation. Agric. Met. 89: 253-262.

CHAVES, M.M. (1991). Effect of water deficit on carbon assimilation. J. Exp. Biol. 42: 1-6.

CHAVES, M.M., PEREIRA, J.S., MAROCO, J., RODRIGUES, M.L., RICARDO, C.P.P., OSORIO, M.L., CARVALHO, I., FARIA, T. & PINHEIRO, C. (2002). How plants cope with water stress in the field. Photosynthesis and growth. Ann. Bot-London. 89: 907-916.

CHAVES, M.M., MAROCO, J.P. & PERIERA, S. (2003). Understanding plant responses to drought from genes to the whole plant. Funct. Plant Biol. 30: 239–64.

CHAVES, M. M., FLEXAS, J. & PINHEIRO, C. (2009). Photosynthesis under drought and salt stress: regulation mechanisms from whole plant to cell. Ann. Bot-London. 103: 551–560.

CHIMONYO, V.G.P. (2012). An evaluation of stress tolerant open pollinated varieties of maize in selected environments in the Eastern Cape Province, South Africa. M.Sc. Thesis, University of Fort Hare, Alice, South Africa.

CISSE, N.D. & EJETA, G. (2003). Genetic variation and relationships among seedling vigor traits in sorghum. Crop Sci. 43: 824–828.

COFFMAN, W.R. (1998). The Future of Public Plant Breeding. 53rd Ann. Corn & Sorghum Res Conf. American Seed Trade Association, Washington, DC.

COMINELLI, E., GALBIATI, M. & TONELLI, C. (2008).Integration of water stress response: Cell expansion and cuticle deposition in Arabidopsis, Thaliana. Plant Signal. Behav. 3: 556-557.

COOPER, M., GHO, C., LEAFGREN, R., TANG, T. & MESSINA, C. (2014). Breeding drought-tolerant maize hybrids for the US corn-belt: discovery to product. J. Exp. Bot. (Advance Access)

CORNIC, C. & MASSACCI, A. (1996). Leaf photosynthesis under drought stress. In: Photosynthesis and Environment. Ed. Baker, N.R.. Kluwer Acad. Publs, 347–366.

CORRAL, J., DURA´N PUGA, N., SA´NCHEZ GONZA´ LEZ, J., RON PARRA, J., GONZA´ LEZ EGUIARTE, D., HOLLAND, J., MEDINA GARCI ´ A. G. (2008). Climatic adaptation and ecological descriptors of 42 Mexican maize races. Crop Sci. 48: 1502‑1512.

CRAUFORD, P.Q. &PEACOCK, J.M. (1993). Effect of heat and drought stress on sorghum (*Sorghum bicolor*) II Grain yield. Exp. Agric. 29: 77-86.

CRAUFURD, P.Q. & WHEELER, T.R. (1999). Effect of drought and plant density on radiation interception, radiation-use efficiency and partitioning of dry matter to seeds in cowpea. Expl Agric. 35: 309-325.

DELAUNEY, A.J. & VERMA, D.P.S. (1993).Proline biosynthesis and osmoregulation in plants. Plant J. 4: 215-223.

DEMIR, I., ERMIS, S., MAVI, K. & MATTHEWS, S. (2008). Mean germination time of pepper seed lots (*Capsicum annuum* L.) predicts size and uniformity of seedlings in germination tests & transport modules. Seed Sci. Technol. 36: 21-30.

DEPARTMENT OF AGRICULTURE, FOOD AND THE MARINE (2013) The Tetrazolium test.

http://www.agriculture.gov.ie/animalhealthwelfare/laboratoryservices/seedtestinglaboratory/tetrazoliumtest/ (accessed 25/10/2013)

DEPARTMENT OF AGRICULTURE. (2003). Maize Production. Nat. Dept. Agric., Private Bag X144, Pretoria, South Africa.

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES (DAFF). (2008). Maize. Pretoria, South Africa.

www.daff.gov.za/docs/Brochures/brochureMaize.pdf (accessed 21/07/2013)

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES (DAFF). (2011). Trends in the agricultural sector. Pretoria, South Africa.

http://www.nda.agric.za/docs/statsinfo/Trends2011.pdf (accessed 12/04/2013)

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES (DAFF). (2012). South African variety list as maintained by the registrar of plant improvement. Pretoria, South Africa.

http://www.daff.gov.za/docs/GenPub/VARIETYseed_032012.pdf (27/05/2013)

DOEBLEY, J. (2004). The genetics of maize evolution. Annu. Rev. Genet. 38: 37–59.

DULAI S., MOLNÁR I., PRÓNAY J., CSERNÁK Á., TARNAI R. & MOLNÁR-LÁNG M. (2006). Effects of drought on photosynthetic parameters and heat stability of PSII in wheat and in *Aegilops* species originating from dry habitats. Acta Biologica Szegediensis 50(1-2): 11-17.

DUNFORD, N.T. & VAZQUEZ, R.S. (2005). Effect of water stress on plant growth and thymol and carvacrol concentrations in Mexican oregano grown under controlled conditions. J. Appl. Hort. 7(1): 20-22.

DU PLESSIS, J. (2003). Maize production. Department of Agriculture, South Africa. Pretoria www.nda.agric.za/publications (21/07/2013)

DWAF. (2006). Implementation guidelines for water conservation and water demand management in agriculture.

http://www.dwaf.gov.za/WaterConservation/Doc_GA.htm (27/05/2013)

DWYER, L.M., TOLLENAAR, M. & HOUWING, L. (1991). A Non-destructive Method to Monitor Leaf Greenness in Corn. Can. J. Plant Sci. 71: 505–509.

DWYER, L.M., ANDERSON, A.M., MA, B.L., STEWART, D.W., TOLLENAR, M., & GREGORICH, E. (1995). Quantifying the nonlinearity in chlorophyll content meter response to corn leaf nitrogen concentration. Can. J. Plant Sci. 75: 179–182.

EARL, H. & DAVIS, R.F. (2003). Effect of drought stress on leaf and whole canopy radiation use efficiency and yield of maize. Agron. J. 95: 688–696.

FARRE, I. & FACI, J.M. (2009). Deficit irrigation in maize for reducing agricultural water use in a Mediterranean environment. Agric. Water Manage. 96: 383-394.

FAROOQ, M., WAHID, A., KOBAYASHI, N., FUJITA, D. & BASRA, S.M.A. (2009). Plant drought stress: effects, mechanisms and management. Agron. Sust. Develop. 29: 185-212.

