Evaluation Of Physiological And Agronomic Responses As Screening Techniques For Yield And Water Stress Tolerance In Wheat Cultivars In Tigray, Ethiopia

Mohammed Mebrahtu Mossa

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DECLARATION

This dissertation is my original work and has not been presented for a degree in any other university. The work of others used in this study has been duly aknowledegd**.**

Signature ________________________________ Date ____________________

Mohammed Mebrahtu Mossa

This dissertation submitted with our knowledge and evaluated under our guidance as Jomo kenyatta university of Agriculture and Technology and Tigray Agricultural Research Institute.

We declare that, this dissertation is from the student's own work and effort and where he has used other sources of information, it has been aknowledged.

Signature______________________________________ Date _________________

Dr. Edward George Mamati

JKUAT, Kenya

Signature ___________________________ Date _________________

Dr. Tesfay Belay

TARI, Ethiopia

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Acronyms and abbreviations

ANOVA	Analysis of variance
CIMMYT	International Maize and Wheat Improvement Center
DH	Day to heading
DF	Day to flowering
ELWR	Excised leaf water retention
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
IWC	Initial water content
LA	Leaf area
MP	Mean productivity
M.s	Mean square
PH	Plant height
RCBD	Randomized Complete Block Design
RWC	Relative water content
RWL	Rate of water loss
SSI	Stress susceptibility index
STI	Stress tolerance index
V.r	Variance ratio
WSR	Water stress regimes
YSI	Yield stability index

Abstract

Water stress is one of the major environmental factors that inhibits metabolic processes and constrains plant growth and crop productivity in the majority of agricultural fields. Wheat is generally grown on arid-agricultural fields and water stress often causes serious challenges in wheat production areas. Field and green house experiments were conducted at Mekelle University to evaluate physiological and agronomic traits as screening techniques for yield and drought tolerance in wheat cultivars. The experiment comprised of six wheat genotypes and three water stress regimes. Water stress was maintained by withholding water for 10 days at tillering and at booting stages. The experiment was laid out in Randomized Complete Block Design in factorial combination of the six wheat genotypes and three water regimes with three replications in both experiments. Analysis of variance for parameters associated with physiological, agronomic and drought tolerance as well as yield componentsrevealed a significant difference among the genotypes . Water stress caused reduction in relative water content, initial water content, rate of water loss, yield and yield components and increment in excised leaf water retention of the six studied wheat genotypes. Pearson’s correlation coefficient at 5% probability level indicated that yield and drought tolerance index were positively and significantly correlated with relative water content, excised leaf water retention, initial water content, spike length, number of seed per spike, yield stability index, mean productivity and seed weight where as stress susceptibility index and rate of water loss were negatively associated with yield and drought tolerance index. Regression analysis also showed that rate of water loss, initial water content, relative water content at both stem elongation and grain filling stage explain more of the variation in grain yield under normal condition where as traits such as relative water contents at stem elongation, excised leaf water retention, initial water content at grain filling stage and plant height when water stress was imposed at tillering stage and traits like days to heading, initial water content at stem elongation and grain filling stage , relative water content ate grain filling stage and rate of water loss explained more of the variation in grain yield and drought tolerance index under water stress at booting stage. More over principal component analysis extracted three components which explained 91.47 percent of the total variation, were the first component explained 58.65 percent with, initial water content at grain filling stage, stress tolerance index, excised leaf water retention, spike length, mean productivity, initial water content at stem elongation, relative water content at stem elongation Seed per spike, yield stability index, seed weight and grain yield per plant. Genotypes Dandea, Mekelle 3 and Mekelle 4 had higher relative water content, excised leaf water retention, initial water content, mean productivity, yield stability index and stress tolerance index than the other three genotypes (Hawii, Shina and Medawalabu) whereas stress susceptibility index and rate of water loss was observed at its lowest. Traits like relative water content, excised leaf water retention, initial water content, days to flowering, are recognized as beneficial water stress tolerance indicators for selecting a stress tolerant variety. Similarly, total grain yield per plant, spike length, seed per spike and 1000 seed weight was also higher in the same wheat varieties, which put it as a good candidate for selection in wheat breeding program for drought resistance. Hence plant breeders should incorporate these physiological traits as a selection criterion in their breeding program for screening water stress tolerance wheat cultivars.

Key words; physiological trait, correlation, moisture stress, drought tolerance index, regression, principal component

CHAPTER ONE

1.0. INTRODUCTION

1.1. General back ground information

Wheat, (*Triticum aestivum* L.) is one of the most important grain crops produced worldwide. About 620 million metric tons of wheat was produced from 217 million hectares in the year 2005/06 with an average yield of 2.85 metric tons per hectare (FAO, 2005). Today, wheat is grown on more land area than any other commercial crop and continues to be the most important food grain for humans. In Ethiopia, wheat is one of the major cereal crops grown between 6 and 14^{o} N and between 35 and 42^{0}E ranging from 1500 m.a.s.l to 3200 m.a.s.l (Hailu, 2006). Ethiopia's economy is chiefly agricultural, it accounts for the lion's share of the total GDP, in foreign currency earnings and in employment creation with more than 80% of the country's population employed in this sector. In Sub-Saharan Africa, Ethiopia is the second largest wheat producer with about 0.75 million ha of durum and bread wheat (Hailu, 2006).

Although agriculture is the foundation of the country's economy, agricultural production is plagued by periodic drought; that, restrict crop production particularly in the Tigray region of Ethiopia. This region is disaster prone and food insecure and vast areas of the region receive little rain that is unreliable and whose distribution during crop growth period is erratic (Hailu, 2006). Since wheat is grown mostly under rain-fed conditions, where water availability is a limiting factor, it inevitably suffers from drought stress. Rain-fed regions are characterized by low yields and severe water shortage which causes large area of land to be unproductive. Balla *et al*. (2008) reported that drought had a negative effect on physiological processes and agronomic traits of wheat. Report from Jason *et at.*, (2004) and Moussa, (2006) showed that water stress causes stomatal closure, which reduces the CO_2/O_2 ratio in leaves and inhibits photosynthesis. Anonymous, (2007) recommend three characteristics of successful rain-fed agriculture; retaining precipitation, reducing evaporation and sowing of crops that have drought tolerance characteristics and fit the rainfall pattern. Siddique *et al*., (2000) suggests that for the purpose of crop production, yield improvement and yield stability under water stress conditions, developing drought tolerant varieties is the best option.

Because yield and drought resistance are controlled at separate genetic loci (Blum, 1983; Morgan, 1984), breeding should involve the identification of physiological traits responsible for drought resistance. Studies on plants including identification and selection of physiological traits that are associated with plant water use efficiency (WUE) and drought tolerance under water-limited conditions are important for well understanding plant physiological characters and taking physiological water saving measures. Several recent studies (Blum,1988; Munjal and Dhanda 2005; and Dulai et.al 2006) suggest that physiological traits have the potential to improve genetic yield gains in wheat. At the International Maize and Wheat Improvement Center (CIMMYT), research has demonstrated associations of a number of physiological traits, including leaf conductance and photosynthetic rate, with performance of a historic series of cultivars in a high-yielding environment (Fischer *et al.,* 1998). In addition, physiological traits associated with drought tolerance have been applied into a number of Australian wheat breeding programmes, including higher transpiration efficiency, greater early vigor and reduced tillering (Richards *et al.,* 1996). Moreover, productivity enhancement of crops grown under drought conditions is not an easy task, because of the un-predictable nature of most periods of drought stress prevailing in the growing areas and gaps in our knowledge of drought biology (Nelson *et al.,* 2007). The difficulty arises from the diverse strategies adopted by plants themselves to combat drought stress depending on the timing, severity and stage of crop growth (Misra, 1990, 1994; Vinod *et al.,* 2006).

1.2. Statement of the Problem

During their life cycle, plants are exposed to both biotic (pathogens, insect pest) and abiotic (drought, salinity, high temperature or freezing etc) stresses, which have a significant effect on growth and cause change in normal physiological function of plants. Among these, drought stress is a major factor limiting crop productivity worldwide and has the highest impact (26%) followed by mineral stress (20%) when the usable area on the earth are classified in view of stress factor (Blum, 1986). Ethiopia has great agricultural potential because of its vast areas of fertile land, diverse climate, and large labor pool. Despite this potential, Ethiopian agriculture has remained underdeveloped and agricultural production is plagued by periodic drought, which has repeatedly affected the country since the early 1970s. The mean wheat yields are around 1.4 t/ha, well below experimental yields of over 5 t/ha (Hailu, 2006) due to lack of well adapted wheat genotype that produce high yield under drought condition. Although developing drought tolerance is the major objective of plant breeders it is hampered by the lack of effective selection criteria (Yield other than all available potential markers). Most plant breeders use the single trait approach in identifying the crop response to drought condition and little priority is given to the physiological traits. Thus all the possible traits have not been critically evaluated and correlation among the different traits and their relation to drought has not yet been critically examined.

1.3 Justification

Drought stress is the most common adverse environmental condition that can seriously reduce crop productivity. Drought stress leads to a wide range of physiological responses in addition to the obvious reductions in photosynthesis, stomatal conductance, and leaf growth (Rahnama et. al., 2010). Given the increasing scarcity and competition for water resources, irrigation is generally not a sustainable option to alleviate drought problems in most rainfed areas, rather developing drought resistance variety is the best option. Increasing crop resistance to drought stress would contribute to improving agricultural productivity and to reduce agricultural use of fresh water resources. As a result, understanding the mechanisms of drought tolerance and breeding for drought-resistant crop plants has been the major goal of plant biologists and crop breeders. It is known fact that any increase or decrease in agronomic and yield traits of a plant is caused by the physiological changes, however, highest priority is nevertheless given to the physiological traits as a selection criterion. Hence identifying physiological traits that may grant simultaneously high yield potential and constitutive tolerance to stress would be critical. Large seasonal variation in yield and subsequent genotype and environment interaction will slow genetic gain for yield thus specific targeting of physiological character that limit yield and have a high heritability are more effective than direct selection for yield (Sayar et.al. 2007). While applying physiological tests to appreciate drought tolerance in wheat varieties can lead to faster selection method. Better adapted and higher yielding genotypes could be bred more efficiently and effectively if attributes that confer drought resistance could be identified and used as a selection criterion. Development of cultivars for water limited environments would involve selection and incorporation of both physiological and morphological mechanisms of drought resistance through traditional breeding programmes. Physiological changes such as flowering time, stomatal conductance, relative water content in leaf, leaf area, spike fertility, etc have been considered important criteria for yield selection as breeders and physiologists regularly select for desirable expression of these traits to maintain adaptation and optional yield of crops in water stress environments.

1.4. Objective

1.4.1. General objective;

- To determine the nature of associations among physiological and agronomic performances contributing to grain yield and drought tolerance in wheat cultivars.

1.4.2. Specific objective;

- To determine the physiological and agronomic response of wheat genotype to water stress
- To quantify associations between physiological traits and yield responses under drought condition

1.5. Hypothesis;

- All genotypes have similar physiological and agronomic response under water stress condition
- There is no association among the agronomic, physiological, yield and drought tolerance indices

CHAPTER TWO

2.0. Literature review

2.1. Introduction

Wheat is one of the first cereals known to have been domesticated, and has the ability to self-pollinate. This greatly facilitated selection of many distinct domesticated varieties. The development of civilization may be directly connected to the cultivation of wheat. Villages developed when primitive man discovered he no longer needed to follow game and forage for his food. Wheat was a key factor enabling the emergence of city-based societies at the start of civilization because it was one of the first crops that could be easily cultivated on a large scale, and had the additional advantage of yielding a harvest that provides long-term storage. Wheat is an important commodity worldwide grown on more than 240 million ha, larger than for any other crop, and world trade is greater than for all other crops combined (Curtis**,** 1982). . Globally, wheat is the leading source of vegetable protein in human food, having higher protein content than either corn or rice, and other major cereals. In terms of total production tonnages used for food, it is currently second to rice as the main human food crop and ahead of maize, after allowing for maize's more extensive use in animal feeds (Hanson *et al*., 1982). However global average productivity is around 2.7 t/ha with high variability among countries and regions. World demand for wheat by 2020 is estimated at 840 to 1000 million tons (Rosegrant et.al. 2001). Yield potential and yield gains are essential to meet this demand, as expanding the wheat area is not feasible.

2.2. Wheat production in Ethiopia

Agriculture is a dominant sector in Ethiopia. It contributes 51 percent to the GDP, employs nearly 85 percent of the total labor force and generates the bulk of foreign exchange. Smallholder farms are predominant, accounting for more than 90 percent of agricultural production and over 95 percent of the total area under cultivation. Crops are the major agricultural commodities on which Ethiopians depend for their daily food. There are no substitutes for cereals, pulses and oil crops for the Ethiopian masses. Ethiopia is the second largest producer of wheat in sub-Saharan Africa, after South Africa. About 900000 ha of bread wheat (Triticum aestivum) and durum (T. turgidum var. durum) wheat varieties are grown in Ethiopia primarily as highland rainfed crop. Mean wheat yields are around 1.4 t/ha, well below experimental yields of over 5 t/ha (Hailu,2006). Ethiopia's current annual wheat production of approximately 1.3 million tons is insufficient to meet domestic needs, forcing the country to import 30 to 50% of the annual wheat grain required.

In Ethiopia, wheat is grown primarily as a rain-fed crop by smallholders in the highlands. A very small area has also been grown as a winter crop under irrigation on state farms at lower elevations (Jamal 1994). Bread wheat accounts for roughly 60% of total wheat production and nearly all cultivars are derived from modern, semi-dwarf wheat. Durum wheat accounts for most of the remaining 40%, although emmer wheat (T. dicoccum L.) is also grown. Bread wheat is produced at slightly higher elevations and on better drained soils than durum wheat, which is primarily found on poorly drained vertisols. Because water deficits and warm night temperatures seemed to be key factors delimiting bread wheat production areas in Ethiopia. Growing wheat under those conditions might require cultivars with more drought tolerant cultivars, supplemental irrigation from small catchments, or agronomic practices such as reduced tillage and residue retention—that reduce runoff (Hailu 1991).

2.3. Water and Agricultural production

Adverse environmental factors, of which water scarcity represents the most severe constraint to agriculture, account for about 70 percent of potential yield loses worldwide (Boyer, 1982). Agriculture is the largest consumer of water in the world, and in the drier areas of the world, which include many developing countries; the use of water for agriculture can exceed 90 percent of consumption. Global warming is also predicted to affect most severely developing countries, where agricultural systems are most vulnerable to climatic conditions and where small increases in temperature are very detrimental to productivity. FAO (2007) estimates that by 2025 approximately 480 million people in Africa could be living in areas with very scarce water, and that as climatic conditions deteriorate; 600,000 square km currently classed as moderately constrained will become severely limited. Water becomes an increasingly scarce and precious commodity. It is thus essential to improve water use efficiency in agriculture. This will require an integrated approach to water resources management to encourage an efficient and equitable use of the resource, and to ensure sustainability. The development of crop varieties with increased tolerance to drought both by conventional breeding methods and by genetic engineering is an important strategy to meet global food demands with less water.

2.4. Breeding for drought tolerance

Plant breeding, the science of crop improvement, has played a significant role in developing wheat cultivars that can grow well under a wide range of environments. It is believed that improved wheat cultivars will photosynthesize more efficiently and convert a greater portion of biomass to grain yield. Accordingly, the best option for crop production, yield improvement, and yield stability under soil moisture deficient conditions is to develop drought tolerant crop varieties. Developing high-yielding variety which will yield economical during a water shortage through conventional breeding requires the identification of genetic variability to drought among crop varieties, or among sexually compatible species, and introducing this tolerance into lines with suitable agronomic characteristics. Although conventional breeding for drought tolerance has and continues to have some success, it is a slow process that is limited by the availability of suitable genes for breeding. On the other hand it is also desirable that its morph-physiological features should make the plant able to utilize water in the most efficient way under dry conditions, with minimization of water losses and simultaneous maximization of water uptake (László Cseuz 2009). The development of tolerant crops by genetic engineering, on the other hand, requires the identification of key genetic determinants underlying stress tolerance in plants, and introducing these genes into crops. Drought triggers a wide array of physiological responses in plants, and affects the activity of a large number of genes: gene expression experiments have identified several hundred genes which are either induced or repressed during drought (Sahi, et. al., 2006). Genetic improvement of crops for drought resistance requires a search for possible physiological components of drought resistance and the exploration of their genetic variation. Approach for breeding under water-limited conditions does not utilize multiple physiological selection criteria, but aims to establish a single drought-resistant character which will benefit yield under water-limited conditions and then to incorporate it into the existing breeding programme. Consequently, there have been many suggestions that improvement in yield could be achieved by identifying physiological characteristics or traits which could be included in a set of selection criteria by plant breeders (Lacape et al. 1998; Alves and Setter 2000). Turner and Nicolas, (1987) suggested that physiological approach would be the most attractive way to develop new varieties rapidly.