FAROOQ, M., HUSSAIN, M., WAHID, A. & SIDDIQUE, K. H. M. (2012). Chapter 1: Drought Stress in Plants: An Overview. Plant responses to drought stress: from morphological to molecular features. Aroca, R. (Ed). Springer.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO). (2006). Quality declared seed system. FAO Plant Production and Protection Paper 185. Rome, Italy.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO). (2010). Seeds in emergencies: a technical handbook. FAO Plant Production and Protection Paper 202. Rome, Italy.

GARCÍA, J.B. (2007). Maize adoption and biodiversity conservation in Mexico. Micro Evidence on Innovation in Developing Economies (MEIDE) conference. UNU-MERIT. Maastricht, Netherlands.

GHASSEMI–GOLEZANI, K. (1992). Effects of seed quality on cereal yields. PhD Thesis, University of Reading, UK, pp 205-222.

GICHANGI, E.M. (2007). Enhancing phosphorus availability in some phosphate fixing soils of the Transkei region, South Africa using goat manure. PhD thesis, University of Fort Hare, Alice, South Africa.

GILL, R.K., SHARMA, A.D., SINGH, P. & BHULLAR, S.S. (2002). Osmotic stress induced changes in germination, growth and soluble sugar content of *Sorghum bicolor* (L.) Moench seeds. Bulg. J. Plant. Physiol. 28: 12-25.

GOGGI, A.S., CARAGEA, P., POLLAK, L., MCANDREWS, G., DEVRIES, M. & MONTGOMERY, K. (2008). Seed Quality Assurance in Maize Breeding Programs: Tests to Explain Variations in Maize Inbreds and Populations. Agron. J. 100: 337‑343.

GREAVES, J. A. (1996). Improving sub optimal temperature tolerance in maize—the search for variation. J. Exp. Bot. 47: 307–323.

GROBMAN, A. SALHAUNA, W. SEVILLA, R. & MANDELSDORF, P. (1961). Races of maize in Peru. Publication 915 National Academy of Science, National Research Council Washington D. C.

HADAS, A. (2004). Seedbed preparation: the soil physical environment of germinating seeds. In: handbook of seed physiology: applications to agriculture, Benech-Arnold RL and Sanchez RA (Eds.). Food Product Press, New York, USA.

HAJIBABAEE, M., AZIZI, F. & ZARGARI, K. (2012). Effect of drought stress on some morphological, physiological and agronomic traits in various foliage corn hybrids. American-Eurasian J. Agric. & Environ. Sci. 12(7): 890-896.

HAMPTON, J.G. & TEKRONY, D.M. (1995). Handbook of vigour test methods. International Seed Testing Association, Zurich, Switzerland.

HARE, P.D. & CRESS, W.A. (1997). Metabolic implications of stress-induced proline accumulation in plants. Plant Growth Regul. 21: 79–102.

HASSANZADEH, M., EBADI, A., PANAHYAN-E-KAVI, M., ESHGHI, A.G., JAMAATI-E-SOMARIN, SH., SAEDI, M. & ZABIHI-E-MAHMOODABAD, R. (2009). Evaluation of drought stress on relative water content and chlorophyll content of Sesame (*Sesamum indicum* L.) genotypes at early flowering stage. Res. J. Environ. Sci. 3(3): 345-350.

HERRERO, M.P. & JOHNSON, R.R. (1980). High temperature stress and pollen viability of maize. Crop. Sci. 20: 796-800.

HUANG, R., GEORGE, D.L. & BIRCH, C.J. (2006). The agricultural water supply challenge - the need for improved water use efficiency. Maize Association of Australia.6th triennial conference.

INTERNATIONAL INSTITUTE OF TROPICAL AGRICULTURE (IITA). (2009). Maize. Oyo State, Nigeria.http://www.iita.org/maize (accessed 14/07/2013)

INTERNATIONAL SEED TESTING ASSOCIATION (ISTA). (1985). International rules for seed testing. Rules 1985. Seed Sci. Technol. 13:356- 513.

INTERNATIONAL SEED TESTING ASSOCIATION (ISTA). (2006). International Rules for Seed Testing. Zurich, Switzerland.

ISLAM, A.K.M.S., EDWARDS, D.G. & ASHER, C.J. (1980). pH optima for crop growth: results of a flowing solution culture experiment with six species. Plant Soil. 54: 339-357.

JALEEL, C.A., MANIVANNAN, P., LAKSHMANAN, G.M.A., GOMATHINAYAGAM. M. & PANNEERSELVAM, R. (2008). Alterations in morphological parameters and photosynthetic pigment responses of *Catharanthus roseus* under soil water deficits. Colloids Surf. B: Biointerfaces. 61: 298–303.

JALEEL, C.A., MANIVANNAN, P., WAHID, A., FAROOQ, M., AL-JUBURI, H.J., SOMASUNDARAM, R. & PANNEERSELVAM, R. (2009). Drought Stress in Plants: A Review on Morphological Characteristics and Pigments Composition. Int. J. Agric. Biol. 11: 100-105.

JAMA, A.O. & OTTMAN, M.J. (1993). Timing of the first irrigation in corn and water stress conditioning. Agron. J. 85: 1159-1164.

JUAN, I., EDREIRA R. & OTEGUI, M.E. (2012). Heat stress in temperate and tropical maize hybrids: Differences in crop growth, biomass partitioning and reserves use. Field Crop Res.130: 87‑98.

KARUNARATNE, A.S., AZAM-ALI, S.N., IZZI, G. & STEDUTO, P. (2011). Calibration and validation of AquaCrop model for irrigated and water deficient bambara groundnut. Exp. Agric. 47: 509-527.

KAVAS, M., BALOĞLU, M.C., AKÇA, O., KÖSE, F.S. & GÖKÇAY, D. (2013). Effect of drought stress on oxidative damage and antioxidant enzyme activity in melon seedlings. Turk J Biol. 37: 491-498.

KANELLIS, A.K. & KALAITZIS, P. (1992). Cellulase Occurs in Multiple Active Forms in Ripe Avocado Fruit Mesocarp. Plant Physiol. 98(2): 530–534.

KHODARAHMPOUR, Z. (2011). Effect of drought stress induced by polyethylene glycol (PEG) on germination indices in corn (*Zea mays L.*) hybrids. Afr. J. Biotechnol. 10 (79): 18222-18227.

KHOSHVAGHTI, H., ESKANDARI-KORDLAR, M. & LOTFI, R. (2013). Responses of morphological characteristic and grain yield of maize cultivars to water stress at reproductive stage. J. Bio. & Env. Sci. 3: 20-24.

KURDIKERI, M.B., ASWATHAIAH, B. & RAJENDRA PRASAD, S. (1996). Seed invigouration studies in maize hybrids. Seed Res. 21: 18-12.

LEA, J. D. (1991).Maize production in KwaZulu: a handbook for extension officers and farmers. Institute of Natural Resources, University of Natal, South Africa.

LEAKEY, A.D.B, URIBELARREA, M., AINSWORTH, E.A., NAIDU, S.L., ROGERS, A., ORT, D.R. & LONG, S.P. (2006). Photosynthesis, productivity, and yield of maize are not affected by open-air elevation of CO_2 concentration in the absence of drought. Plant Physiol. 140: 779–790.

LEE, T.D. (1988). Patterns of fruit and seed production. In: Lovett DJ, Lovett DL (eds) Plant Reproductive ecology, patterns and strategies. Oxford University Press, New York, USA, pp 179–202.

LEGWAILA, G.M., KARIKARI, S.K., MOGAMISI, K. & MATHOWA, T. (2013). Response of three Bambara groundnut landraces to pre-sowing hydration in Botswana. Agric. Biol. J. N. Am. 4(4): 430-434.

LEVITT, J. (1980). Responses of Plants to Environmental Stresses. Vol 2.Water, Radiation, Salt and other Stresses. Academic Press, New York, USA.

LININGTON, S., MKHONTA, D., PRITCHARD, H.W. & TERRY, J. (1996). A provisional germination testing scheme for seed of the *Compositae*, pp. 223–235, volume 2. In: P.D.S. Caligari and D.J.N. Hind (eds). *Compositae: biology & utilisation. Proceedings of the international* Compositae *conference, Kew, 1994.*Royal Botanic Gardens, Kew, UK.

LOOMIS R.S. & CONNOR, D.J. (1992). Crop Ecology: productivity and management in agricultural systems, Cambridge University Press.

LOVATO, A. & BALBONI, N. (1997). Seed vigour in maize (*Zea mays* L.): two-year laboratory and field test compared. Ital. J. Agron. 1: 1-6.

LU, Y., HAO, Z., XIE, C., CROSSA, J., ARAUS, J., GAO, S., VIVEK, B, S., MAGOROKOSHO, C., MUGO, S., MAKUMBI, D., TABA, S., PAN, G., LI, X., RONG, T., ZHANG, S. & XU, Y. (2011). Large-scale screening for maize drought resistance using multiple selection criteria evaluated under water-stressed and well-watered environments. Field Crops Res. 124: 37‑45.

MABHAUDHI, T. (2009). Responses of maize (*Zea mays* l.) landraces to water stress compared with commercial hybrids. MSc thesis, University of KwaZulu-Natal, Pietermaritzburg, South Africa.

MABHAUDHI, T. (2012). Drought tolerance and water–use of selected South African landraces of taro (*Colocasia esculenta* l. Schott) and Bambara groundnut (*Vigna subterranea* L. Verdc). PhD thesis, University of KwaZulu-Natal, Pietermaritzburg, South Africa.

MABHAUDHI, T. & MODI, A.T. (2010). Early establishment performance of local and hybrid maize under two water stress regimes. S. Afr. J. Plant Soil. 27: 299-304.

MABHAUDHI, T. & MODI, A.T. (2011). Can hydro-priming improve germination vigour, speed and emergence of maize landraces under water stress? J. Agric. Sci. Technol. B1: 20–28.

MABHAUDHI, T. & MODI, A.T. (2013). Growth, phenological and yield responses of a bambara groundnut (*Vigna subterranea* L. Verdc) landrace to imposed water stress: I. Field conditions. S.Afr. J. Plant Soil 30(2) (in press).

MABHAUDHI. T., MODI, A.T. & BELETSE, Y.G. (2013). Growth, phenological and yield responses of a bambara groundnut *(Vigna subterranea* L. Verdc) landrace to imposed water stress: II. Rain shelter conditions. Water SA vol.39 no.2. Pretoria.

MANDELSDORF, P. & REEVES, R. (1939). The origin of Indian Corn and its relatives. Texas Agric. Exp. Station Bull. No. 574

MANDIRINGANA, O.T., MNKENI, P.N.S., MKILE, Z., VAN AVERBEKE, W., VAN RANST, E. & VERPLANCKE, H. (2005). Mineralogy and fertility status of selected soils of the Eastern Cape Province. S. Afr. Commun. Soil Sci. Plan. 36: 2431–2446.

MANZANILLA, D.O, HONDRADE, R.D, CRUZ, V.C.M. & JOHNSON, D.E. (2011). Improving food security through community-based seed systems in the rainfed rice areas of Asia. SeameoSearca policy brief series. ISSN 1656-8818.

MATTHEWS, S & KHAJEH HOSSEINI, M. (2006). Mean germination time as an indicator of emergence performance in soil of seed lots of maize (*Zea mays*). Seed Sci. Techno. 34: 361-369.

MATTHEWS, S & KHAJEH HOSSEINI, M. (2007). Length of the lag period of germination and metabolic repair explain vigour differences in the seed lots of maize. Seed Sci. & Technol. 35: 200-212.

MATHUVA, M.N., RAO, M.R., SMITHSON,. P.C. & COE, R. (1998). Improving maize (Zea mays)yields in semiarid highlands of Kenya: agroforestry or inorganic fertilizers? Field Crop Res. 55: 57-72.

MAVI, K., DEMIR, I. & MATTHEWS, S. (2010). Mean germination time estimates the relative emergence of seed lots of three cucurbit crops under stress conditions. Seed Sci. Technol. 38: 14-25.

McCANN, J. (2005). Maize and Grace: Africa's encounter with a new crop, 1500-2000. Harvard University Press, New York.

McCOUCH, S. (2004). Diversifying Selection in Plant Breeding. PLoSBiol 2(10): e347. doi:10.1371/journal.pbio.0020347.

MERCER, K.L & WAINWRIGHT, J.D. (2008). Gene flow from transgenic maize to landraces in Mexico: an analysis. Agr. Ecosyst. Environ. 123: 109–115.