2.5. Importance of physiological traits in plant breeding

Until the year 2020 at least, demand for wheat is expected to grow by approximately 1.6 percent/year worldwide and by 2 percent/year in developing countries (Rosegrant et al.,2001). This implies a need to almost double the world average wheat yields in that period, and recent rates of yield growth, as well as improvement in genetic yield potential are too low to keep pace with future demand (Sayre et al., 1997). Direct selection for yield in dry environments is inefficient due to large seasonal variation in weather and generally a large genotype x environment interaction, resulting in low heritability for yield, it would seem that selection for an underlying physiological trait that limits yield could be effective and contribute substantially to yield improvements. Richards et al., (2002) outlined the importance of physiological approach to yield improvement, which are, increase genetic variability in traits for further yield progress, result in faster response to selection as physiological traits may have a higher heritability than yield, enable out-of-season selection, be more cost effective in comparison to yield evaluation, be more amenable to marker-assisted selection, and lead to pyramiding multiple yield-enhancing traits. Breeders, as well as physiologists, generally agree that future successes will be realized through a greater integration of interdisciplinary research (Jackson et al., 1996). Thus, there is an urgent need to develop new and more efficient wheat breeding methodologies to complement existing breeding techniques, as well as to identify new traits, which will drive faster yield gains. Several research studies (Richard, et.al 2002; Munns 2010; and Boyer et.al 2008) suggested that physiological selection traits have the potential to improve genetic yield gains in wheat. In addition, work emphasizing genetic improvement under marginal environments has illustrated that physiological traits, including canopy temperature depression, when measured in hot selection environments in Mexico, were strongly associated with performance in yield trials at a number of warmer wheat-growing regions worldwide (Reynolds et al., 1994).

2.6. Drought tolerance and resistance

Usually, any environmental factor capable of inducing a potentially injurious strain in plants may be defined as stress. A stress factor can be any external constraint that limits the rate of dry matter production of all or part of the plant. Plant growth under environmental stress requires physiological or biochemical adaptations. Such adaptations are expected to result in physiological, biochemical and morphological heterogeneity amongst plants. Drought resistance and drought tolerance are general terms used to describe a wide range of water usage issues. In agriculture, drought resistance refers to the ability of a crop plant to produce its economic product with minimum loss in a water-deficit environment relative to the water-constraint-free management.

2.7. Drought adaptation mechanisms in Wheat

Plants response to changing environment in a complex; integrated way that allows them to react to the specific set of conditions and constraints present at a given time. Therefore, the genetic control of tolerance to a biotic stresses is not only complex, but is also highly influenced by other environmental factors and by the developmental stage of the plant. Responses that can determine wheat cultivar adaptation to drought are: (1) drought escape, (2) drought avoidance, and (3) drought tolerance (Ludlow and Muchow, 1990).

Drought escape is defined as the ability of a plant to complete its life cycle before serious soil and plant water deficits develop. This mechanism involves rapid phenological development (early flowering and early maturity), developmental plasticity (variation in duration of growth period depending on the extent of water-deficit) and remobilization of pre anthesis assimilates to grain.

Drought avoidance is the ability of plants to maintain relatively high tissue water potential despite a shortage of soil-moisture. Drought avoidance is performed by maintenance of turgor through increased rooting depth, efficient root system and increased hydraulic conductance and by reduction of water loss through reduced epidermal (stomatal and lenticular) conductance, reduced absorption of radiation by leaf rolling or folding and reduced evaporation surface (leaf area) (Turner, 1986).

Drought tolerance is the ability to withstand water-deficit with low tissue water potential. The responses of plants to tissue water-deficit determine their level of drought tolerance. The mechanisms of drought tolerance are maintenance of turgor through osmotic adjustment (a process which induces solute accumulation in cell), increase in elasticity in cell and decrease in cell size and desiccation tolerance by protoplasmic resistance (Ugherughe, 1986).

2.8. Physiological traits associated with drought tolerance

2.8.1. Leaf Area Index

Leaf Area Index (LAI) represents the amount of leaf material in an ecosystem and is geometrically defined as the one sided green leaf area per unit ground area in broadleaf canopies, or as the projected needle leaf area per unit ground area in needle canopies. The LAI of plant canopies plays an important role in controlling the interactions between terrestrial environments and atmospheric variables. Monitoring the distribution and changes of LAI is important for assessing growth and vigor of vegetation on the planet. It is fundamentally important as a parameter in land-surface processes and parameterizations in climate models. This variable represents the amount of leaf material in ecosystems and controls the links between biosphere and atmosphere through various processes such as photosynthesis, respiration, transpiration and rain interception.

The interaction between vegetation surface and the atmosphere, e.g. radiation uptake, precipitation interception, energy conversion, momentum and gas exchange, is substantially determined by the vegetation surface (Monteith and Unsworth, 1990). LAI of plants, especially grasses, consists of photosynthetically active green and senescent leaves. Even though old leaves do not influence photosynthesis, they still play an important role in intercepting precipitation. Therefore, as in the case of modeling water interception, a LAI greater than zero has to be maintained throughout the year for forests and pasture species in contrast to agricultural sites

2.8.2. Water related traits

A number of studies (Merah, 2001; Sinclair and Ludlow 1985; and Boyer et al., 2008) considered various physiological traits (excised leaf water loss, relative leaf water content, leaf water potential, leaf temperature, water use efficiency and initial water content) which are related to drought resistance in wheat genotypes.

Relative water content (RWC), excised leaf water loss, excised leaf water retention has been reported as an important indicator of water stress in leaves (Merah, 2001). RWC is closely related to cell volume, therefore it may more closely reflect the balance between water supply to the leaf and transpiration rate (Farquhar et al. 1989). This influences plant ability to recover from stress and consequently affect yield and yield stability (Jones et al. 1989). Sinclair and Ludlow (1985) proposed that leaf relative water content and excised leaf water retention was a better indicator of water status than was water potential. Measurement of relative water content involves hydrating detached leaves for 3–4 h in distilled water, and measuring the increase in water content relative to the dry weight (protocol described by Munns, 2010, in Prometheus Wiki). RWC measures the dehydration of a leaf, and is useful for assessing changes in leaf water status when osmotic adjustment has not occurred (Boyer et al., 2008).

2.9. Drought tolerance indices

Drought tolerance indices which provide a measure of drought based on yield loss under drought conditions in comparison to normal conditions have been used for screening drought-tolerant genotypes (Mitra, 2001). These indices are either based on drought resistance or susceptibility of genotypes.

2.9.1. Drought resistance index

Fernandez (1992) defined a new advanced index, the stress tolerance index (STI), which can be used to identify genotypes that produce high yield under both stressed and non-stressed conditions. Drought resistance index is the relative yield of a genotype compared to other genotypes subjected to the same drought stress (Hall, 1993).

There is interest in identifying drought resistance of a cultivar beyond its capacity for potential yield and drought escape. With this analysis drought resistance index (DRI) is identified as variation in grain yield under stress which is not explained by yield potential and drought escape (Bidinger et al. 1982). Jafari et al. (2009) observed that stress tolerant index (STI) was more useful in order to select favorable corn cultivars under stressful and stress-free conditions. Khalili et al. (2004) also showed that based on GMP and STI indices, corn hybrids with high yield in both stress and non-stress environments could be selected.

Drought tolerance index is given by Fernandez (1992) as; DRI = (Ys/Yn)/(Ms/Mn),

Where, Ys and Yn are the genotype yields (or biomass) under stress and non-stress respectively and Ms and Mn are the mean yields (or biomass) over all genotypes in the given test under stress and non-stress respectively.

2.9.2. Drought Susceptibility Index and Drought tolerance Efficiency

These indices are yield stability parameters which are based on how much reduction is realized under drought stress. Drought susceptibility of a genotype is often measured as a function of the reduction in yield under drought stress, whilst the values are confounded with differential yield potential of genotypes (Ramirez and Kelly, 1998). Parameshwarappa et al. (2008) reported that the minimum yield reduction in chickpea genotypes was shown in a line which had the highest DTE and the lowest DSI. Some researchers announced that the cultivars which had the lowest DSI values were drought resistant than the cultivars with the highest DSI values (Ghodsi, 2004; Golabadi et al., 2006; Sio-Se Mandeh et al., 2006). Ahmad et al., 2003 suggested that DSI can be used for identification of genotypes with yield stability in moisture stressed environments. Clarke et al. (1992) used SSI for evaluation of drought tolerance in wheat genotypes and found a year-to-year variation in SSI for genotypes and their ranking pattern. In spring wheat cultivars, Guttieri et al. (2001) using SSI criterion suggested that SSI more than 1 indicating above-average susceptibility and SSI less than 1 indicated below-average susceptibility to drought stress.

DSI = (1 - Yd/Yp)/D (Fischer and Maurer, 1978)

Yd = Grain yield of the genotype under moisture stress Yp = Grain yield of the genotype under non-stress D = 1- (Mean yield of all genotypes under stress / Mean yield of all genotypes under non-stress)

DTE (%) = (Yield under stress /Yield under non-stress) * 100 (Fischer and Wood, 1981).

2.9.3. Stress tolerance and mean productivity

Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between the stress and non-stress environments and mean productivity (MP) as the average yield of yield under stress and non stress. Mitra, (2001), defined a new advanced index (STI = stress tolerance index), which can be used to identify genotypes that produce high yield under both stress and non-stress conditions. Other yield based estimates of drought resistance are geometric mean (GM), mean productivity (MP) and TOL. Golabadi et al. (2006) and Sio-Se Mardeh et al. (2006) suggested that selection for drought tolerance in wheat could be conducted for high MP, GMP and STI under stressed and non-stressed environments.

2.10. Correlation and regression analysis in wheat breeding

Yield is the product of its several component traits developing sequentially in the ontogeny of wheat plants. The yield, yield component, physiological and agronomic traits are all influenced by the changes in the growing environment and the plant inheritance (Sanjari, 1994). Moreover yield is a complex trait which is the result of environmental factors as well as interaction of many minor-effect characteristics by low heritability especially under dryland condition (Blum, 1988). The morpho-physiological trait based breeding approaches has merit over breeding solely on the basis of grain yield (Condon et al., 2004). Royo et al., 2003 reported that the efficiency of selection will increase especially in early generations or when the yield may not be properly evaluated. A great number of physiological traits have the potential to improve crop performance under abiotic stress (Araus et. al., 2002; Richards, 2006). The existence of correlation between different traits with grain yield under drought stress shows compatibility with drought conditions is not unexpected (Richards et.al. 2003)**.**

Information on the correlation and regression coefficient is of considerable importance in selection practice for the prediction of correlated response (Larner, 1958).The degree of association between plant traits are determined by correlation coefficient and the rate of change in one trait due to changes in the other measured by regression coefficient (Ikiz et al., 2006). Mohamed (1999) reported that Correlation coefficient is an important statistical procedure to evaluate breeding programs for high yield, as well as to examine direct and indirect contribution of the yield variables and multiple linear regressions proved to be more efficient than the full model regression to determine the predictive equation for yield (Naser and Leilah, 1993; Mohamed, 1999). Correlation analysis is widely used in statistical evaluations and it shows efficiency of relationship between two variables (Rees, 1995; Ozdamar, 1999). Furthermore Ozdamar, 1999; Hiltbrunner et al., 2007 reported that correlation and path analyses are important procedures to examine yield, and direct and indirect contribution of yield components and they have been successfully used in wheat breeding programs (Massart et al., 1997). Thus traits that are significantly correlated with yield and drought tolerance index can be used as selection criterion for yield and drought tolerance. Regression analysis is efficiently used in modeling crop yield (Ozdamar, 1999; Ikiz et al.,2006) and is used to reveal individual effects of independent variables on dependent one (Naser and Leilah, 1993). Hence traits that explained more of the variation on the dependent variable would be included in the model and used for selection. On top of that precision of model is heavily depends on effectiveness and number of components considered on yield and its analysis could be confidently used in prediction of yield components in wheat (Andales et al., 2007). Regression analysis is the better way to make crop yield prediction (Massart et al., 1997; Qingwu et al., 2006). Andales et al. (2007) precisely predicted wheat yield by linear regression model.

2.11. Multivariate analysis and principal component in breeding program

Plant breeders, geneticists and agronomists are increasingly faced with theoretical and practical questions of multivariate nature. With increases in germplasm sizes, number of plant and crop variables and evaluation and characterization data on molecular, biochemical, morphological and agronomic traits. Multivariate data analysis facilitated a graphic display of the underlying latent factors and interface between individual samples and variables (Nielsen and Munck 2003). Multivariate statistical techniques which simultaneously analyze multiple measurements on each individual under investigation, are widely used in analysis of genetic diversity irrespective of whether it is morphological, biochemical or molecular marker-based and subsequently, classification of germplasm collections. Among the multivariate techniques, principal component analysis (PCA) is most commonly employed and appear particularly useful (Mohammadi and Prasanna, 2003). Principal component analysis has been widely used in plant sciences for the reduction of variables and grouping of genotypes. Hotelling (1933) indicated that principal component analysis is an exploratory tool designed by Karl (1901) to identify unknown trends in a multi-dimensional data set. Kamara et al. (2003) used PCA to identify traits of maize (*Zea mays* L.) that accounted for most of the variance in the data. In principal component analysis, one of the most commonly used criteria for solving the number-of-components problem is the eigenvalue-one criterion, also known as the Kaiser criterion (Kaiser, 1960). With this approach, it can be retain and interpret any component with an eigenvalue greater than 1.00. Granati et al. (2003) used PCA to investigate the relationship among Lathyrus accessions. Žáková and Benková (2006) identified traits that were the main sources of variation of genetic diversity among 106 Slovakian barley accessions using the principal component analysis. Cartea et al. (2002) and Salihu et al. (2006) used PCA and cluster analysis to group kale populations and winter wheat genotypes, respectively. Factor analysis (FA) and principal component analysis identified some similar characters as the most important for classifying the variation among corn hybrids. While PCA does not rely on any statistical model and assumptions, factors analysis does. It is also imperative to note that factor analysis suffers from other drawbacks, such as absence of “error” structure and the dependence upon scale used to measure the variables (Bartual et al., 1985).

CHAPTER THREE

3.0. Materials and methods

3.1. Plant Material

Six wheat varieties; Hawii, Dandea, Shina, Medawalabu, Mekelle 4 and Mekelle 3 were used in this study (Table 1). Seed for Hawii, Dandea, Shina and Medawalabu was obtained from Alamatta Agricultural Research Center while seed for Mekelle 4 and Mekelle 3 was obtained from Mekelle Agricultural Research Center and sown under irrigated conditions in pots on 25th Feb. 2012 in green house experiment and second in outdoor and sown on 6th March 2012 and relevant metrological parameters were obtained from the observatory for the field and recorded for the green house.

3.2. Experimental design

Experiment was conducted in the field and green house using pots to evaluate the physiological and agronomic response of six wheat genotypes under three water stress regimes following the methodology of Zadock *et al*., (1974). Plants were subjected to water stress at different growth stages: 1) well watered control treatments. 2) water stress at tillering (23 and 20 days after planting in the field and green house experiments, respectively), 3) stress at booting stage (45 and 40 days after planting in the field and green house experiments, respectively). Pots were arranged in Randomized Complete Block Design (RCBD) in factorial combination of the six wheat genotypes and three water regimes with three replications. There were a total of 18 treatment combinations. The combination of the three water stress regimes and the genotype were randomly assigned to the experimental pots in each block. In all water stressed pots, water stress was maintained by withholding water for 10 days at the selected growth stage. Seed of each genotype was sown in pot of 50 cm deep and 34cm wide in case of green house and 65 cm deep and 40 cm wide in the field. The pots are equipped with drainage holes and 10 seed per pot were sown. One liter of water was added to each pot every other day except during the water stress period. All other agronomic management practices (weeding, application of fertilizer, seed rate, soil preparation e.t.c) were uniformly applied to all experimental pots.

All those cultural practices were carried out as recommended for wheat production in this area. The seed rate was 120 kg/ ha; hence 1.09 and 1.5g was used for the green house and field pots respectively.

Table 1. Name of genotypes used for drought tolerance assessment

S. No	Common name	Genotype code	Breeder	Year of release
1	Hawii	HAR 2501	SARC/OARI	1999/2000
2	Shina	HAR 1868	ADARC/ARARI	1998/99
3	Medawalabu	HAR1480	KARC/EIAR	1999/2000
4	Mekelle 3	M17SWASN79	MARC	2012
5	Mekelle 4	FRET1	MARC	2012
6	Dandea	Danphe	KARC	2010

3.3. Data collection

Data was measured and recorded on the following physiological, agronomic, yield and yield components during the experimentation.

Physiological /Water related traits;

Water related traits were estimated on the first fully expanded leaf (third from top) at vegetative stage (Figure 1) and flag leaf at grain filling stage.