MIRACLE, M. P. (1966). Maize in tropical Africa Madison: University of Wisconsin Press. U. S. A.

MODI, A.T. (2007). Effect of indigenous storage method on performance of taro (*Colocasia esculenta* (L.) schott) under field conditions in a warm sub-tropical area. S. Afri. J. Plant Soil 24: 214-219.

MOHAMMADKHANI, N. & HEIDARI, R. (2008). Effects of drought stress on protective enzyme activities and lipid peroxidation in two maize cultivars. Pak. J. Biol. Sci. 10: 3835-3840.

MOUSAVI1, R., ABOUTALEBIAN1, M.A. & SEPEHRI, A. (2012). The effects of on-farm seed priming and planting date on emergence characteristics, yield and yield components of a corn cultivar (S.C. 260) in Hamedan. Ann. Biol. Res. 3(9): 4427-4434.

MUGO, S., SONGA, J., DEGROOTE, H. & HOISINGTON, D. (2002). Insect Resistant Maize for Africa (IRMA) Project (overview). Syngenta Symposium, Washington DC.

MUNGOMA C. & POLLAK L.M. (1991). Photoperiod sensitivity in tropical maize accessions early inbreds and their crosses. Crop Sci. 31(2): 388-391.

MWALE, S.S., HAMUSIMBI, S. & MWANSA, K. (2003). Germination, emergence and growth of sunflower (*Helianthus annus* L.) in response to osmotic seed priming. Seed Sci. Technol. 31: 199-206.

NADERIDARBAGHSHAHI, M. & BAHARI, B. (2012). Assessment the relationship between seed vigor tests and seed field performance of some forage crops of Iran. Intl. J. Agri. Crop Sci.4 (23): 1763-1766.

NAFZIGER, E.D. (2009). Growth and production of maize: mechanized cultivation. University of Illinois extension. Illinois, USA. Available online:

http://www.eolss.net/sample-chapters/c10/E1-05A-13-00.pdf (accessed 24/08/2014)

NAYYAR, H. & GUPTA, D. (2006). Differential sensitivity of C3 and C4 plants to water deficit stress: Association with oxidative stress and antioxidants. Environ. Exp. Bot. 58: 106-113.

NESMITH, D.S. & RITCHIE, J.T. (1992). Effects of soil water-deficits during tassel emergence on development and yield component of maize (*Zea mays*). Field Crops Res. 28: 251–56.

NGUGI, K., CHESEREK, J., MUCHIRA, C. & CHEMINING'WA.G. (2013). Anthesis to silking interval usefulness in developing drought tolerant maize. J. Renew. Agric. 84-90.

NOLI, E., CASARINI, E., URSO, G. & CONTI S. (2008). Suitability of three vigour tests procedures to predict field performance of maize seed in early sowing. Seed Sci. Technol. 36:168-176.

OBER, E.S. & SHARP, R.E. (1994). Proline accumulation in maize (*Zea mays* L.)Primary roots at low water potentials. Plant Physiol. 105: 981-987.

OTEGUI, M.E., NICOLINI, M.G., RUIZ, R.A. & DODDS, P.A. (1995). Sowing date effects on grain yield components for different maize genotypes. Agron. J. 87:29-33.

PANDEY, D.K. (1992). Conductivity testing of seeds. In: *Seed analysis: Modern Methods in Plant Analysis*, vol 14 (Editors: HF Linskins and JF Jackson). Springer-Verlag, Berlin, Hidelberg, New York, pp 273-304.

PANDEY, R.K., MARANVILLE, J.W. & CHETIMA, M.M. (2000). Deficit irrigation and nitrogen effects on maize in a Sahelian environment. II. Shoot growth. Agric. Water Manage. 46: 15-27.

PANNAR (2013). Product catalogue

http://www.pannar.com/assets/countries/pannar_sa_PRODUCTCAT_eng.pdf (accessed 23/06/2013)

PATTERSON, D.T. (1995). Effects of environmental stress on weed/crop interactions. Weed Sci. 43:483-490.

PENG, S., GARCIA, F.V., LAZA, R.C. & CASSMAN, K.G. (1993). Adjustment for specific leaf weight improves chlorophyll meter's estimate of rice leaf nitrogen concentration. Agron. J. 85: 987–990.

POSTMA, J.A. & LYNCH, J.P. (2011). Theoretical evidence for the functional benefit of root cortical aerenchyma in soils with low phosphorus availability. Ann. Bot. 107(5): 829-841.

RAHIMI, A. (2013). Seed priming improves the germination performance of cumin (Cuminum syminum L.) under temperature and water stress. Ind. Crop. Prod. 42: 454– 460.

RANDOLPH, L.F., (1959). The origin of maize. Indian J. Genet. Pl. Br. 19: 1-12.

RITCHIE, S.W., HANWAY, J.J. & BENSON, G.O. (1992). How a corn plant develops. Special Report: 48. Iowa State University, Cooperative Extension Service, Ames, IA, USA.

http://maize.agron.iastate.edu/corngrows.html.

SANTOS, B.M. (2010). Seed quality and seeding technology. Horticultural Sciences Dept., University of Florida. Cooperative Extension Services, IFAS, Fla.

SCHARPF, R.F. (1970). Seed viability, germination and radicle growth of dwarf mistletoe in California. USDA Forest Serv. Res. Pap. PSW-59, 18 p. Pac. Southwest Forest and Range Exp. Sta., Berkeley, Calif. USA.

SCHLEMMER, M. R., FRANCIS, D. D., SHANAHAN, J. F. &SCHEPERS, J.S. (2005). Remotely measuring chlorophyll content in corn leaves with differing nitrogen levels and relative water content. Agron. J. 97: 106–112.

SCHMIDT, L., Danida Forest Seed Centre. (2000). Seed quality testing. Guide to Handling of Tropical and Subtropical Forest Seed.

SCHUSSLER, J.R. & WESTGATE, M.E. (1991). Maize kernel set at low water potential. 1. Sensitivity to reduced assimilates during early kernel growth. Crop Sci. 31: 1189–1195.

SCHULZE, R.E. (2011). Approaches towards practical adaptive management options for selected water related sectors in South Africa in a context of climate change. Water S.A. 37(5).

SECTOR, J., SHIBLES, R. & STEWART, C. R. (1984). A metabolic comparison between progressive and monocarpic senescence of soybean. Can. J. Bot. 62: 806-811.