Leaf area (cm^2); flag leaf was used to measure leaf area in cm^2 using the leaf area meter at grain filling stage (Figure 1)

Relative water content (RWC %); RWC was measured at stem elongation using the third leaf from the top and at grain filling stage using flag leaves after imposing drought conditions. Immediately after cutting at the base of lamina, leaves were sealed within plastic bags and quickly transferred to the lab. Fresh weight (FW) was determined within 1h after excision. Turgid weight (TW) was obtained after soaking leaves in distilled water in test tubes for 16 hours at room temperature (25^oC). After soaking, leaves were quickly and carefully blotted dry with tissue paper in preparation for determining turgid weight. Dry weight (DW) was obtained after oven drying the leaf samples for 72 hours at 70ºC. RWC was calculated from the formula:

RWC % = [(fresh weight - dry weight) / (Saturated weight - dry weight)] x 100 (Slatyer (1967)

Excised leaf water retention (ELWR %): ELWR was measured at grain filling stage using the flag leaf. The flag leaves were collected and weighed and then kept at 30ºC for 5 hours and reweighed. ELWR was then calculated using the following formula:

ELWR = [1-(weight of fresh leaves – weight of leaves after 5 hours)/ weight of fresh leaves]×100

Rate of water loss (RWL %): RWL was computed in percentage using flag leaf at grain filling stage . The flag leaves were collected and weighed (W1). The leaves were wilted at 30ºC and re-weighed three times at an interval of 2hours (w2, w4, w6) and transferred to an oven for 24 h and weighed (Wd)

RWL= [(W0-W2) + (W2-W4)+(W4-W6)]/(3*Wd)(t2-t1) (McCaig and Romagosa (1989)

Where (t2-t1) = time interval between two subsequent measurement W0= Fresh weight;

W2, W4, W6= weight after 2hr, 4hr and 6hr respectively Wd = dry weight of the flag leaf

Initial water content (IWC): IWC was calculated at both stem elongation using the third leaf from the top and at grain filling stage using the flag leaf as: (W0-Wd)/Wd

W0 = fresh weight, Wd= leaves placed in an oven at 50º C for 24 h and re-weighed.

Drought tolerance indices were computed on the basis of grain yield per plant to determine whether genotypes with high yield potential are drought tolerance varieties and yield is associated with drought tolerance indices as follows;

Mean productivity (MP) = (Ys +Yn)/2 (Rosielle and Hamblin, 1981)

Yield stability index (YSI) = Ys/Yn (Bouslama and Schapaugh, 1984)

Stress susceptibility index (SSI) = (1-(Ys/Yn))/(1-(YMs/YMn) (Fischer and Maurer, 1978)

Stress tolerance index (STI) = (Ys/Yn)/(YMs/Mn) (Fernandez ,1992)

Where: Ys and Yn are the genotype yields under stress and non-stress respectively and YMs and YMn are the mean yields over all genotypes in the given test under stress and non-stress respectively

Agronomic parameters; During the growth period, five randomly selected plants were used to measure plant height (from the ground level to the top of the spike excluding the awns) , number of tiller per plant, day to 50% flowering, spike length, grain per spike, 1000grain weight, grain yield per plant.

3.4. Data analysis

Data was explored using the descriptive ANOVA (mean), and normality of the data was determined using Skewness /Kurtosis tests for normality in STATA-version 11. Multivariate Analysis of variance (MANOVA) was performed on all collected (physiological, agronomic, yield and drought tolerance indices) data to determine the overall difference among the genotype and water stress treatments and then ANOVA was performed for each trait using Genstat version 13 and treatment mean was compared using Duncan's multiple range tests. Pearson's (product moment) correlation coefficient was estimated to identify the relationship between different traits, yield and drought tolerance indices. Principal component analysis were performed to find a pattern in the data and to determine the traits associated with yield and drought tolerance. All subset Regression analysis was also conducted to determine the independent variable(s) that could best predict drought stress tolerance and yield. Akaikes Information Criterion (AIC), Adjusted R^2 and probability was used to enter and select the best model. Graphs were drawn using MS Excel and STATA software.

Regression model for the dependent variable (yield and STI) on the independent variable (physiological, agronomic and yield component) would be given as follows.

$$Yi= \alpha + \beta_1 X1 + \beta_2 X_2 + \beta_3 X_3 + \ldots\ldots + \beta_k X_k + e_{ijk}$$

Where α is the intercept

βi (i= 1….k) is the regression coefficient associated with the independent variable Xi (physiological or Agronomic parameter)

Yi = dependent variable (water stress tolerance index, Yield)

e_{ijk}; random error (residual) associated with the y_{ijk} experimental unit

Statistical Model of the design

The model for the factorial (two factor) experiment with RCBD design is given by;

$y_{ijk} = \mu + Wsri + Vj + WsrVij + B_k + e_{ijk}$

Where $y_{ijk=}$ the observed value for the k^{th} block of the i^{th} water stress regime and the j^{th} variety

μ= the grand mean (the overall mean of the observation) Wsri=main effect of i^{th} water stress regime

Vrj= main effect of j^{th} variety   WsrVij= the interaction effect of water stress and variety

$Bk_{=}$ k^{th} Block effect $e_{ijk=}$ random error (residual) associated with the y_{ijk} experimental unit.

Figure 1. Experimental pots , sampling and measurements

CHAPTER FOUR

4.0. Results and Discussion

4.1. Weather data for the study area

Data for mean monthly maximum and minimum temperatures as well as relative humidity was recorded during all growth stages for the green house experiment where as for the field experiment data was obtained from the meteorology station (Figure 2 and 3). The difference in mean temperature and relative humidity of the green house and field is presented in Appendix 1. The data shows that both mean minimum and maximum monthly temperature was higher in green house than in the field. The mean maximum temperature (38^{o}C) in green house occurred in May. While in the filed the mean maximum temperature was 27^{o}C and occurred in April. However relative humidity was higher in the field except in March.

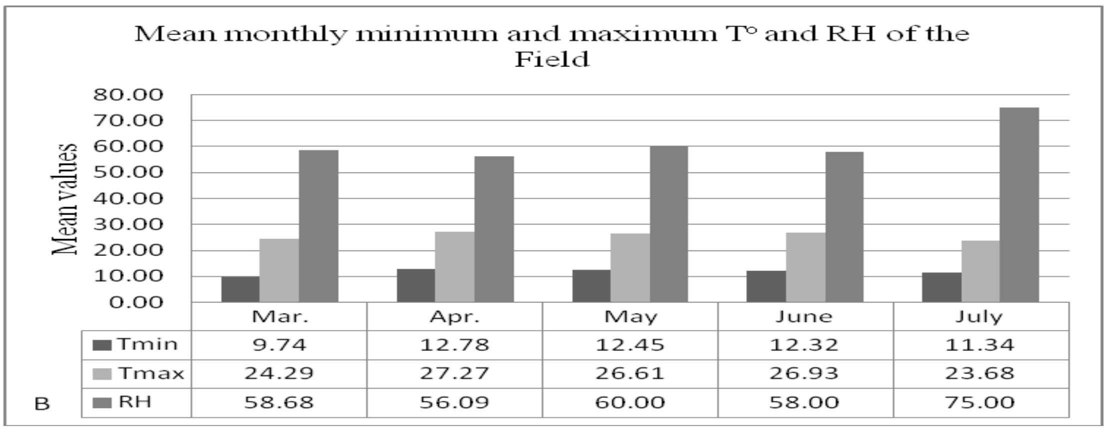

Figure 2. Mean monthly minimum and maximum temperature of field

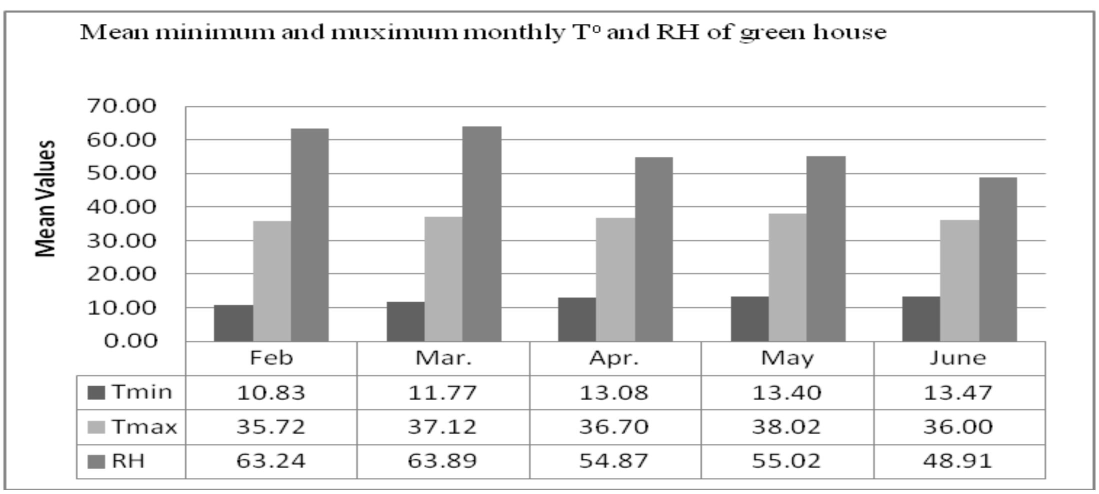

Figure 3. Mean monthly minimum and maximum temperature of green house

4.2. Agronomic, physiological, and yield performance of wheat genotypes

4.2.1. Agronomic performance of the genotypes

Analysis of variance on the data computed for the characterization of agronomic parameters; days to heading, number of tillers, plant height, leaf area and day to flowering revealed significant difference ($p<0.001$) among the genotypes in both green house and field tests (Table 2). Genotypes showed differential response for the agronomic traits under water stress regimes. The mean performance of studied wheat genotype for the studied trait under field and green house condition is given in Appendix 2, 3, 5 & 6. A significant difference on water stress regimes was observed as well except for tiller number (Table 2). The water stress × cultivar interactions were significant only for days to heading (Table 2) in field and for both days to heading and flowering in green house test. This interaction revealed that genotypes performed differently over the water stress conditions for days to heading and flowering.

Table 2. Mean square of wheat genotype for PH, DF, DH, Tiller, and LA under water stress regimes.

S.V	d.f.	PH		DF		DH		Tiller		LA(cm^2)	
		GH	Field	GH	Field	GH	Field	GH	Field	GH	Field
Block	2	3.37	2.074	7.57	13.2	0.17	14.6	0.4	0.04	0.30	0.96
WSR	2	104.9**	310.8**	934**	622**	1054**	697**	0.4^{ns}	0.8^{ns}	31.5**	8.9**
Gen	5	26.64*	71.14**	47**	33**	41.9**	47**	1.2**	0.8**	17.1**	3.19*
WSR.Gen	10	11.64**	5.55^{ns}	31**	11^{ns}	22.5**	16.4*	0.3^{ns}	0.5^{ns}	0.2^{ns}	1.03^{ns}
Residual	34	8.20	6.388	7.79	6.03	1.09	6.7	0.17	0.26	0.32	1.254
CV		8.0	4.6	4.3	3.5	1.8	4.1	10.3	12.6	4.5	8.7

ns, *, **, sequentially non significant and significant in 5% and 1% WSR= Water Stress regimes, Gen= Genotypes, CV: Coefficient of variation, PH= plant height DF= days to flowering, DH= days to heading, Tiller= number of tiller per plant, LA= Leaf Area, GH= Green house

For the traits plant height, number of tillers and days to flowering the mean comparison was done in combination of the different water stress conditions as the interaction was not significant for those traits and the mean comparison of genotypes for day to heading was done separately for each water stress regimes.

Plant height Analysis of variance (Appendix 8.1) revealed the main effect of water stress and genotype has shown a significant difference on plant height indicating a variation in plant height among the genotypes. Water stress significantly reduced the plant height for all genotypes. Water stress at tillering stage reduced plant height by 3.5cm (5.9%) and by 8.28 cm (14%) when water stress was imposed at booting stage in field. The mean comparison for the genotype indicates that genotypes Dandea and Hawii had significantly higher plant height than Mekelle3, Mekelle4 and Medawalabu. While Shina has shown the lowest plant height (50.22cm) which is significantly lower than the genotypes Mekelle3, Mekelle4 and Medawalabu. In green house tests genotypes Medawalabu, Mekelle3 and Dandea had shown the highest plant height than the other genotypes (Table 3). Water stress at both tillering and booting stages reduced plant height by 3.8cm and 8.28cm, respectively. The results showd that water stress at booting stage significantly reduced plant height than water stress imposed at tillering stage. Malik and Hassan, (2002) and Khanzada *et al*., (2001) have also reported that shoot length of guar genotypes were significantly reduced under water stress. Similarly Inamullah *et al*., (1999) observed that plant height of wheat varieties was reduced significantly under water stress compared to irrigated conditions.

Days to flowering: A significant difference was observed in days to flowering among the genotypes and water stress regimes at green house and field tests (Table 2). However water stress and genotype interaction were also significant in green house condition indicating that genotype perform differently at different water stress regimes. Mean genotype comparison for the field experiment showed that Hawii took the shortest time (66.44 days) to flowering while Shina took longest time to flowering (71.78). Water stress at tillering stage also increased the time to flowering by 10 days (15%) in field and by 11 days (17%) in green house experiment which are significantly higher than at normal condition. However days to flowering was not significantly affected when water stress was imposed at booting stage (Table 4).

Number of tillers: A significant difference was detected in number of tillers among genotypes. The mean comparison among the genotypes indicates that Dandea, Mekelle4 and Medawalbu had the highest number of tillers though were significantly different in both tests. The lowest numbers of tillers were observed in Hawii, Shina and Mekelle3 (Table 3). Significant differences were not observed between the water stress treatments and this may be attributed to the stage at which water stress was imposed.

Table 3. Mean estimates for number of tillers, plant height, leaf area and days to flowering for the genotypes under field and green house condition.

Genotype	**PH**	**DF**	**Tiller**		**LA(cm^2)**	
	Field	**Field**	**Field**	**GH**	**Field**	**GH**
Dandea	58.11a	70.11ab	4.334a	4.408a	12.25b	12.73c
Mekelle3	54.78b	69.22b	3.852ab	4.000a	13.90a	14.75a
Mekelle4	55.22b	71.33ab	4.222a	4.037a	12.43b	13.36b
Medawalabu	55.11b	69.11b	4.296a	4.147a	13.12ab	11.25e
Shina	50.22c	71.78a	3.704b	3.594b	13.97ab	11.13e
Hawii	57.67a	66.44c	3.667b	3.444b	12.67b	12.03d
CV	4.6	3.5	12.6	10.3	8.7	4.5
S.e	0.842	0.818	0.1686	0.1357	0.373	0.1894
S.e.d	1.191	1.158	0.2384	0.192	0.528	0.2678

CV:Coefficient of variation; S.e: Standard error of the mean; S.e.d: standard error of the difference; Non similar letter in each column show significant difference among the genotypes at 5% probability

Leaf area: A significant difference was detected among the genotypes and water stress significantly affected the leaf area of the genotypes (Table 2). However water stress and genotype interaction were not significant for the traits. Mean genotype comparison (Table 3) indicates that Mekelle3 had the largest leaf area of $13.90cm^2$ and $14.75cm^2$in field and green house conditions, respectively. Although a significant difference was not detected among the other genotype the lowest leaf area was observed for Hawii ($12.67cm^2$) and Mekelle4 ($12.43cm^2$) in field condition while in the green house Medawalabu and shina had shown the smallest leaf area. This shows that genotypes perform differently in green house and field condition and this may be due to the difference in temperature and relative humidity between the study sites. For instance genotype Medawalabu and shina had the largest leaf area when the temperature is lower (field) and the smallest when the temperature is high (green house). Thus some genotypes perform well when the temperature is high while others when the temperature is optimum and this is what we called the genotype environment interaction. The mean comparisons for water stress regimes showed that water stress at booting stage significantly reduced the flag leaf area for all genotypes. However water stress at tillering stage did not significantly reduced the flag leaf area in the field condition, where as in the green house water stress at both stage significantly reduce the flag leaf area (Table 4). Water stress at booting stage reduced the flag leaf area by 1.41 cm^2 (10.4%) in the field and by 2.37 (17.2%) cm^2 in green house.

Table 4. Mean estimates for leaf area, days to flowering and plant height under different water stress regimes at field and green house conditions

Water stress	**PH**	**DF**	**LA(cm^2)**	
	Field	**Field**	**Field**	**GH**
Control	59.11a	66.61b	13.57a	13.77a
Tillering	55.61b	76.44a	12.98a	12.71b
Booting	50.83c	65.94b	12.16b	11.14c
CV	4.6	3.5	8.7	4.5
S.e	0.596	0.579	0.264	0.1339
S.e.d	0.842	0.818	0.373	0.1894

CV:Coefficient of variation; S.e: Standard error of the mean; S.e.d: standard error of the difference; Non similar letter in each column show significant difference between water stress regimes at 5% probability

Days to heading: the analysis of variance indicates that water stress and genotype interaction was significant. The mean comparison for the interaction on days to heading (Table 5) showed that genotypes performd inconsistently at different water stress regimes but over all water stress at tillering stage increased the days to heading in all genotypes. The mean comparison for the interaction on day to heading (Table 5) showed that Genotype Medawalabu took the longest time (74days) to head when water stress was imposed at tillering stage. Genotypes Shina and Mekelle4 took 62.67 and 62 days to head at normal water regime. Both varieties also took 61.67 and 63 days when water stress was imposed at booting stage. Hawii however had the shortest days to heading (54 days) when water stress was impossed at booting and while it took 55.67 days to head at normal conditions. Mekelle3 however had the shortest time to head when water stress was imposed at tillering stage (Table 5). 17.86% increment in days to heading was observed when water stress was imposed at tillering stage as compared to the control.

Table 5. Water stress and genotype interaction effect on day to heading, of the wheat genotypes under field condition

Genotype	Booting	Control	Tillering
Dandea	59fgh	60fg	70abc
Mekelle4	59.33fgh	59fgh	65.67de
Hawii	54i	55.67hi	68.33cd
Mekelle3	59.33fgh	59fgh	65.67de
Medawalabu	57.33ghi	57ghi	74a
Shina	61.67ef	62.67ef	72.67ab
R.D	0.564		-17.865
CV		4.1	
S.e		1.498	

4.2.2. Physiological water related traits

The analysis of variance (Appendix 8.2) revealed a significant difference among the genotypes for all water related studied traits and water stress also showed a significant effect in both tests for traits except excised leaf water retention at grain filling stage in field experiment (Table 6). The interaction was also significant for initial water content at stem elongation and relative water content at grain filling stage and this interaction illustrate that genotypes performed disconnectedly over the different water stress regimes. However the interaction for rate of water loss, excised leaf water retention, initial water content at grain filling stage relative water content at stem elongation stage were not significant which indicates that the genotype perform consistently at the different water stress regimes and this notifies an important criteria for screening drought tolerance of wheat genotypes. Significant variation due to genotypes for the traits suggests that the magnitude of difference in genotypes was sufficient to provide some scope for selecting traits of drought tolerance in wheat genotypes.

Table 6. Mean squares of wheat genotype for water related traits under water stress regimes.

S.V	d.f.	RWLg		ELWR		IWCg		IWCs		RWCg		RWCs	
		GH	Field	GH	Field	GH	Field	GH	Field	GH	Field	GH	Field
Block	2	4.1	19.1	1.4	15.8	0.0	0.0	0.1	0.0	9.4	0.8	27.5	1.8
WSR	2	291**	202**	159.9**	13.88^{ns}	2.3**	2.59**	2.49**	3.4**	830.3**	1823.7**	1110**	1031**
Gen	5	106**	957**	120.2**	216.6**	1.1**	2.41**	0.68**	2.9**	193.9**	375.15**	211**	189.8**
WSR.Gen	10	2.04*	15.2^{ns}	11.56^{ns}	5.732^{ns}	0.01^{ns}	0.01^{ns}	0.03^{ns}	0.2**	13.37^{ns}	2.34**	68.6**	3.25^{ns}
Residual	34	0.8	18.4	8.2	5.9	0.0	0.0	0.1	0.0	11.9	0.2	16.7	2.3
CV		3.7	9.5	7.7	9.3	4.5	4	6.7	3.5	5.1	0.7	5.4	2

RWCg; relative water content at grain filling stage and RWCs=relative water content at stem elongation RWLg= rate of water loss at grain filling stage

Rate of water loss: The analysis of variance (Appendix 8.2) indicates that water stress affects the rate of water loss for all genotypes and a significant difference was observed among the genotypes (Table 7). Water stress at tillering and booting stage reduced rate of water loss by 7.23% and 9.12% in the field and by 5.85% and 7.71% in the green house experiment (Table 8). This result suggests that the rate at which water evaporates from the flag leaf at grain filling stage was lower when water stress was imposed at booting stage than stress at tillering stage and the magnitude varying from one genotype to another. Whatever the stage were water stress was imposed; the rate of water loss in the studied wheat genotypes was significantly reduced by water stress regimes. The rate of water loss for the genotypes ranges from 29.58 - 54.81% in the field test while it varied from 19.24 to 27.72 in the green house tests. Overall, the rate of water loss was higher in leafs sampled from the field than leafs from the green house and this may be due to the difference in temperature between the sites. Shina had the highest rate of water loss, followed by Medawalabu and Hawii where as genotype Dandea has shown the lowest rate of water loss followed by Mekelle3 and Mekelle4 in both tests (Table7). The lower rate of water loss may indicate that the ability of the genotype to maintain internal water content from evaporation. The same result was obtained from experiment studied by Basal et al. (2005) for excised leaf water loss (ELWL) under water stress and non stressed conditions suggesting that excised leaf water loss could be used as reliable screening criteria for drought resistance. In addition thirty wheat genotypes were evaluated by Munjal and Dhanda (2005) for excised leaf water loss (ELWL), relative water content (RWC) and grain yield per plant (GY) under drought stress (rainfed). They found significant differences due to genotype and genotypes exhibited low ELWL, high RWC and high GY values, indicating that the criterion can distinguish drought resistant from drought susceptible genotypes. Similarly Randhawa et al. (1988) observed varietal differences in leaf water content and water retention. They finally concluded that high leaf water retention (low rate of water loss) may be used as an indicator of drought tolerance.

Excised leaf water retention: The analysis of variance (Appendix 8.2) indicates a significant variation among the genotypes; however water stress regime and the interaction were not significant for ELWR in field experiment. Mean comparison for the genotypes signifies that there is no significant difference between Dandea and Mekelle3 and they had shown the highest water retention 32.54% and 30.58% in field and 42.42 % and 40.34 % in green house, respectively, followed by Mekelle4 (27.80% and 38.41%) which is significantly different from Dandea and Mekelle3 (Table7). The lowest water retention was observed in genotypes Medawalabu, Hawii and Shina however significant difference was not observed among those genotypes. Dandea, Mekelle3 and Mekelle4 showed significantly minimum water loss and better water retention under drought stress conditions. This suggested that these varieties may be able to give good results by avoiding drought through lesser water loss and retaining more water and, therefore, maintaining water balance in leaves. Genotypic variation amongst wheat for excised-leaf water retention, rate of water loss and relative water content at anthesis stage was also reported by Blum (1988), McCaig and Romagosa (1991).

Table 7. Mean performance of wheat genotypes for water related traits under field and green house condition

Genotype	RWLg	ELWR		IWCg		IWCs	RWCs	RWCg
	Field	**Field**	**GH**	**Field**	**GH**	**GH**	**Field**	**GH**
Dandea	29.58f	32.54a	42.42a	2.580a	2.42a	3.785b	79.28a	73.18a
Mekelle3	33.06e	30.58a	40.34ab	2.106b	2.26b	4.161a	77.54b	72.88a
Mekelle4	37.00d	27.80b	38.41b	1.807c	2.12c	3.885b	76.30b	70.34a
Medawalabu	51.79b	22.58c	33.75c	1.396e	1.776d	3.468c	70.32c	63.70b
Shina	54.81a	21.46c	34.23c	1.192f	1.548f	3.510c	68.40d	65.14b
Hawii	47.09c	21.41c	34.44c	1.467d	1.689e	3.508	70.04c	63.01b
Cv	4.2	9.3	7.7	4.0	4.5	6.7	2.0	5.1
S.e	0.585	0.81	0.954	0.0236	0.0296	0.0834	0.503	1.15
S.e.d	0.828	1.145	1.35	0.3334	0.0418	0.118	0.712	1.626

CV:Coefficient of variation; S.e: Standard error of the mean; S.e.d: standard error of the difference; Non similar letter in each column show significant difference among the genotypes at 5% probability

Table 8. Mean physiological traits of wheat genotype under water stress regime at field and Green House conditions.

Water Stress regimes	RWLg	ELWR	IWCg		IWCs	RWCs	RWCg
	Field	**GH**	**Field**	**GH**	**GH**	**Field**	**GH**
Control	47.67a	34.08c	2.094a	2.288a	3.848a	78.43a	75.69a
Tillering	40.44b	37.71b	1.833b	2.035b	3.3b	64.92b	65.70b
booting	38.55c	39.99a	1.347c	1.581c	4.010a	77.59a	62.73c
Cv	4.2	7.7	4.0	4.5	6.7	2.0	5.1
S.e	0.414	0.675	0.01667	0.0209	0.059	0.356	0.813
S.e.d	0.585	0.954	0.02357	0.0296	0.0834	0.503	1.15

CV:Coefficient of variation; S.e: Standard error of the mean; S.e.d: standard error of the difference; Non similar letter in each column show a significant difference among the genotypes at 5% probability

Initial water content (IWC): A significant difference was noticed among the genotypes and water stress regimes for IWC both at stem elongation and grain filling stages. Water stress and genotype interaction were also significant for IWC at stem elongation stages but not at grain filling stage. This suggests that IWC at grain filing stage may be an important selection criterion as the genotype performs consistently at different water stress treatments. Comparing means for IWC amongst genoptes, (Table 7) Dandea had the highest IWC of 3.695 at stem elongation and 2.58 at booting stages followed by Mekelle3 and Mekelle4. A significant difference was not detected between Mekelle3 and Mekelle4 in IWC at stem elongation stage (Table 7). The lowest IWC was observed in Shina 2.088 and 1.192 at stem elongation and grain filling stages, respectively. Hawii and Medawalabu were not significantly different for IWC at stem elongation stage.

These results were is in agreement with McCaig and Romagosa (1989) who evaluated initial water content (IWC) and rate of water loss (RWL) of leaves in tetraploid (Triticum turgidum) and hexaploid (Triticum aestivum) wheat. Those genotypes adapted to dry land exhibited high IWC and/or low RWL, which suggested that both characters may contribute to maintenance of leaf water status under severe drought stress. Hence Dandea, Mekelle3 and Mekelle4 with the highest IWC and lowest RWL could be considered as drought tolerant/ adaptable to water stress while genotype with the highest RWL and low IWC such as Shina and Medawalabu would be the susceptible varieties to water stress. The result also indicated that water content was reduced from the vegetative stage to the grain filling stage that is low water content was observed at grain filling stage on all genotypes.

Relative water content: Significant differences in RWC at stem elongation and grain filling stage was observed on the tested wheat genotypes and water stress regimes. Mean genotype comparison suggests that the difference on RWC at stem elongation was not significant between Mekelle3 and Mekelle4 and between Hawii and Medawalabu as well, whereas at grain filling stage the difference was significant (Table 7). The lowest RWC at stem elongation was recorded in Shina (68.40%) followed by Hawii (70.04%) and Medawalabu (70.32%). The results also showed reduction in RWC in water stressed pots during tillering and booting stages and more reduction were recorded under water stress during booting stages (Table 8). The relative decrease in percentage showed that water stress at booting stage reduced the RWC at grain filling stage by 27.1382% and by 9.989 % when water stress was experienced at tillering stage (Table 9). Genotype Dandea had the highest RWC followed by Mekelle3 and Mekelle4. The interaction for water stress and genotype in the green house experiment regarding RWC at stem elongation indicates that genotype Mekelle3 had the highest RWC followed by Mekelle4 and Dandea when water stressed at tillering stage (Table 10). RWC decreased with water stress in all the genotypes; and this deviation in RWC may be attributed to differences in the ability of the genotypes to absorb more water from the soil and or the ability to control water loss through the stomata's. It may also be due to differences in the ability of the tested varieties to accumulate and adjust osmotically to maintain tissue turgor pressure and hence physiological activities. Similar observations have been reported in common bean (Korir *et al.*, 2006). These findings are also in agreement with those reported by Sinclair and Ludlow (1985). RWC is used extensively to determine the water status of plants relative to their fully turgid condition. According to Beltrano et al., (2006), plants that are able to maintain high levels of RWC under water deficit conditions are less affected by stress and are able to maintain normal growth and yield. The findings of several researchers working on durum wheat genotypes have shown that with decreasing RWC in the leaves, under water deficit conditions, the water balance of the plants are disrupted (Molnár et al., 2004; Dulai et al., 2006). Recently Dulai et al., (2006), Adejare and Umebese (2007) reported that RWC values were significantly reduced under water stress treatments at the booting, anthesis and soft dough growth stages in the bread and durum wheat plants they studied. Schonfeld *et al*. (1988) observed a decline in the amount of RWC in wheat due to drought stress and reported the highest RWC in the tolerant genotype.

Table 9. Mean estimates of the interaction for IWCS and RWCg stage of the wheat genotypes under field condition

Genotype	**IWCs**			**RWCg**		
	Booting	**Control**	**Tillering**	**Booting**	**Control**	**Tillering**
Dandea	4.208a	4.016b	2.861e	61.872i	80.605a	72.688d
Mekelle4	3.097d	3.161d	2.298g	56.543l	75.551c	69.992f
Hawi	2.535f	2.529f	2.056i	50.594m	71.238e	63.662h
Mekelle3	3.387c	3.169d	2.129hi	59.801j	78.79b	71.26e
Medawalbu	2.551f	2.591f	2.104hi	48.602n	69.349f	60.492j
Shina	2.14hi	2.239gh	1.887j	43.185o	64.47g	57.959k
R.D	-1.2		24.68	27.1382		9.989
CV		3.5			0.7	
S.e		0.0545			0.2772	
S.e.d		0.0771			0.3920	

R.D. % = Relative decrease in percentage in water stress treatment.

Table 10. Mean estimate of genotype and water stress interaction for traits RWCs, RWLg, in green house tests

Genotypes	RWCs			RWLg		
	Booting	Control	Tilering	Booting	Control	Tillering
Dandea	81.22a	82.15a	70.8c	14.45j	25.03de	18.24hi
Mekelle4	79.27ab	81.77a	71.85bc	18.82hi	26.77c	20.8g
Hawii	79.45ab	77.66abc	63.75d	22.5f	29.74b	23.66ef
Mekelle3	82.73a	83.69a	80.88a	17.63i	24.14e	19.67gh
Medawalabu	77.36abc	78.21abc	52.33e	23.78ef	31.11ab	24.62e
Shina	78.24abc	77.69abc	58.51de	25.04de	31.69a	26.42cd
CV		5.4			3.7	
S.e		2.356			0.502	
S.e.d		3.332			0.71	

4.2.3. Yield and Yield components

A significant difference among the genotypes and between water stress regimes was recorded with regard to yield and yield associated traits. The interaction were highly significant ($p<0.01$) for yield and yield component in the field experiment (Table 11). However the interaction for grain yield per plant, seed per spike and spike length were not significant in the green house experiment. A significant reduction in yield and yield components was recorded in water stress treatments with more reduction during stress at booting stage (Table 12).

Table 11. Mean square of wheat genotype for yield and yield component under water stress regimes

S.V	d.f.	Spike-length		Seed/spike		Seed weight		Gy/plant	
		GH	Field	GH	Field	GH	Field	GH	Field
Block	2	0.17	0.13	1.69	2.02	8.96	5.89	0.067	0.0123
WSR	2	63.6**	23.1**	437.2**	1021.4**	850.59**	981.08**	1.61**	3.3064**
Gen	5	9.75**	9.74**	123.5**	172.3**	190.36**	205.76**	0.42**	0.6151**
WSR.Gen	10	0.23^{ns}	0.56**	2.00^{ns}	3.24**	5.90**	3.23**	0.006^{ns}	0.0122**
Residual	34	0.25	0.18	1.35	0.78	0.75	0.34	0.003	0.0014
CV		7.2	5.6	5.2	3.1	3.5	2	7.9	4.1

ns, *, **, sequentially non significant and significant in 5% and 1% WSR= Water Stress regimes, Gen= Genotypes, CV: Coefficient of variation, GH= green house Gy/plant= grain yield per plant, 1000seedwt= 1000 seed weight

Spike length: Analysis of variance detected a significant difference among the genotypes and water stress regimes (Appendix 8.3). The interaction for spike length were also significant indicating genotype performs differently at different water stress regimes (Table 11). The shortest spike length (6.313cm) were recorded while water stress was imposed through booting stage which is significantly lower than the spike length obtained under water stress at tillering stage. The longest spike length was obtained when the genotypes are not exposed to water stress at any stages (Table 12). The mean genotype comparison (Table 13) indicated that Mekelle4 showed the longest spike length (9.144) followed by Dandea and Mekelle3 (8.344 and 7.789, respectively) in the field experiment. In green house, Mekelle3 had the longest spike followed by Mekelle4 and Dandea. Significant differences were not detected between Shina (6.583) and Hawii (6.611) and both genotypes had the smallest spike length. Mean comparison for the interaction showed non significant differences between Mekelle3 and Dandea, and amongst Medawalabu, Hawii and Shina at control and water stress at booting stages (Table 14). Mean spike length ranged from 5.247 (Shina) to 7.633 (Mekelle4) when water stressed at booting stage, while water stress at tillering stage, mean spike length ranged from 6.533 (Shina and Hawii) to 9.467 (Mekelle4) and in the control it ranges from 7.833 (Shina and Hawii) to 10.333 (Mekelle4) (Table 14).Water stress at tillering stage reduces spike length of the genotypes by 7.05 % and when the genotypes are exposed to water stress at booting stage spike length is reduced by 25.772%. The overall spike length was reduced in water stress treatments and more reduction was recorded in water stress at booting stage in case of field condition and in water stress at tillering stage in the green house. Genotypes Mekelle4, Dandea and Mekelle3 are the top three that possessed the longest spike length in both experiments. Khanzada *et al*., (2001), found that pod length in Guar genotypes decreased significantly with application of water stress when compared with control.