SERRANO, L., PARDOS, J. & PUGNAIRE, F.I. (1999).Constraints by Water Stress on Plant Growth. Handbook of Crop Stress. 2nd Edition: 271-283. Marcel Dekkar Inc.

SESTAK, Z. (1977). Photosynthetic characteristics during ontogenesis of leaves. I. Chlorophylls. Photosynthetica 11: 367-448.

SHEN, T.Y. & ODEN, P.C. (2000). Fumarase activity as a quick vigour test for scots pine (*Pinus sylvestris* L.) seeds. Seed Sci. Technol. 28: 825-835.

SHIBGHATALLAH, M.A.H. KHOTIMAH, S., SUHANDONO, S. & SPARISOMA VIRIDI. (2013). Measuring Leaf Chlorophyll Concentration from Its Color: A Way in Monitoring Environment Change to Plantations. arXiv:1305.1148v2

SMITH, B. (2006). The Farming Handbook. University of KwaZulu- Natal Press, Pietermaritzburg.

SOKCHEA, H. & PRESTON, T.R. (2011). Growth of maize in acid soil amended with biochar, derived from gasifier reactor and gasifier stove, with or without organic fertilizer (biodigester effluent). Livestock Research for Rural Development 23(4).

STATISTICS SOUTH AFRICA. (2013). Mid-year population estimates: Statistical release P0302.

http://beta2.statssa.gov.za/publications/P0302/P03022013.pdf

STONE, P.J., SORENSEN, I.B. & JAMIESON, P.D. (1999). Effect of soil temperature on phenology, canopy development, biomass and yield of maize in a cool-temperature climate. Field Crop Res. 63: 169-178.

STONE, P. J., WILSON, D. R., REID, J. B. & GILLESPIE, R. N. (2001).Water deficit effects on sweet corn. I. Water use, radiation use efficiency, growth, and yield. Aust. J. Agric. Res. 52: 103–13.

TEKRONY, D.M., EGLI, D.B. & WICKHAM, D.A. (1989). Corn seed vigor effect on no-tillage field performance: I. Field emergence. Crop Sci.29:1523-1528.

THELEN, K. (2007). Assessing drought stress effects on corn yield. Michigan State University Extension, Department of Crop & Soil Sciences. Michihan, USA.

TRUEMAN, S.J. & WALLACE, H.M. (1999). Pollination and resource constraints on fruit set and 46 fruit size of *Persooniarigida* (Proteaceae). Ann. Bot. 83: 145–155.

UCHIDA, N., WADA, Y. & MURATA, Y. (1982). Studies on the photosynthetic activity of a crop leaf during its development and senescence. II. Effect of nitrogen deficiency on the changes in senescing leaf of rice. Jap. J. Crop. Sci. 51: 577-593.

VAN DE VENTER, A. (2000). Seed Vigor Testing. Journal of New Seeds 2(4):51-58. DOI: 10.1300/J153v02n04_06

VAN DEN BERG, A.K. & PERKINS, T.D. (2004). Evaluation of a portable chlorophyll meter to estimate chlorophyll and nitrogen contents in sugar maple (*Acer saccharum* Marsh.) leaves. Forest Ecol. Manag. 200: 113–117.

VAVILOV, N.I. (1931). Mexico and Central America as the principal centre of origin of cultivated plants of the New World. Bull. Appl. Bot. Genet. Plant Breed. 26: 179–199.

VERBRUGGEN, N. & HERMANS, C. (2008). Proline accumulation in plants: a review. Amino Acids: 35:753–759.

VILLA, T.C.C., MAXTED, N., SCHOLTEN, M. & FORD-LLOYD, B. (2005). Defining and identifying crop landraces. Plant Genet. Resour. 3(3): 373–384.

WEATHERWAX, P. (1936). The origin of the maize plant and maize agriculture in ancient America. N Mex Univ Bul (Symposium on prehistoric agriculture) 296: 11-18.

WILLENBORB, C.J., GULDEN, R.H., JHONSON, E.N. & SHIRTLIFFE, S.J. (2004). Germination characteristics of polymer-coated canola (*Brassica napus* L.) seeds subjected to moisture stress at different temperatures. Agron. J. 96: 786-791.

WILSON, D.W., MUCHOW, R.C. & MURGATROYD, C.J. (1995). Model analysis of temperature and solar radiation limitations to maize potential productivity in a cool climate. Field Crop Res. 43: 1-18.

WRIGHT, G.C., NAGESWARA RAO, R.C. & FARQUHAR, G.D. (1994). Water use efficiency and carbon isotope discrimination in peanut under water deficit conditions. Crop Sci. 34: 92-97.

YAMAMOTO, A., NAKAMURA, T., ADU-GYAMFI, J.J. & SAIGUSA, M. (2002). Relationship between chlorophyll content in leaves of sorghum and pigeon pea determined by extraction method and by chlorophyll meter (SPAD-502). J. Plant Nutr. 25, 2295–2301.

YANG, Q., LI, Z., LI, W., KU, L., WANG, C., YE, J., LI, K., YANG, N., LI, Y., ZHONG, T., LI, J., CHEN, Y., YAN, J., YANG, X. & XU, M. (2013). CACTA-like transposable element in ZmCCTattenuated photoperiod sensitivity and accelerated the post domestication spread of maize. Proc. Natl. Acad. Sci. USA. 110(42): 16969-16974.

YI, L., SHENJIAO, Y., SHIQING, L., XINPING, C. & FANG, C. (2010). Growth and development of maize (*Zea mays* L.) in response to different field water management practices: Resource capture and use efficiency. Agric. For. Met. 150: 606–613.

YUNUSA, I. A. M., WALKER, R. R. & GUY, J. R. (1997). Partitioning of seasonal evapotranspiration from a commercial furrow irrigated Sultana vineyard. Irrig. Sci.18: 45–54.

ZEVEN, A.C. (1998). Landraces: A review of definitions and classifications. Euphytica 104: 127–139.

ZIDAN, I., AZAIZEH, H. & NEUMANN, P.M. (1990). Does salinity reduce growth in maize root epidermal cells by inhibiting their capacity for cell wall acidification? Plant Physiol. 93:7-11.

ZLATEV, Z. & LIDON, F.C. (2012). An overview on drought induced changes in plant growth, water relations and photosynthesis. Emir. J. Food Agric. 24(1): 57-72.