Seeds per spike: A significant variation was obtained among genotypes and water stress regimes in number of seeds per spike. The interactions were also significant in field experiment (Table 11).

The minimum number of grains per spike in field and green house were 20.61 and 18.67, respectively when water stress was imposed at booting stage (Table 12). Then there has been a decrease in number of seeds per spike when water stress was applied at tillering stage as compared with normal water regimes. The mean comparison indicated that the highest numbers of seeds per spike were recorded on Dandea followed by Mekelle4 and Mekelle3 in both experiments. In the field tests significant differences in mean numbers of seeds per spike were not detected between Mekelle4 and Mekelle3 (Table 13). Mean grains per spike ranged from 14 (Shina) to 27 (Dandea) when water stressed was imposed at booting stage while the mean grains per spike ranged from 21.33 (Shina) to 35 (Dandea) when water stress was applied at tillering stage (Table 14). In the control the mean grain per spike ranged from 31 (Shina) to 40 (Dandea). Dandea even when stressed at tillering stage had the highest number of seed per spike compared to Hawii, Medawalbu and Shina at normal moisture regimes. Mekelle3 and Mekelle4 had significantly higher number of seeds when stressed at tillering stage than Shina at control (Table 14). Thus genotypes Dandea, Mekelle4 and Mekelle3 possessed the highest number of seed per spike. Water stress at booting stage reduces the number of seeds per spike by 42.21% while stress at tillering reduces by 19.78%. Thus booting stage is a critical stage for seed formation and a considerable reduction in number of seeds per spike can be occurs when water stress was imposed during this stage.

The current results support Belay et al. (1993) finding, that kernels/spike are affected by drought. Their study evaluated 60 tetra-ploid wheat landraces including the commercial cultivar (Boohai) from the central highlands of Ethiopia. They found that kernels/spike were a critical determinant of grain yield per unit area. The present results suggest that under drought conditions, part of the grain yield advantage is an attribute of the number of kernels/spike. Garcia-del-Moral (2006) reported that moisture-deficit affected the number of seeds per spike, consequently decreased grain yield. Fisher (2007) reviewed 10 years research and found that increased kernel number/m^2 still remains strongly associated with genetic progress in grain yield and new research reinforces the importance of spike dry weight (g/m^2) at anthesis in its determination. Tompkins *et al.*, (1991) reported significant suppressive effect of water stress on number of grains per spike. Khanzada *et al.*, (2001) and Qadir *et al.*, (1999) have also reported that water stress throughout vegetative and reproductive development caused a significant reduction in number of grains per spike on wheat.

Table 12. Mean thousand seed weight, seed/spike, spike length and grain yield/plant for water stress regimes under field and green house conditions

Water stress	Spike length		Seed/spike		Seed weight		Gy/plant	
	Field	GH	Field	GH	Field	GH	Field	GH
Control	8.506a	8.711a	35.67a	28.11a	37.01a	31.83a	1.3313a	1.0423a
Tillering	7.906b	4.955c	28.61b	20.94b	29.28b	24.24b	0.8627b	0.6509b
booting	6.313c	6.946b	20.61c	18.67c	22.25c	18.11c	0.4754c	0.4543c
CV	5.6	7.2	3.1	5.2	2.0	3.5	4.1	7.9
S.e	0.1004	0.117	0.209	0.274	0.1372	0.205	0.00867	0.01338
S.e.d	0.1420	0.1654	0.295	0.388	0.1941	0.29	0.01227	0.01892

Table 13. Mean thousand seed weight, seed/spike, spike length and grain yield/plant for the wheat genotypes under field and green house conditions.

Genotype	Spike length.		Seed/spike		Seed weight		Gy/plant	
	Field	GH	Field	GH	Field	GH	Field	GH
Dandea	8.344b	7.24b	34.00a	28.56a	36.51a	31.47a	1.2710a	1.06a
Mekelle3	7.789c	8.24a	31.22b	24.78b	33.09b	28.14b	1.0693b	0.86b
Mekelle4	9.144a	7.70b	30.44b	22.78c	30.65c	25.75c	0.9714c	0.75c
Medawalabu	7.022d	5.53d	26.78c	20.22d	27.23d	22.72d	0.7678d	0.60d
Hawii	6.611e	6.52c	25.22d	21.00d	25.70e	21.07e	0.6897e	0.56d
Shina	6.538e	5.98d	22.11e	18.11e	23.91f	19.23f	0.5695f	0.48e
Cv	5.6	7.2	3.1	5.2	2.0	3.5	4.1	7.9
S.e	0.142	0.1654	0.295	0.388	0.1941	0.29	0.01227	0.01892
S.e.d	0.2009	0.2339	0.417	0.548	0.2745	0.411	0.01735	0.02675

Table 14. Genotype x water stress interaction effect on seed per spike and spike length of wheat genotypes under field conditions.

Genotypes	Spike length			Seed/spike		
	Water stress regimes			Water stress regimes		
	Booting	Control	Tillering	Booting	Control	Tillering
Dandea	7.533ef	8.5cd	9bc	27g	40a	35c
Mekelle4	7.633e	10.333a	9.467b	22.67ij	37.67b	31f
Hawii	5.233h	7.833de	6.767g	17.33L	33.33de	25h
Mekelle3	6.867fg	8.5cd	8de	23.67hi	37.33b	32.67e
Medawalabu	5.367h	8.033de	7.667e	19k	34.67cd	26.67g
Shina	5.247h	7.833de	6.533g	14m	31f	21.33j
R.D (%)	25.772		7.05	42.21		19.78
Cv		5.6			3.1	
S.e		0.246			0.511	
S.e.d		0.3479			0.723	

Grain weight: a significant difference among the genotypes and water stress regimes was detected regarding to grain weight (Appendix 8.3). Mean grain weight ranged from 22.25 (water stressed at booting stage) to 37.01 (control) (Table 12). Differences in grain weight amongst genotypes were significant ($p < 0.05$). Genotype Dandea had the maximum grain weight (29.31) followed by Mekelle3 (24.860) and Mekelle4 (23.153). Shina (17.65) had the minimum grain weight followed by Hawii (18.49) and Medawalabu (20.037) when water stressed at booting stage. Similarly Dandea (37.52) and Shina (22.3) respectively had the maximum and minimum grain weight when water stress at tillering stage, (Table 15). Water stress significantly reduces grain weight in all genotypes and 39.88% reduction in grain weight was occurred when water stress was imposed at booting and 20.9% reduction when water stressed at tillering stages (Table 15). The current results are in accord with a study by Tesemma et al. (1993) who showed thousand kernel weights is adversely affected by drought. The growth of the wheat grain, from initiation to maturity follows a complex course of several phases that can be affected by environmental conditions almost until maturity (Evans et al., 1975). Moreover, the current study agrees with Haun (1973) that reported thousand kernel weights, decreases when drought is imposed at the vegetative stages. In another study, Belay et al. (1993) demonstrated that thousand kernel weights can be used as a predictor for gain yield.

Guller (2002) reported that the increase in water use leaded to increase of grain weight in cultivars. Present result indicates spike length, thousand grain weight, number of seeds per spike and grain yield per plant were decreased under stressed environment which is also reported by Chandler and Singh (2008). They observed that grain yield particularly showed maximum sensitivity to moisture stress. Blum and Pnuel (1990) worked on twelve spring wheat varieties and reported that yield and yield components were significantly decreased under minimum annual precipitation. Plaut *et al.* (2004) reported that thousand kernel weights were drastically decreased by water deficit in wheat cultivars.

The decrease in 1000 grains weight may be due to disturbed nutrient uptake efficiency and photosynthetic translocation within the plant (Iqbal *et al.,* 1999) that produced shriveled grains. This is likely due to the shortage of moistures which forces plant to complete its grain formation in relatively lesser time (Riaz and Chowdhrv, 2003).

Grain yield; Water stress significantly ($p < 0.01$) reduced the final grain yield irrespective of the stage at which drought was experienced. Data (Table 15) showed that withholding water at booting stage resulted in a significant yield loss. The final grain yield of the plants subjected to water stress at the booting stage was dramatically lower than those subjected to water stress at tillering stage and those of control (Table 15). Water stress at tillering stage reduced grain yield of the genotypes by 35.2 % and by 64.29 % at booting stage.

Differences in grain yield amongst genotypes were significant ($p < 0.001$) (Appendix 8.3). The magnitude of yield reduction due to water stress was variable in all genotypes and at the different water stress regimes. The highest reduction in grain yield (74.90%) as compared to its control was found in genotype Shina when water stressed at booting stage. Dandea displayed the highest water stress tolerance, as the reduction in grain yield was only 23.14% and 53.69% when stressed at tillering and booting stages respectively in comparison with its corresponding control. Shina exhibited the highest sensitivity to the imposed stress at tillering and booting stages and has showed a reduction in yield of 51.69% and 74.9%, respectively, relative to the control. Overall Dandea produced the highest yield among all the genotypes studied, whereas Shina had the lowest yield as compared to the other genotypes. Grain yield per plant is the ultimate result of all physiological and agronomical responses of cultivars to drought stress conditions. Drought had different effect on grain yield depending on the developmental stage at which it occurs (Agboma *et al.,* 1997). The present results agree with Simane et al. (1993) and Van den Boogaard et. al., (1996) who reported that grain yield is reduced by drought. All cultivars, tolerant and susceptible, are to some degree affected by drought. Guttieri et al., (2001) reported that water stress during tillering until physiological maturity causes significant reduction of wheat grain yield cultivars. This reduction in yield results from both grain weight reduction and reduction in number of grains per spike. In another study by Ahmadi et al., (2006), it was found that there was a significant reduction in grain yield and 1000-grain weight under drought stress.

Table 15. Genotype and water stress interaction effect on 1000 grain weight and grain yield per plant in studied wheat genotype under field condition

Genotypes	**Seed weight**			**Grain yield per plant**			**R.D Grain yield per plant**	
	Booting	**Control**	**Tillering**	**Booting**	**Control**	**Tillering**	**Tillering**	**Booting**
Dandea	29.31g	42.713a	37.52c	0.7912g	1.7086a	1.3133c	23.1359	53.69308
Mekelle4	23.153j	38.423c	30.38f	0.5247j	1.4473b	0.9422f	34.89947	63.74629
Hawii	18.49L	34.053d	24.548i	0.32bk	1.1353e	0.6139i	45.92619	71.81362
Mekelle3	24.86i	40.247b	34.157d	0.5883i	1.5028b	1.1169e	25.67873	60.85307
Medawalabu	20.037k	34.85d	26.79h	0.3807k	1.2084d	0.7143h	40.88878	68.49553
Shina	17.65L	31.773e	22.3j	0.2473L	0.9853f	0.4759j	51.69999	74.90105
R.D(%)	39.88		20.879	64.29		35.294		
Cv		2.00			4.1			
S.e		0.3362			0.02124			
S.e.d		0.4754			0.03004			

R.D. % = Relative decrease in percentage in water stress treatment

4.2.4. Drought tolerance indices

Computed drought tolerance indices based on the grain yield are given in Appendix 3 and 6 for field and green house experiments, respectively.

Table 16. Mean square of wheat genotype for drought tolerance traits under different water stress regimes.

S.V	d.f.	MP		SSI		STI		YSI	
		GH	Field	GH	Field	GH	Field	GH	Field
Block	2	0.034	0.015	0.055	0.003	0.114	0.020	0.012	0.004
WSR	2	0.4**	0.83**	6.109**	6.45**	1.352**	1.05**	1.551**	1.94**
Gen	5	0.5**	0.63**	0.097**	0.19**	1.724**	0.8**	0.020**	0.040**
WSR.Gen	10	$.001^{ns}$	0.003^{*}	0.033**	0.08**	0.005^{ns}	0.004*	0.006**	0.01**
Residual	34	0.002	0.0014	0.005	0.001	0.006	0.002	0.001	0.00002
CV		4.6	3.4	10.8	5.1	4.6	3.4	4.6	2.0

SSI= stress susceptibility index, STI= stress tolerance index, YSI= yield stability index, MP= mean productivity

Mean productivity (Mp); A significant difference was observed among the genotypes and between water stress regimes (Table 16). Water stress significantly reduced the mean productivity of the studied wheat genotypes under field and green house experiments. More reduction was recorded when water stress was experienced at booting stage in both tests (Table 17). The mean genotype comparison (Table 18) shows Dandea had the highest Mp (1.49) over the other genotypes followed by Mekelle3 (1.286) and Mekelle4 (1.237) where as Shina, Hawii and Medawalabu shown the lowest Mp (0.777, 0.913, and 0.988 respectively). The performance of genotypes in the green house was also similar except it is a bit lower in magnitude (Table 18). Mp is mean production under both stress and non-stress conditions (Rosielle and Hamblin, 1981). Cultivars with a high MP would belong to uniform performance in both stress and non stress conditions. Hence Dandea, Mekelle3 and Mekelle4 can be considered as water stress tolerant wheat cultivar based on the Mp. Mardeh *et al*. (2006) reported that relatively low yields obtained under stress condition, exhibited high Mp values. But, this is not found in this investigation, because wheat cultivars showed similar values under irrigated conditions.

Table 17. Main estimates of water stress regimes on STI, MP, SSI and YSI under field and green house condition

Water stress	MP		SSI		STI		YSI	
	Field	GH	Field	GH	Field	GH	field	GH
Control	1.331a	1.0423a	0.000c	0.0000b	1.502a	1.919a	1.0000a	1.000a
Tillering	1.097b	0.8548b	1.0525a	0.9901a	1.238b	1.574b	0.6296b	0.6278b
booting	50.83c	0.7483	1.020b	1.0269a	1.019c	1.378c	0.3442c	0.4207c
Cv	3.4	4.6	5.1	10.8	3.4	4.6	2.00	4.6
SE	0.0089	0.0096	0.00826	0.01713	0.01006	0.0177	0.00316	0.00744
S.e.d	0.0126	0.01357	0.01169	0.02423	0.0142	0.025	0.00447	0.01052

CV:Coefficient of variation; SE: Standard error of the mean; S.e.d: standard error of the difference; Non similar letter in each column show significant difference between water stress regimes at 5% probability.

Table 18. Main effect of genotypes on drought tolerance indices under field and green house conditions

Genotype	MP		SSI		STI		YSI	
	Field	GH	Field	GH	Field	GH	Field	GH
Dandea	1.490a	1.244a	0.4975f	0.4938c	1.681a	2.291a	0.7439a	0.7650a
Mekelle3	1.286b	1.057b	0.5592e	0.6505b	1.451b	1.946b	0.7114b	0.6951b
Mekelle 4	1.237c	0.9237c	0.6610d	0.6782b	1.365c	1.700c	0.6713c	0.6775b
Medawalabu	0.988d	0.7397d	0.7421c	0.6892b	1.115d	1.362d	0.6355d	0.6740b
Shina	0.777f	0.627f	0.8777a	0.8139a	.877f	1.154f	0.5781f	0.6221c
Hawii	0.913e	0.6989e	0.8074b	0.7086b	1.030e	1.287e	0.6075e	0.6632b
Cv	3.4	4.6	5.1	10.8	3.4	4.6	2.0	4.6
S.e	0.0126	0.01357	0.01169	0.02423	0.01423	0.025	0.00447	0.01052
S.e.d	0.0178	0.0192	0.01653	0.03427	0.02012	0.0353	0.00632	0.01388

Stress susceptibility index (SSI); A significant difference was detected among the genotypes and between the water stress regimes for the traits SSI (Table 16). Mean comparison showed genotypes Shina, Hawii, and Medawalabu had shown the SSI value of the order 1.4675, 1.3053 and 1.1611, respectively when water stressed at tillering stage. The same varieties had an SSI value of 1.1655, 1.1169 and 1.0650, respectively when water stress was imposed at booting stage in the field condition (Table 19). SSI has been widely used by researchers to identify sensitive and resistant genotypes (Fischer and Maurer, 1978; Clarke *et al*., 1984; Winter *et al*., 1988 and Clarke *et al*., 1992). In this study, the mean SSI was a suitable selection index to distinguish resistant cultivars. Guttieri et al. (2001) using SSI criterion suggested that SSI more than 1 indicated above-average susceptibility to drought stress. Accordingly Shina, Hawii, and Medawalabu could be conceived as above average drought susceptible. Whereas Dandea, Mekelle3 and Mekelle4 with the lower SSI (<1) were identified as resistant. Similarly Fischer and Maurer (1978) explained that genotypes with an SSI of less than unit are drought resistant, since their yield reduction in drought condition is smaller than the mean yield reduction of all genotypes (Bruckner and Frohberg, 1987).

Stress Tolerance Index (STI); a significant difference among the genotypes and between water stress regimes was observed with regard to STI. Water stress affects stress tolerance ability of all genotypes. Significant reduction of STI among the genotypes was recorded when water was withheld at booting than tillering stage in both tests (Table 17). Mean genotype comparison also indicated that Dandea had the highest STI followed by Mekelle3 and Mekelle4 while Shina had the lowest STI in both field and green house tests. STI consider not only the ability of genotypes to grow well under stressed environments, but also good performance in non-stressed environments. Thus, they identify materials which are compatible with stressful and optimal conditions, to achieve genotypes that can tolerate long intervals between irrigation and probably no irrigation at sensitive growth stages (Jafari et al., 2009). Thus based on the index Dandea, Mekelle3 and Mekelle4 with the highest STI can be considered water stress tolerant wheat varieties.

Yield stability Index (YSI); a significant difference was detected among the genotypes and water stress affects YSI of all genotypes. Dandea had the highest YSI followed by Mekelle3 and Mekelle4 (Table 19). Genotypes with the highest YSI gave the highest yield under both non stress and stressed conditions. Sundari et.al (2005) introduced MP, SSI and STI indices as the best indices to stress tolerance. Similar results were reported by Sio-se Mardeh et al (2006) in evaluating wheat genotypes to water stress. Richard (1996) believes that choosing genotypes in both non-stress and stressed conditions cause the aggregation of favorite alleles and high-yielding genotypes will be selected as a result. Golabadi et al. (2006) and Sio-Se Mardeh et al. (2006) suggested that selection for drought tolerance in wheat could be conducted for high MP, and STI and low SSI under stressed and non-stressed environments.

In the present study, Considering MP, SSI and STI indices, Dandea, Mekelle3 and Mekelle4 were the most tolerant wheat varieties under water stress at tillering and booting stages, while Shina was the most sensitive cultivar under both conditions (Table 18). Dandea was developed and recommended for high rainfall areas while Mekelle3 and Mekelle4 were developed for mid altitude with reasonably good rainfall. This study further verified that these varieties had the ability to withstand water stress.

Table 19. Mean interaction effect of genotype and water stress on SSI, YSI and STI of studied wheat genotypes under field conditions.

Genotypes	SSI		STI			YSI	
	Booting	**Tillering**	**Booting**	**Control**	**Tillering**	**Booting**	**Tillering**
Dandea	0.8349f	0.6576h	1.4105cd	1.9282a	1.7051b	0.4632g	0.7685b
Mekelle4	0.9911e	0.9918e	1.1127fg	1.6332b	1.3482de	0.475i	0.6509d
Hawii	1.117cd	1.3053b	0.8212j	1.2812e	0.987h	0.2819k	0.5406f
Mekelle3	0.9465e	0.7313g	1.1799f	1.6958b	1.4781c	0.3915h	0.7426c
Medawalabu	1.065d	1.1611c	0.8966i	1.3637d	1.0849g	0.3153j	0.5913e
Shina	1.1655c	1.4675a	0.6955k	1.1118fg	0.8245j	0.2507L	0.4835g
CV	5.1			3.4		2.00	
S.e	0.02024			0.02464		0.00774	
S.e.d	0.02863			0.03485		0.01094	

CV: Coefficient of variation; SE: Standard error of the mean; S.e.d: standard error of the difference; Non similar letter in each column show significant difference among the genotypes at 5% probability

4.3. Correlation analysis

4.3.1. Correlation among agronomic and yield traits

Correlation coefficients for all studied traits under different water stress regimes are given in Tables 20, 21 and 22.

Under normal conditions grain yield per plant was significantly and positively correlated with grains per spike, spike length and grain weight. Grains per spike were significantly and positively correlated with grain weight and spike length. Similarly days to heading was positively correlated with plant height, days to flowering. Grain yield per plant had a positive but non-significant correlation with days to heading and flowering and with plant height as well (Table 20). Traits such as grain per spike, grain weight and spike length had a positive and significant correlation with grain yield indicating their importance for selection with higher yield under normal condition. These results weresimilar to those of

Ahmadizadeh et al. (2011) who showed that spike length had more direct positive effects on grain yield. Sen and Toms (2007) also revealed that grain weight showed a direct relationship with grain yield. Gulmezoglu et al. (2010) discovered that grain yield of wheat are depended on plant height, length of spike and spike weight. Shamsi et al. (2011) also showed that the most important yield component on grain yield was grain weight.

Under water stress conditions at tillering stage, tiller number was positively correlated with spike length, seed per spike, seed weight, plant height and grain yield per plant. Spike length was positively and significantly correlated with seed per spike, seed weight and grain yield per plant. Seed per spike were also positively and significantly correlated with seed weight and grain yield per plant. Grain yield per plant was negatively correlated with days to heading and flowering under water stress at tillering stage (Table 21). These results indicate that increase in spike length, spike number, seed weight and reducing the number of days to heading and flowering would also increase in grain yield per plant. Singh et al. (2001) reported that the spike length had positive and highly significant correlation with grain yield of main spike. Okuyama et al. (2004) also reported a positive correlation for number of spike/m^2 with grain yield.

A significant correlation among the traits was also obtained when water stress was imposed at booting stage (Table 22). Plant height was positively correlated with spike length, seed per spike, seed weight and grain yield per plant.

Spike length was positively correlated with seed weight, seed per spike and grain yield per plant. There was also a positive and significant correlation between seed per spike and 1000seed weight and between grain yield per plant and seed weight. These positive and significant correlations indicated that increase in grains per spike, grain weight, plant height and spike length cause simultaneous increase in grain per plant and those traits could be used as selection criterion under water stress at booting stage. Some of these correlations among yield traits are in conformity with those of Gupta *et al.* (2001) who also noted significant and positive correlation among grains per spike, spike length, grain yield per plant and harvest index. Shadhu and Mangat, (1985) and Belay et al. (1993) also observed positive correlation between plant height with spike length and grain yield per plant.

Dogan (2009) also indicated positive and significant correlations between grain yield and grain weight. Dagustu (2008) indicated significant and positive correlations between grain yield and spike length.

Table 20. Correlation coefficient of among the agronomic, water related traits and yield and yield components under normal conditions.

Traits	Rwcs	Iwcs	ELWRg	RWLg	IWCg	RWCg	DH	DF	PH
RWCs	1								
IWCs	0.83**	1.00							
ELWRg	0.71**	0.71**	1.00						
RWLg	-0.89**	-0.92**	-0.72**	1.00					
IWCg	0.83**	0.95**	0.70**	-0.93**	1.00				
RWCg	0.86**	0.91**	0.63**	-0.98**	0.94**	1.00			
DH	0.21^{ns}	0.14^{ns}	0.27^{ns}	-0.12^{ns}	0.05^{ns}	-0.05^{ns}	1.00		
DF	0.36^{ns}	0.28^{ns}	0.41^{ns}	-0.30^{ns}	0.23^{ns}	0.14^{ns}	0.94**	1.00	
PH	0.28^{ns}	0.15^{ns}	0.23^{ns}	-0.07^{ns}	0.14^{ns}	0.01^{ns}	0.64**	0.60**	1.00
spike len	0.48*	0.36^{ns}	0.28^{ns}	-0.46*	0.29^{ns}	0.41^{ns}	0.38^{ns}	0.41^{ns}	0.34^{ns}
Seed/spike	0.86**	0.93**	0.67**	-0.89**	0.86**	0.90**	0.04^{ns}	0.17^{ns}	0.05^{ns}
1000seedwt	0.89**	0.94**	0.66**	-0.94**	0.95**	0.96**	0.07^{ns}	0.25^{ns}	0.17^{ns}
Gy/plant	0.89**	0.96**	0.69**	-0.93**	0.93**	0.95**	0.07^{ns}	0.23^{ns}	0.13^{ns}

Continued

Traits	spike length	Seed/spike	1000Seed wt	Gy/plant
spike length	1.00			
Seed/spike	0.48*	1.00		
Seed weight	0.44ns	0.94**	1.00	
Gy/plant	0.45*	0.98**	0.99**	1

Where: ns: non significant * significant at 5% and ** significant at 1% probability level

4.3.2. Correlation among physiological traits

Under normal condition, relative water content at stem elongation and grain filling stage was significantly and positively correlated with initial water content at stem elongation and grain filling stages, excised leaf water retention and negatively correlated with rate of water loss. Excised leaf water retention was significantly associated with initial water content at stem elongation andgrain filing stage and negatively correlated with rate of water loss. Rate of water loss was negatively and significantly associated with initial water content at stem elongation and grain filling stage (Table 20). These correlations suggest that the lower the rate of water loss from the leaf the higher the relative water content and water retention capacity. Similarly, the higher water retention capacity the higher relative water content with the leaf. Similar results were obtained in water stress at tillering (Table 21) and booting stages (Table 22) with a little variation in magnitude.

Relative water content at grain filling stage was significantly and positively related with initial water content at stem elongation and grain filling stage, excised leaf water retention and negatively correlated with rate of water loss at water stress regime imposed during tillering and booting stage. While Excised leaf water retention was significantly associated with relative water content and initial water content at stem elongation, initial water content at grain filing stage and negatively correlated with rate of water loss. Rate of water loss was negatively and significantly correlated with all studied water related traits.

Results suggested that physiological traits showed a close relationship with each other, thus it can be presumed that if a reliable trait with high heritability is used as drought tolerance criterion, this may increase yield traits in the same direction. Similar results were also reported by Gupta *et al.* (2001).

4.3.3. Correlation between yield and physiological traits

The correlation coefficients between yield and physiological traits indicates that grain yield per plant was positively and significantly associated with relative water content at both stem elongation and grain filling stages, excised leaf water retention, initial water content at grain filling stage under all water stress regimes. Rate of water loss were negatively and significantly associated grain yield per plant under all water stress regimes (Table 20, 21 and 22). These correlation indicates that increment in relative water content, initial water content and excised leaf water retention and reduction in rate of water loss could simultaneously increased yield traits in water stress conditions. According to the correlation coefficients, to increase grain yield under normal and water stress condition, the more focus should be on physiological traits such as relative water content, initial water content, excised leaf water retention and rate of water loss which have a high correlation with grain yield and also should utilize them in drought resistance breeding programs. Similarly Jaradat and Kozak (1983) observed a positive and significant correlation between excised leaf water retention and yield in wheat. Clarke and Townley (1986) also concluded that low rate of water loss (high leaf water retention) was associated with high grain yield potential under drought. Clark and Romagosa (1989) reported the association of low rate of excised leaf water loss with improved yields under very dry environments in wheat. It means there is a greater scope of using physiological traits in selection for improving yield in wheat. Similar results were also achieved by Gupta *et al.* (2001).

Table 21. Correlation coefficient among agronomic, water related traits and yield and yield components at water stress during tillering stage

Traits	***LA(cm2)***	***Tiller***	**Rwcs**	**Iwcs**	**ELWRg**	**RWLg**	**IWCg**	**RWCg**
LA(cm2)	1							
Tiller	-0.01^{ns}	1						
RWCs	0.18^{ns}	0.52*	1					
IWCs	-0.21^{ns}	0.5*	0.77**	1				
ELWRg	0.26^{ns}	0.37^{ns}	0.95**	0.7**	1			
RWLg	-0.1^{ns}	-0.4^{ns}	-0.94**	-0.73**	-0.94**	1		
IWCg	0.09^{ns}	0.43^{ns}	0.94**	0.85**	0.94**	-0.93**	1	
RWCg	0.18^{ns}	0.33^{ns}	0.95**	0.75**	0.94**	-0.96**	0.93**	1
DH	-0.21^{ns}	0.31^{ns}	-0.34^{ns}	-0.14^{ns}	-0.38^{ns}	0.4^{ns}	-0.3^{ns}	-0.46*
DF	0	0.38^{ns}	-0.24^{ns}	-0.13^{ns}	-0.26^{ns}	0.3^{ns}	-0.22^{ns}	-0.36^{ns}
PH	-0.06^{ns}	0.43^{ns}	0.13^{ns}	0.28^{ns}	-0.03^{ns}	0.02^{ns}	0.15^{ns}	-0.08^{ns}
spike len	0.09^{ns}	0.66**	0.84**	0.69**	0.7**	-0.71**	0.7**	0.75**
Seed/spike	0.09^{ns}	0.48*	0.95**	0.81**	0.9**	-0.91**	0.92**	0.94**
seedweight	0.09^{ns}	0.48*	0.94**	0.83**	0.91**	-0.91**	0.96**	0.92**
Gy/plant	0.07^{ns}	0.47*	0.95**	0.84**	0.91**	-0.92**	0.96**	0.93**

Continued

Traits	**DH**	**DF**	**PH**	**spike len**	**Seed/spike**	**seedweight**	**Gy/plant**
DH	1						
DF	0.95**	1					
PH	0.18ns	0.14ns	1				
spike len	-0.09ns	-0.06ns	0.28ns	1			
Seed/spike	-0.38ns	-0.28ns	0.04ns	0.76**	1		
seedweight	-0.27ns	-0.17ns	0.12ns	0.71**	0.97**	1	
Gy/plant	-0.32ns	-0.22ns	0.11ns	0.72**	0.98**	1	1

Where ns: non significant * significant at 5% and ** significant at 1% probability level

Table 22. Correlation among agronomic, water related traits, yield and yield components at water stress during booting stage

Traits	*LA(cm2)*	*Tiller*	Rwcs	Iwcs	Elwrg	Rwlg	Iwcg	Rwcg
LA(cm2)	1.00							
Tiller	-0.23^{ns}	1.00						
RWCs	-0.05^{ns}	0.31^{ns}	1.00					
IWCs	-0.05^{ns}	0.24^{ns}	0.94**	1.00				
ELWRg	-0.09^{ns}	0.35^{ns}	0.97**	0.94**	1.00			
RWLg	0.09^{ns}	-0.32^{ns}	-0.96**	-0.94**	-0.98**	1.00		
IWCg	-0.05^{ns}	0.20^{ns}	0.94**	0.98**	0.95**	-0.96**	1.00	
RWCg	-0.12^{ns}	0.32^{ns}	0.95**	0.93**	0.96**	-0.99**	0.95**	1.00
DH	-0.11^{ns}	0.28^{ns}	0.26^{ns}	0.12^{ns}	0.24^{ns}	-0.15^{ns}	0.09^{ns}	0.07^{ns}
DF	-0.19^{ns}	0.32^{ns}	0.34^{ns}	0.19^{ns}	0.32^{ns}	-0.22^{ns}	0.17^{ns}	0.14^{ns}
PH	0.22^{ns}	-0.28^{ns}	0.55*	0.55*	0.49*	-0.42ns	0.53*	0.37^{ns}
spike len	-0.13^{ns}	0.42^{ns}	0.89**	0.83**	0.90**	-0.88**	0.81**	0.87**
Seed/spike	-0.07^{ns}	0.33^{ns}	0.96**	0.96**	0.94**	-0.94**	0.94**	0.96**
1000seedwt	-0.08^{ns}	0.16^{ns}	0.92**	0.97**	0.93**	-0.92**	0.97**	0.91**
Gy/plant	-0.06^{ns}	0.23^{ns}	0.95**	0.99**	0.95**	-0.94**	0.98**	0.93**

Continued

Traits	DH	DF	PH	spike len	Seed/spike	seedweight	Gy/plant
DH	1.00						
DF	0.97**	1.00					
PH	0.49*	0.52*	1.00				
spike len	0.47*	0.49*	0.50*	1.00			
Seed/spike	0.14^{ns}	0.21^{ns}	0.49*	0.88**	1.00		
seedweight	0.20^{ns}	0.28^{ns}	0.64**	0.85**	0.95**	1.00	
Gy/plant	0.17^{ns}	0.25^{ns}	0.60**	0.86**	0.98**	0.99**	1

Where ns: non significant * significant at 5% and ** significant at 1% probability level

4.3.4. Correlation among physiological, yield and drought tolerance indices

The results indicated that grain yield per plant under water stress at tillering stage was positively and significantly correlated with MP, STI and YSI and a negative and significant correlation was observed between grain yield and SSI (Table 23).Grain yield under stress during booting stage is positively and significantly correlated with MP, YSI and STI (Table 24). Grain yield per plant is however, negatively and significantly correlated with SSI under water stress at booting stage. This relation indicates that the highest the yield performance under water stress and non stress condition the more resistance would be.