APPENDICES

Appendix 1: List if ANOVAs for Seed Quality Testing

Variate: Germination (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	2283.5	570.9	4.56	
Rep.*Units* stratum					
Day	6	181825.9	30304.3	241.91	<.001
Variety	3	15173.0	5057.7	40.37	<.001
Day.Variety	18	11397.3	633.2	5.05	<.001
Residual	108	13529.0	125.3		
Total	139	224208.7			

Variate: GVI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	12.4556	3.1139	6.87	
Rep.*Units* stratum					
Day	6	605.2555	100.8759	222.59	<.001
Variety	3	94.0160	31.3387	69.15	<.001
Day.Variety	18	44.7283	2.4849	5.48	<.001
Residual	108	48.9455	0.4532		
Total	139	805.4008			

Variate: MGT (days)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	0.4591	0.1148	0.80	
Rep.*Units* stratum					
Variety	3	4.5196	1.5065	10.45	0.001
Residual	12	1.7297	0.1441		
Total	19	6.7084			

Variate: Root length (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	3	5.0326	1.6775	1.74	0.211

Residual	12	11.5401	0.9617		
Total	19	17.2557			

Variate:Shoot length (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	3	1.7585	0.5862	3.55	0.038
Residual	16	2.6410	0.1651		
Total	19	4.3995			

Variate: root:shoot

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	3	2.7877	0.9292	1.66	0.216
Residual	16	8.9653	0.5603		
Total	19	11.7530			

Variate: Dry Mass (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	3	6.23945	2.07982	61.27	<.001
Residual	16	0.54314	0.03395		
Total	19	6.78259			

Variate: EC (µS/g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	3	4847902.	1615967.	24.35	<.001
Residual	236	15662828.	66368.		
Total	239	20510729.			

Variate: Imbibition (% weight increase)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	4	22.760	5.690	3.83	
Replicate.*Units* stratum					
Variety	3	181.044	60.348	40.62	<.001
Min	14	39191.344	2799.382	1884.42	<.001
Variety.Min	42	427.292	10.174	6.85	<.001
Residual	236	350.588	1.486		
Total	299	40173.028			

Appendix 2: List if ANOVAs for Controlled Experiment study

Variate: Daily emergence (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1687.9	562.6	1.84	
Rep.*Units* stratum					
Variety	3	27937.9	9312.6	30.40	<.001
DAS	11	680299.0	61845.4	201.91	<.001
Variety.DAS	33	36483.4	1105.6	3.61	<.001
Residual	525	160812.1	306.3		
Total	575	907220.3			

Variate: Final emergence (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	3	10625.0	3541.7	17.00	<.001
Residual	44	9166.7	208.3		
Total	47	19791.7			

Variate: Stomatal conductance (mmol m^{-2} s^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	4450.	1483.	1.38	
Replicate.*Units* stratum					
Water_Treatment	2	321.	160.	0.15	0.861
Variety	3	4266.	1422.	1.32	0.266
Week	18	418443.	23247.	21.62	<.001
Variety.Water_Treatment	6	9793.	1632.	1.52	0.169
Variety.Week	54	37988.	703.	0.65	0.974
Water_Treatment.Week	36	165537.	4598.	4.28	<.001
Variety.Water_Treatment.Week	108	55417.	513.	0.48	1.000
Residual	681	732132.	1075.		
Total	911	1428347.			

Variate: Chlorophyll content index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	155.285	51.762	6.23	
Replicate.*Units* stratum					
Variety	3	341.276	113.759	13.69	<.001
Treatment	2	61.096	30.548	3.68	0.026
Week	13	2865.598	220.431	26.53	<.001
Variety.Treatment	6	143.103	23.851	2.87	0.009
Variety.Week	39	377.799	9.687	1.17	0.231
Treatment.Week	26	772.938	29.728	3.58	<.001
Variety.Treatment.Week	78	424.386	5.441	0.65	0.989
Residual	501	4161.915	8.307		
Total	671	9303.396			

Variate: Leaf protein

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.6666	0.3333	0.68	
Replicate.*Units* stratum					
Water_Treatment	2	80.2639	40.1320	81.64	<.001
Variety	3	63.7971	21.2657	43.26	<.001
Water_Treatment.Variety	6	121.7451	20.2909	41.28	<.001
Residual	22	10.8149	0.4916		
Total	35	277.2876			

Variate: Seed proline (mg/g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.0739	0.0369	0.26	
Replicate.*Units* stratum					
Water_treatment	2	693.5738	346.7869	2418.48	<.001
Variety	3	416.1666	138.7222	967.44	<.001
Water_treatment.Variety	6	545.4074	90.9012	633.94	<.001
Residual	22	3.1546	0.1434		
Total	35	1658.3762			

Variate: Leaf proline (mg/g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.9682	0.4841	4.21	
Replicate.*Units* stratum					
Water_Treatment	2	2942.6042	1471.3021	12806.74	<.001
Variety	3	1697.9283	565.9761	4926.46	<.001
Water_Treatment.Variety	6	3314.9724	552.4954	4809.12	<.001
Residual	22	2.5275	0.1149		
Total	35	7959.0007			

Variate: Final plant height (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	3	15719.	5240.	4.70	0.007
Water_Treatment	2	3105.	1553.	1.39	0.261
Variety.Water_Treatment	6	5473.	912.	0.82	0.563
Residual	36	40117.	1114.		
Total	47	64414.			

Variate: Final leaf number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Variety	3	1.7500	0.5833	1.04	0.389
Water_Treatment	2	2.0417	1.0208	1.81	0.179
Variety.Water_Treatment	6	6.1250	1.0208	1.81	0.127
Residual	33	18.5833	0.5631		
Total	47	31.9167			

Variate: Time to tasselling (days)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	7263.2	2421.1	4.13	
Replicate.*Units* stratum					
Variety	3	395.1	131.7	0.22	0.879
Treatment	2	4644.8	2322.4	3.96	0.029
Variety.Treatment	6	5849.4	974.9	1.66	0.162
Residual	33	19356.0	586.5		
Total	47	37508.5			

Variate: Total biomass (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.101388	0.033796	4.09	
Rep.*Units* stratum					
Variety	3	0.028012	0.009337	1.13	0.351
Water_treatment	2	0.084024	0.042012	5.08	0.012
Variety.Water_treatment	6	0.066368	0.011061	1.34	0.268
Residual	33	0.272804	0.008267		
Total	47	0.552595			

Variate: Ear No. plant^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1.2292	0.4097	1.80	
Rep.*Units* stratum					
Variety	3	0.8958	0.2986	1.31	0.288
Water_treatment	2	0.7917	0.3958	1.74	0.192
Variety.Water_treatment	6	1.5417	0.2569	1.13	0.368
Residual	33	7.5208	0.2279		
Total	47	11.9792			

Variate: Ear mass plant^{-1} (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	43844.	14615.	1.58	
Replicate.*Units* stratum					
Variety	3	15727.	5242.	0.57	0.641
Water_Treatment	2	36993.	18497.	2.00	0.151
Variety.Water_Treatment	6	36806.	6134.	0.66	0.680
Residual	33	305285.	9251.		
Total	47	438655.			