Table 23. Correlation coefficient of yield and yield components with drought tolerance indices under water stress at tillering

Traits	*spike len*	*Seed/spike*	*1000seedwt*	*Gy/plant*	*STI*	*SSI*
spike length	1.00					
Seed/spike	0.76**	1.00				
seedweight	0.71**	0.97**	1.00			
Gy/plant	0.72**	0.98**	1.00	1.00		
STI	0.74**	0.99**	0.99**	1.00	1.00	
SSI	-0.71**	-0.98**	-0.98**	-0.98**	-0.97**	1.00
MP	0.74**	0.99**	0.99**	1.00	1.00	-0.97**

Where ns: non significant * significant at 5% and ** significant at 1% probability level

Table 24. Correlation coefficient of yield and yield component with drought tolerance indices under water stress at booting stage.

Traits	*spike len*	*Seed/spike*	*1000seedwt*	*Gy/plant*	*STI*	*SSI*
spike len	1.00					
Seed/spike	0.88**	1.00				
seedweight	0.85**	0.95**	1.00			
Gy/plant	0.86**	0.98**	0.99**	1.00		
STI	0.88**	0.98**	0.98**	0.99**	1.00	
SSI	-0.86**	-0.98**	-0.98**	-0.99**	-0.98**	1.00
MP	0.88**	0.98**	0.98**	0.99**	1.00	-0.98**

Where ns: non significant * significant at 5% and ** significant at 1% probability level

Physiological traits such as ELWR, RWCs, RWCg, IWCs, and IWCg were positively and significantly correlated with the drought tolerance indices (STI, YSI and MP) and negative correlation with SSI under water stress at tillering (Table 25) and booting stages (Table 26). RWL is however negatively correlated with the aforementioned drought tolerance traits. Positive and significant correlation was also observed between RWL and SSI under water stress at tillering and booting stages (Table 25 and 26), respectively. This result is in agreement with Taheri et al. (2011) who obtained a positive and significant correlation between stress tolerance index with grain yield and RWC in stress conditions.

Traits such as MP, YSI, ELWR, RWCg, and IWC had positive and significant correlation coefficient and traits RWL had negative and significant correlation coefficient with grain yield and stress tolerance index indicating their importance for selection with higher yield and drought tolerance.

Therefore these traits could be used as selection criteria for improving wheat grain yield under normal and water stress at tillering and booting stages. Genotypes with high MP, YSI, STI, ELWR, RWCg and IWCg and low SSI and RWL can be regarded as high yielders and water stress tolerant varieties. The observed relationships were in agreement with those reported on mung-bean (Fernandez 1992) showed that relative water content was positively correlated with number of seeds per pod and the yield, maize (Farshadfar and Sutka 2002) reported that excised leaf water loss was negatively correlated with yield, and durum wheat (Golabadi et al. 2006) observed a positive and significant correlation between relative water content and grain yield per plant..

Table 25. Correlation coefficient of physiological traits and drought tolerance indices under water stress at tillering stage

Traits	*LA(cm2)*	*RWCs*	*IWCs*	*ELWRg*	*RWLg*	*IWCg*	*RWCg*	*STI*	*SSI*
LA(cm2)	1.00								
RWCs	0.18^{ns}	1.00							
IWCs	-0.21^{ns}	0.77**	1.00						
ELWRg	0.26^{ns}	0.95**	0.70**	1.00					
RWLg	-0.10^{ns}	-0.94**	-0.73**	-0.94**	1.00				
IWCg	0.09^{ns}	0.94**	0.85**	0.94**	-0.93**	1.00			
RWCg	0.18^{ns}	0.95**	0.75**	0.94**	-0.96**	0.93**	1.00		
STI	0.05^{ns}	0.95**	0.85**	0.90**	-0.92**	0.96**	0.93**	1.00	
SSI	-0.16^{ns}	-0.94**	-0.77**	-0.92**	0.90**	-0.93**	-0.91**	-0.97**	1.00
MP	0.05^{ns}	0.95**	0.85**	0.90**	-0.92**	0.96**	0.93**	1.00	-0.97**

Table 26. Correlation coefficient of physiological traits and drought tolerance indices under water stress at booting stage.

Traits	*LA(cm2)*	*RWCs*	*IWCs*	*ELWRg*	*RWLg*	*IWCg*	*RWCg*	*STI*	*SSI*
LA(cm2)	1.00								
RWCs	-0.05^{ns}	1.00							
IWCs	-0.05^{ns}	0.94**	1.00						
ELWRg	-0.09^{ns}	0.97**	0.94**	1.00					
RWLg	0.09^{ns}	-0.96**	-0.94**	-0.98**	1.00				
IWCg	-0.05^{ns}	0.94**	0.98**	0.95**	-0.96**	1.00			
RWCg	-0.12^{ns}	0.95**	0.93**	0.96**	-0.99**	0.95**	1.00		
STI	-0.09^{ns}	0.95**	0.98**	0.95**	-0.94**	0.97**	0.95**	1.00	
SSI	0.04^{ns}	-0.95**	-0.97**	-0.94**	0.93**	-0.96**	-0.94**	-0.98**	1.00
MP	-0.09^{ns}	0.95**	0.98**	0.95**	-0.94**	0.97**	0.95**	1.00	-0.98**

4.4. Multiple Regression Analyses:

4.4.1. Regression model under Control /Normal condition

Results from all possible subset regression analysis under normal condition showed that seed weight, initial water content at stem elongation, relative water content at grain filling stage, rate of water loss, seed per spike and spike length cumulatively could explain more than 99.96% of the variation for grain yield per plant (Appendix 9). These traits are the best six traits that could explain more variation for the grain yield per plant at normal condition.

Regression equation of grain yield under normal condition

Gy/plant = **-**0.817 +0.03987(seed weight) + 0.02771(IWCs) + 0.00593(RWCg) **-**0.001688(RWL) + 0.03218(seed per spike) -0.00489(spike length)

The regression coefficient indicate that grain yield was positively influenced by seed weight, IWCs, RWCg, and seed per spike, hence increase in the value of these character would increase the yield. For instance if a unit in seed weight were increased the yield per plant would increase by 0.04 unit. Similraly IWCs, RWCg and seed per spike the yield per plant would increase by 0.03, 0.006 and 0.032 unit, respectively. RWL and spike length showed negative correlation with grain yield suggesting that grain yield per plant would be decreased with the increase in RWL and spike length. Hence, if 1.0 unit of RWL were increased the yield per plant would decrease by 0.002 unit and incase of spike length it would decrease by 0.005 unit. Leilah et al. (2004) demonstrated that five traits of grain weight per spike, harvest index, biological yield, number of spikes per square meter, and spike length could be introduced in to a stepwise regression model.

Beside that traits such as initial water content at stem elongation, rate of water loss at stem elongation and grain filling stage and rate of water loss at grain filling stage explains 95% of the variation in grain yield per plant (Table 27).

Table 27. Regression coefficient for traits IWCs,RWCg, RWCs and RWLg under normal condition on grain yield

Parameter	estimate	s.e.	t(13)	t pr.
Constant	-3.18	1.36	-2.34	0.036
IWCs	0.2298	0.0587	3.91	0.002
RWCg_	0.0285	0.0115	2.48	0.028
RWCs	0.01592	0.00679	2.34	0.036
RWLg	- 0.01040	0.00697	1.49	0.160
R^2	95			

The relationship between grain yield under normal condition and grain yield under water stress at tillering and booting stage was positive (Figure 4) suggesting that high yield potential under normal condition necessarily results in improved yield under stress at tillering and booting stages.

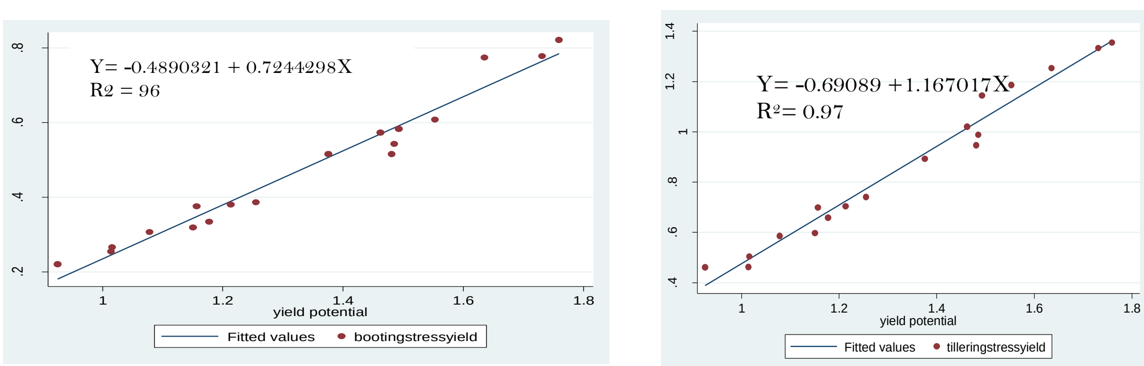

Figure 4. Relationship between grain yield of wheat genotypes at non stressed and stressed conditions at tillering and booting stages under field condition.

4.4.2. Regression model for water stress at tillering stage

Generalized linear model with all subset regression analysis indicated that seed weight; initial water content at stem elongation, plant height, rate of water loss, spike length and seed per spike cumulatively could explain more than 99.85 % of the variation for grain yield per plant (Appendix 10). In addition seed weight, day to flowering, initial water content at both stem elongation and grain filling stage, and rate of water loss are the best five traits that could explain about 99.71 % of variation for stress tolerance index (Appendix 10) when water stress was experienced at tillering stage.

Regression equation for grain yields per plant and STI under water stress at tillering stage is given by;

Gy/plant = -0.74 +0.03096(1000seedwt) +0.00286(PH) – 0.002407(RWLg) +0.0476(IWCs) +0.02308(seed per spike) – 0.01666(Spike length)

STI = 0.101 + 0.05729 (1000seedwt) -0.00482(DF) -0.00443(RWLg) +0.1532(IWCs) + 0.182(IWCg)

The regression coefficient indicated that for a unit increase in seed weight the yield per plant would increase by 0.031unit. Similarly incase of PH, IWCs, and seed per spike the yield per plant would increase by 0.003, 0.05 and 0.023 unit respectively. On the other hand if 1.0 unit of RWL were increased the yield per plant would decrease by 0.0024 unit and incase of spike length it would decrease by 0.02 units. This result is similar to the results illustrated by Mohamed (1999) who found that spike number, grains/spike, spike weight and straw yield were associated significantly with wheat grain yield. Furthermore Asseng et al. (2002) reported that increased kernel number had improved potential yield of wheat under certain environmental conditions limited by water supply.

Furthermore 93.6% of the variation in grain yield per plant (Table 28) and 93.8% of variation in stress tolerance index (Table 28) was accounted for by excised leaf water retention, initial water content at grain filling stage, plant height and relative water content at stem elongation.

Table 28. Regression coefficient for ELWR, IWCg, PH and RWCs, under water stress at tillering stage

Parameter	**Dependent Variables**							
	Grain yield per plant				**Stress tolerance index**			
	estimate	**s.e.**	**t(13)**	**t pr.**	**estimate**	**s.e.**	**t(13)**	**t pr.**
Constant	-1.199	0.576	-2.08	0.058	-0.958	0.587	-1.63	0.127
ELWRg	0.0227	0.0150	-1.51	0.154	0.0325	0.0153	-2.13	0.053
IWCg	0.490	0.134	3.65	0.003	0.531	0.137	3.88	0.002
PH	-0.00773	0.00647	-1.20	0.253	-0.01107	0.00659	-1.68	0.117
RWCs	0.0340	0.0132	2.58	0.023	0.0419	0.0135	3.11	0.008
R^2	93.6				93.8			

Grain yield under water stress at tillering stage was negatively correlated with rate of water loss (Figure 5), and positively correlated with stress tolerance index (Figure 6) suggesting that the lowest rate of water loss the better the yield would be under water stressed at tillering stage and this further necessitate the more tolerant in the imposed water stress. For a unit increase in rate of water loss the yield per plant would decrease by 0.031 unit (Figure 5). On the other hand for a unit increment in STI the yield per plant under water stress at tillering stage would increase by 0.96 (Figure 6).

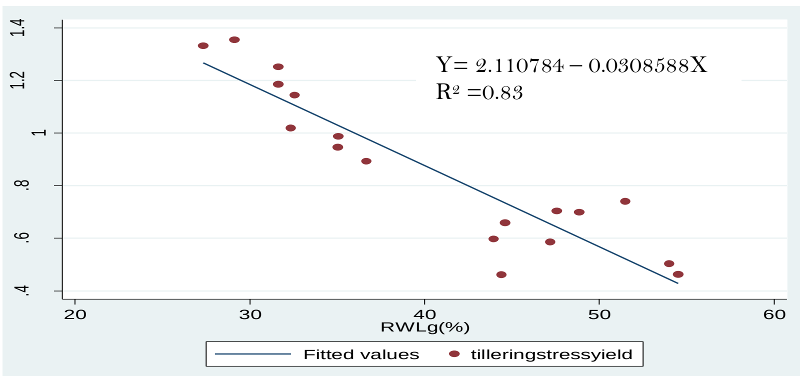

Figure 5. Relationship between Rate of water loss and grain yield under water stress tillering stage.

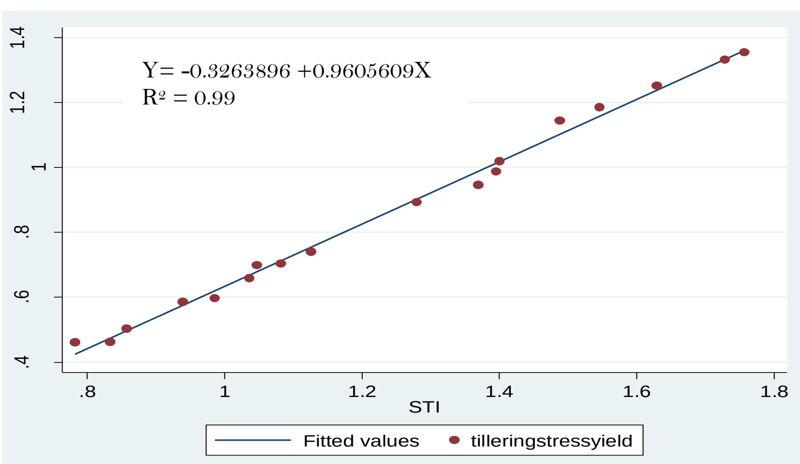

Figure 6. Relationship between grain yield under water stress at tillering and Stress tolerance index.

4.4.3. Regression analysis for Stress at booting stage

All subset regression analysis under water stress at booting stage (Appendix 11) indicates 99.96 % of the variation for grain yield per plant was accounted for by seed weight, days to heading, excised leaf water retention, initial water content at stem elongation and grain filling stage, relative water content at grain filling stage and stem elongation stage, seed per spike and spike length. Traits like seed weight and seed per spike are the best two traits that could explain 99.32 % of the variation in stress tolerance index (Appendix 11).

Regression equation for grain yield and STI under water stress at booting stage is given by;

Gy/plant = -0.3951+ 0.02321(1000seedwt) + -0.002753 (DH) + 0.00258(ELWRg) +0.05947(IWCs)+ 0.00546 (RWCg) + 0.00318(RWCs) + 0.01226(Seed/spike) + 0.01042(spike length)

STI = -0.2322+ 0.03074(seed weight) + 0.02754 (Seed/spike)

The regression coefficient indicate that grain yield was positively correlated with seed weight, ELWRg, IWCs, RWCg, RWCs , seed per spike and spike length indicating that increase in the value of these character would increase the yield. For instance if 1.0 unit in seed weight were increased the yield per plant would increase by 0.023 unit. Similarly incase of ELWR, IWCs, RWCg, RWCs, seed per spike and spike length the yield per plant would increase by 0.003, 0.06, 0.005, 0.003, 0.012 and 0.01 unit respectively. DH showed negative correlation with grain yield suggesting that grain yield per plant would be decreased with the increase in DH. Hence if 1.0 unit of DH were increased the yield per plant would decrease by 0.003 unit. Traits such as days to heading, initial water content at stem elongation and grain filling stage, relative water content at grain filling stage and rate of water loss at grain filling stage could explain 98.8% of the variation in grain yield per plant (Table 29) and 98.3% of variation in stress tolerance index (Table 29). Hence these traits can be used as a selection criterion for high yield and stress tolerance index. Garcia del Moral et al. (2003) demonstrated that, under moisture stress condition, the number of spikes per square meter, number of grains per spike, number of days prior to flowering all had significant positive correlations with grain yields of plants.