Variate: Ear length (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	2696.6	898.9	2.14	
Replicate.*Units* stratum					
Variety	3	1747.4	582.5	1.39	0.264
Water_Treatment	2	11341.2	5670.6	13.49	<.001
Variety.Water_Treatment	6	3583.2	597.2	1.42	0.236
Residual	33	13873.2	420.4		
Total	47	33241.5			

Variate: Kernel rows ear^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	43.23	14.41	0.76	
Replicate.*Units* stratum					
Variety	3	195.06	65.02	3.41	0.029
Water_Treatment	2	108.79	54.40	2.85	0.072
Variety.Water_Treatment	6	44.88	7.48	0.39	0.879
Residual	33	629.02	19.06		
Total	47	1020.98			

Variate: Kernel No. row^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	125.14	41.71	1.79	
Replicate.*Units* stratum					
Variety	3	220.50	73.50	3.15	0.038
Water_Treatment	2	83.05	41.53	1.78	0.184
Variety.Water_Treatment	6	36.50	6.08	0.26	0.951
Residual	33	769.25	23.31		
Total	47	1234.44			

Variate: Harvest index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	0.08079	0.02693	1.78	
Replicate.*Units* stratum					
Variety	3	0.00282	0.00094	0.06	0.979
Water_Treatment	2	0.07893	0.03947	2.61	0.089
Variety.Water_Treatment	6	0.05923	0.00987	0.65	0.688
Residual	33	0.49908	0.01512		
Total	47	0.72085			

Appendix 3a: List if ANOVAs for Field Study at Ukulinga

Variate: Final emergence (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicte stratum	3	1618.0	539.3	1.75	
Replicte.*Units* stratum					
Water_Treatment	1	8.0	8.0	0.03	0.873
Variety	3	6626.0	2208.7	7.18	0.002
Water_Treatment.Variety	3	388.0	129.3	0.42	0.740
Residual	21	6462.0	307.7		
Total	31	15102.0			

Variate: Chlorophyll content index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	193.29	64.43	3.72	
Replicate.*Units* stratum					
Water_Treatment	1	6.73	6.73	0.39	0.533
Variety	3	1576.91	525.64	30.35	<.001
Week	13	47597.46	3661.34	211.38	<.001
Water_Treatment.Variety	3	533.65	177.88	10.27	<.001
Water_Treatment.Week	13	543.68	41.82	2.41	0.004
Variety.Week	39	744.98	19.10	1.10	0.317
Water_Treatment.Variety.Week	39	776.27	19.90	1.15	0.257
Residual	333	5768.02	17.32		
Total	447	57741.00			

Variate: Plant height at tasselling (cm)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3		2405.6	801.9	2.18	
Replicate.*Units* stratum						
Water_Treatment	1		933.5	933.5	2.53	0.128
Variety	3		8394.1	2798.0	7.59	0.002
Water_Treatment.Variety	3		915.5	305.2	0.83	0.495
Residual	19	(2)	7001.2	368.5		
Total	29	(2)	19015.7			

Variate:Leaf number at tasselling

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3		12.9863	4.3288	6.02	
Replicate.*Units* stratum						
Water_Treatment	1		0.2869	0.2869	0.40	0.535
Variety	3		0.5266	0.1755	0.24	0.864
Water_Treatment.Variety	3		4.3964	1.4655	2.04	0.143
Residual	19	(2)	13.6619	0.7190		
Total	29		(2) 31.4056			

Variate:Plant height (cm)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3		3351.4	1117.1	10.39	
Replicate.*Units* stratum						
Water_Treatment	1		11949.0	11949.0	111.10	<.001
Variety	3		17626.2	5875.4	54.63	<.001
Week	16		1801128.7	112570.5	1046.62	<.001
Water_Treatment.Variety	3		2520.8	840.3	7.81	<.001
Water_Treatment.Week	16		11408.5	713.0	6.63	<.001
Variety.Week	48		14285.5	297.6	2.77	<.001
Water_Treatment.Variety.Week	48		3290.7	68.6	0.64	0.971
Residual	371	(34)	39903.3	107.6		
Total	509	(34)	1802745.8			

Variate: Time to tasselling (days)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3		49.00	16.33	0.84	
Replicate.*Units* stratum						
Water_Treatment	1		153.13	153.13	7.92	0.011
Variety	3		502.25	167.42	8.66	<.001
Water_Treatment.Variety	3		202.13	67.38	3.48	0.036
Residual	19	(2)	367.50	19.34		
Total	29	(2)	1247.87			

Variate: Time to silking (days)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3		75.18	25.06	1.12	
Replicate.*Units* stratum						
Water_Treatment	1		753.44	753.44	33.72	<.001
Variety	3		17.93	5.98	0.27	0.848
Water_Treatment.Variety	3		147.56	49.19	2.20	0.121
Residual	19	(2)	424.52	22.34		
Total	29	(2)	1274.00			

Variate: Anthesis-silking interval (days)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3		194.04	64.68	4.40	
Replicate.*Units* stratum						
Water_Treatment	1		300.13	300.13	20.42	<.001
Variety	3		642.38	214.13	14.57	<.001
Water_Treatment.Variety	3		116.86	38.95	2.65	0.078
Residual	19	(2)	279.30	14.70		
Total	29	(2)	1443.87			

Variate: Total biomass (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	0.26901	0.08967	1.26	
Replicate.*Units* stratum					
Water_treatment	1	0.07607	0.07607	1.07	0.313
Variety	3	0.00697	0.00232	0.03	0.992
Water_treatment.Variety	3	0.32681	0.10894	1.53	0.237
Residual	21	1.49757	0.07131		
Total	31	2.17642			

Variate: Ear No. plant^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	7.4850	2.4950	2.86	
Replicate.*Units* stratum					
Water_treatment	1	2.4846	2.4846	2.85	0.106
Variety	3	1.6586	0.5529	0.63	0.601
Water_treatment.Variety	3	0.5649	0.1883	0.22	0.884
Residual	21	18.3049	0.8717		
Total	31	30.4980			

Variate: Ear mass plant^{-1} (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	0.10071	0.03357	1.73	
Replicate.*Units* stratum					
Water_treatment	1	0.02288	0.02288	1.18	0.290
Variety	3	0.03305	0.01102	0.57	0.643
Water_treatment.Variety	3	0.00881	0.00294	0.15	0.928
Residual	21	0.40823	0.01944		
Total	31	0.57368			

Variate: Ear length (mm)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3		2873.	958.	0.46	
Replicate.*Units* stratum						
Water_treatment	1		2.	2.	0.00	0.975
Variety	3		2531.	844.	0.41	0.749
Water_treatment.Variety	3		5045.	1682.	0.81	0.503
Residual	19	(2)	39341.	2071.		
Total	29	(2)	49403.			

Variate: Kernel rows ear^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	64.39	21.46	1.57	
Replicate.*Units* stratum					
Water_treatment	1	13.63	13.63	1.00	0.330
Variety	3	61.23	20.41	1.49	0.246
Water_treatment.Variety	3	17.47	5.82	0.43	0.737
Residual	21	287.19	13.68		
Total	31	443.92			

Variate: Kernel No. row^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	210.81	70.27	0.94	
Replicate.*Units* stratum					
Water_treatment	1	117.59	117.59	1.57	0.224
Variety	3	197.96	65.99	0.88	0.467
Water_treatment.Variety	3	41.56	13.85	0.18	0.906
Residual	21	1574.08	74.96		
Total	31	2142.00			

Variate: 100 grain mass (g)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3		87.8	29.3	0.15	
Replicate.*Units* stratum						
Water_treatment	1		190.8	190.8	1.00	0.329
Variety	3		445.5	148.5	0.78	0.519
Water_treatment.Variety	3		310.9	103.6	0.54	0.658
Residual	19	(2)	3613.7	190.2		
Total	29	(2)	4515.7			

Variate: Harvest index

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3		0.17996	0.05999	3.52	
Replicate.*Units* stratum						
Water_treatment	1		0.01770	0.01770	1.04	0.321
Variety	3		0.10903	0.03634	2.14	0.131
Water_treatment.Variety	3		0.06131	0.02044	1.20	0.338
Residual	18	(3)	0.30632	0.01702		
Total	28	(3)	0.57441			

Variate: Yield (kg ha^{-1})

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3		133.328	44.443	4.58	
Replicate.*Units* stratum						
Water_treatment	1		22.694	22.694	2.34	0.144
Variety	3		56.180	18.727	1.93	0.161
Water_treatment.Variety	3		31.695	10.565	1.09	0.380
Residual	18	(3)	174.804	9.711		
Total	28	(3)	344.699			

Appendix 3b: List if ANOVAs for Field Study at Swayimani

Variate: Final emergence (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicte stratum	3	210.5	70.2	0.67	
Replicte.*Units* stratum					
Variety	3	5325.3	1775.1	16.93	<.001
Residual	9	943.9	104.9		
Total	15	6479.6			

Variate: Chlorophyll content index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	79.97	26.66	1.38	
Replicate.*Units* stratum					
Variety	3	65.51	21.84	1.13	0.346
Week	3	100.41	33.47	1.74	0.173
Variety.Week	9	62.30	6.92	0.36	0.948
Residual	45	866.89	19.26		
Total	63	1175.08			

Variate: Plant height (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	230.54	76.85	2.78	
Replicate.*Units* stratum					
Variety	3	62.63	20.88	0.76	0.523
Week	5	33914.34	6782.87	245.51	<.001
Variety.Week	15	194.88	12.99	0.47	0.948
Residual	69	1906.30	27.63		
Total	95	36308.68			

Variate:Leaf number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	2.5047	0.8349	2.26	
Replicate.*Units* stratum					
Variety	3	0.5553	0.1851	0.50	0.683
Week	5	495.9252	99.1850	268.69	<.001
Variety.Week	15	9.9246	0.6616	1.79	0.053
Residual	69	25.4712	0.3691		
Total	95	534.3810			

Variate: Total biomass (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	0.118790	0.039597	4.07	
Replicate.*Units* stratum					
Variety	3	0.101903	0.033968	3.49	0.063
Residual	9	0.087518	0.009724		
Total	15	0.308211			

Variate: Ear No. plant^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	0.069635	0.023212	3.31	
Replicate.*Units* stratum					
Variety	3	0.053802	0.017934	2.56	0.120
Residual	9	0.063073	0.007008		
Total	15	0.186510			

Variate: Ear mass plant^{-1} (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	0.025756	0.008585	4.05	
Replicate.*Units* stratum					
Variety	3	0.015954	0.005318	2.51	0.125
Residual	9	0.019083	0.002120		
Total	15	0.060793			

Variate: Ear length (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	5757.4	1919.1	5.43	
Replicate.*Units* stratum					
Variety	3	459.0	153.0	0.43	0.734
Residual	9	3178.4	353.2		
Total	15	9394.9			

Variate: Kernel rows ear^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	2.932	0.977	0.14	
Replicate.*Units* stratum					
Variety	3	34.659	11.553	1.65	0.246
Residual	9	63.067	7.007		
Total	15	100.659			

Variate: Kernel No. row^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	33.89	11.30	0.29	
Replicate.*Units* stratum					
Variety	3	101.09	33.70	0.85	0.500
Residual	9	356.45	39.61		
Total	15	491.43			

Variate: 100 grain mass (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	556.73	185.58	2.34	
Replicate.*Units* stratum					
Variety	3	23.09	7.70	0.10	0.960
Residual	9	713.18	79.24		
Total	15	1293.00			

Variate: Harvest index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	0.096707	0.032236	4.40	
Replicate.*Units* stratum					
Variety	3	0.167483	0.055828	7.62	0.008
Residual	9	0.065979	0.007331		
Total	15	0.330169			

Variate: Yield (kg ha^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	3	18.316	6.105	4.05	
Replicate.*Units* stratum					
Variety	3	11.346	3.782	2.51	0.125
Residual	9	13.570	1.508		
Total	15	43.232			