Table 29. Regression coefficient for DH, IWCg, IWCs, RWCg, and RWLg under water stress at booting stage

Parameter	**Dependent Variables**							
	Grain yield per plant				**Stress tolerance index**			
	estimate	**s.e.**	**t(12)**	**t pr.**	**Estimate**	**s.e.**	**t(12)**	**t pr.**
Constant	-2.761	0.598	-4.62	<.001	-4.060	0.924	-4.39	<.001
DH	0.00918	0.00216	4.26	0.001	.01391	.00333	4.18	0.001
IWCg	0.2299	0.0830	2.77	0.017	0.202	0.128	1.58	0.140
IWCs	0.1488	0.0399	3.73	0.003	0.2050	0.0616	3.33	0.006
RWCg_%	0.02309	0.00594	3.89	0.002	.04259	.00917	4.65	<.001
RWLg_%	-0.01834	0.00494	3.71	0.003	- .02847	.00763	3.73	0.003
R^2	98.8				98.3			

Grain yield under water stress at booting stage was negatively correlated with rate of water loss (Figure 7) while positively with stress tolerance index (Figure 8) signifying that the lowest rate of water loss would result a better yield and more tolerant under water stressed at booting stage. If 1.0 unite in rate of water loss were increased the yield per plant would decrease by 0.018 unit (Figure 7). On the other hand for a unit increment in STI the yield per plant under water stress at booting stage would increase by 0.75 (Figure 8).

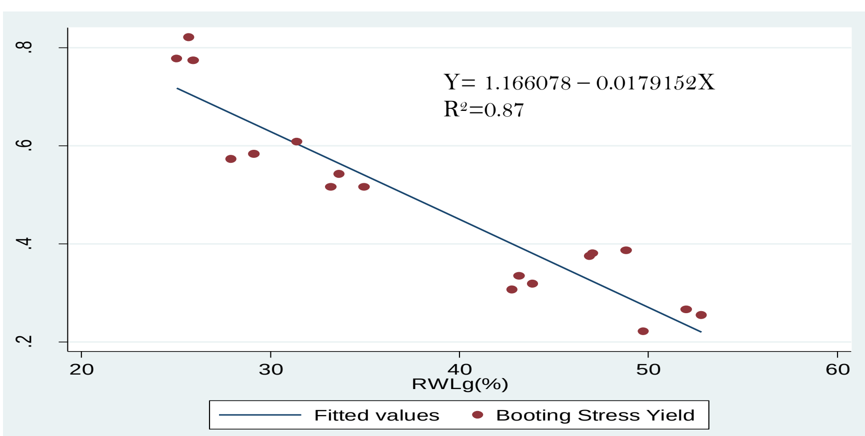

Figure 7. Relationship between Rate of water loss and grain yield under water stress tillering stage

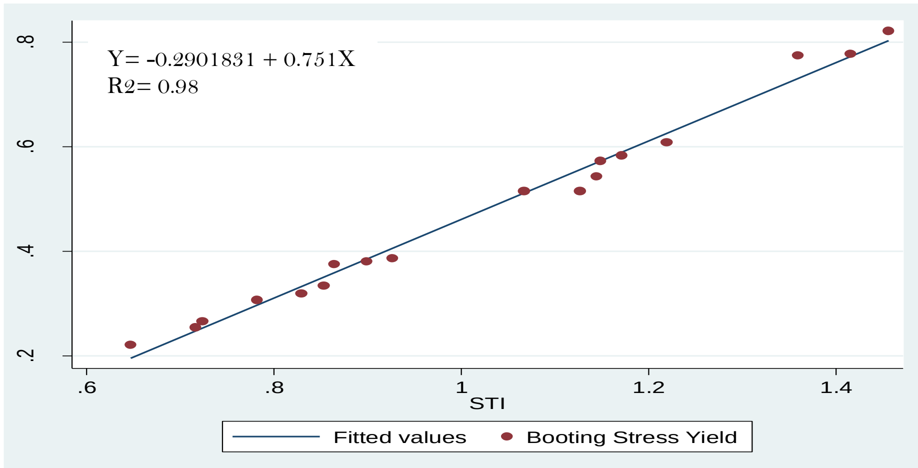

Figure 8. Relationship between grain yield under water stress at tillering and Stress tolerance index

4.5. Principal Component Analysis

Principal Component Analysis was performed as a data reduction tool to summarize the information. A total of 14 principal components were extracted, though the first three principal components were considered significant based on the eigenvalue criterion that is retaining component with the eigenvalue of greater than 1. A summary of the composition of variable for the first three components, eigenvalue and percentage variance are given (Table 30). The first two components were plotted to see the overall variability among the population. The principal component analysis revealed that the first three components explain 91.47 percent of the total variation, where the first component explained 58.65 percent with Seed per spike, yield stability index, seed weight, grain yield per plant, initial water content at grain filling stage, stress tolerance index, excised Leaf water retention, spike length, mean productivity, initial water content at stem elongation and relative water content at stem elongation hence the first component was positively associated with these traits and a genotype that hase high values of these traits will be considered as a more adaptable genotype that can perform well across different environments.

The second Principal component explained 18.40 of the total variability and correlated positively with days to heading, day to flowering, SSI and rate of water loss. Therefore, selection of genotypes with high first principal component and low second principal component are suitable for both stress and non-stress environments. Hence, genotypes Dandea, Mekelle3 and Mekelle4 were superior genotypes for both environments with high PC1 and low PC2. Similarly PCA biplot had been used by many researchers in comparing different genotypes. For instance, Kaya et al. (2002), Dadbakhsh et al. (2011) and Abdolshahi et al. (2010) were able to reveal that bread wheat genotypes with larger PCA1 and lower PCA2 scores gave high yields (stable genotypes) and genotypes with lower PCA1 and larger PCA2 scores had low yields (unstable genotypes). Farshadfar and Sutka (2003), Sio-Se Mardeh et al. (2006) and Golabadi et al. (2006) obtained similar results in multivariate analysis of drought tolerance in different crops.

Table 30. principal component with their eigenvalues and the percentage of variance

Principal Component	Eigenvalues	%Variance	Cumulative
1	9.97	58. 65	58.65
2	3.128	18.40	77.08
3	2.451	14.42	91.47

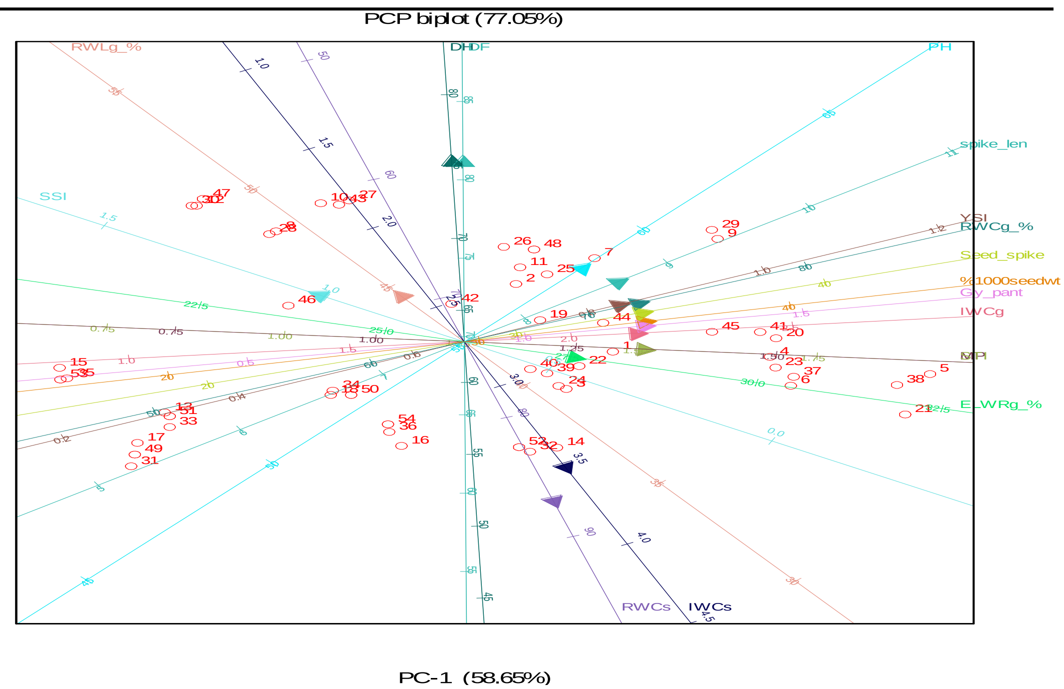

Figure 9. Principal component analysis of agronomic, physiological, yield, yield component and drought tolerance indices

The results obtained from bi-plot graph confirmed correlation analysis and principal component bi-plot revealed that agronomic, physiological and yield component traits are super imposed on the plot as vectors. Distance of each trait with respect to PC1 and PC2 indicated the contribution of this variable in the variation of the genotypes. The correlation coefficient among any two indices is approximately by the cosine of the angle between their vectors. Hence the most prominent relations revealed by these bi-plot are: a strong negative association between SSI and RWL with YSI, ELWR, RWC, MP, STI, grain yield per plant, seed weight and seed per spike as indicated by the large obtuse angles between their vectors, a near zero correlation between RWL and PH and also DH and DF with MP, STI, IWCg, grain yield per plant and seed weight as indicated by the near perpendicular vectors and a positive association between grain yield per plant with MP, seed weight, seed per spike, ELWR, IWCg, RWCg, spike length and STI, as indicated by the acute angles. Kaya et al. (2002) were able to reveal that genotypes with larger PCA1 and lower PCA2 scores gave high yields (stable genotypes), and genotypes with lower PCA1 and larger PCA2 scores had low yields (unstable genotypes).

CHAPTER FIVE

5.0. Conclusions and Recommendations

5.1. Conclusions

It is concluded from the results of this study that water stress significantly reduced the yield and mean value of the studied traits in wheat genotypes. Thus, wheat, a staple food, appears to be suffering yield losses due to deficiency of water at any critical stage.

1. The studied wheat genotypes showed differential sensitivity to the different water stress regimes. The results provide clear evidence of differences between the tested genotypes in plant water relations, drought tolerance indices, yield and yield components and their response to the imposed stress.
2. Under stress and non stress condition, grain yield and stress tolerance Index (STI) showed positive and significant correlation with Spike length, number of grains per spike, seed weight, Relative Water content, Excised Leaf water retention, initial Water content, yield stability index while a negative and significant association with stress susceptibility index (SSI) and Rate of water loss.
3. Traits RWL, IWC, RWCs and RWCg explained more of the variation in grain yield under normal condition where as traits such as RWCs, ELWR, IWCg and PH when water stress was imposed at tillering stage and traits like DH, IWCs, IWCg, RWCg and RWL explained more of the variation in grain yield and drought tolerance index under water stress at booting stage.
4. Three principal component was extracted and 91.47 percent of the total variation was explained by these three components, the first component explains 58.65 percent with Seed per spike, yield stability index, seed weight, grain yield per plant, initial water content at grain filling stage, stress tolerance index, excised Leaf water retention, spike length, mean productivity, initial water content at stem elongation and relative water content at stem elongation.
5. Genotypes Dandea, Mekelle3 and Mekelle4 showed high yield potential and stability under drought stress and they maintained their yield across a range of water availabilities..

5.2. Recommendations

- Physiological traits like RWC, ELWR, IWC, RWL, PH, and DF, , were effective in identifying suitable wheat genotypes for moisture stresses conditions and there is a strong need to consider these traits in crop improvement program.
- Dandea, Mekelle3 & Mekelle4 were superior in terms of withstanding imposed water stresses and they would be excellent candidates for situations of climate change induced water stresses and farmers in different areas of the country should try these varieties.
- Wheat breeders should, take into account the stress severity of the environment and the crop growth stage at which the water stress occurs in choosing a variety.
- Root morphology of these genotypes and making out their correlation with the studied physiological water related traits and exploration of their genetic variation should be next research to be carried out.
- Finally because of limitted sample size and testing environments, further research under different environment and several genotypes should be conducted.

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7. Appendices

Appendix 1. Mean temperature and relative humidity difference between the study areas

Month	Minimum Temperature			Maximum temperature			Relative humidity		
	GH	Field	Difference	GH	Field	Difference	GH	Field	Difference
March	11.77	9.74	2.02	37.12	24.29	12.83	63.89	58.68	5.21
April	13.08	12.78	0.3	36.7	27.27	9.43	54.87	56.09	-1.22
May	13.4	12.45	0.95	38.02	26.61	11.4	55.02	60	-4.98
June	13.47	12.32	1.15	36	26.93	9.07	48.91	58	-9.09

Appendix 2. Mean performance of wheat genotype under different water stress regimes in field conditions

WSR	Gen	DF	DH	ELWR	PH	IWCg	LA (cm^2)	RWCg	RWCs	RWLg	IWCs
Booting	Dandea	66.33	59.00	32.07	54.33	2.10	12.24	61.87	82.60	25.55	4.208
	Mekelle4	69.33	63.00	27.78	50.67	1.37	11.34	56.54	79.40	33.92	3.097
	Hawii	61.33	54.00	22.08	46.00	1.10	11.84	50.59	74.25	43.28	2.535
	Mekelle3	66.33	59.33	30.07	51.33	1.69	12.49	59.80	80.93	29.47	3.387
	Medawalabu	64.33	57.33	21.29	51.33	1.00	12.41	48.60	75.23	47.59	2.551
	Shina	68.00	61.67	20.15	51.33	0.81	12.65	43.19	73.12	51.51	2.14
Control	Dandea	67.67	60.00	32.38	61.33	3.02	12.38	80.61	83.87	33.85	4.016
	Mekelle4	69.00	62.00	27.01	59.67	2.15	12.86	75.55	80.94	41.48	3.161
	Hawii	63.33	55.67	21.25	54.00	1.79	13.61	71.24	75.90	52.74	2.529
	Mekelle3	67.00	59.00	28.87	59.33	2.41	14.51	78.79	82.20	37.54	3.169
	Medawalabu	63.67	57.00	19.91	57.00	1.72	14.40	69.35	74.07	58.48	2.591
	Shina	69.00	62.67	23.79	63.33	1.48	13.68	64.47	73.61	61.94	2.239
Tillering	Dandea	76.33	70.00	33.17	58.67	2.62	12.12	72.69	71.36	29.35	2.861
	Mekelle4	75.67	69.33	28.60	55.33	1.90	13.08	69.99	68.56	35.59	2.298
	Hawii	74.67	68.33	24.40	50.67	1.51	12.55	63.66	59.98	45.26	2.056
	Mekelle3	74.33	65.67	32.81	53.67	2.21	14.69	71.26	69.49	32.18	2.129
	Medawalabu	79.33	74.00	23.02	57.00	1.47	12.54	60.49	61.66	49.30	2.104
	Shina	78.33	72.67	20.45	58.33	1.29	12.88	57.96	58.48	50.98	1.887

Appendix 3. Mean performance of yield, yield component and drought tolerance indices of studied wheat genotypes under different water stress regime in field condition

WSR	Gen	Seed/spike	Tiller	Spike Len.	seedweight	Gy/plant	SSI	MP	YSI	STI
Booting	Dandea	27.00	4.00	7.53	29.31	0.79	0.83	1.25	0.46	1.41
	Mekelle4	22.67	4.67	7.63	23.15	0.52	0.99	1.07	0.48	1.11
	Hawii	17.33	4.11	5.23	18.49	0.32	1.12	0.73	0.28	0.82
	Mekelle3	23.67	4.00	6.87	24.86	0.59	0.95	1.05	0.39	1.18
	Medawalabu	19.00	3.67	5.37	20.04	0.38	1.07	0.79	0.32	0.90
	Shina	14.00	3.67	5.25	17.65	0.25	1.17	0.62	0.25	0.70
Control	Dandea	40.00	4.78	8.50	42.71	1.71	0.00	1.71	1.00	1.93
	Mekelle4	37.67	3.89	10.33	38.42	1.45	0.00	1.45	1.00	1.63
	Hawii	33.33	3.67	7.83	34.05	1.14	0.00	1.14	1.00	1.28
	Mekelle3	37.33	3.89	8.50	40.25	1.50	0.00	1.50	1.00	1.70
	Medawalabu	34.67	5.11	8.03	34.85	1.21	0.00	1.21	1.00	1.36
	Shina	31.00	4.00	7.83	31.77	0.99	0.00	0.99	1.00	1.11
Tillering	Dandea	35.00	4.22	9.00	37.52	1.31	0.66	1.51	0.77	1.71
	Mekelle4	31.00	4.11	9.47	30.38	0.94	0.99	1.19	0.65	1.35
	Hawii	25.00	3.22	6.77	24.55	0.61	1.31	0.87	0.54	0.99
	Mekelle3	32.67	3.67	8.00	34.16	1.12	0.73	1.31	0.74	1.48
	Medawalabu	26.67	4.11	7.67	26.79	0.71	1.16	0.96	0.59	1.08
	Shina	21.33	3.45	6.53	22.30	0.48	1.47	0.73	0.48	0.82

Appendix 4. Computed Drought tolerance index based on the grain yield of studied wheat genotype under different water stress regimes in field condition

Block	Genotype	Control	Water stress at Tillering stage					Water stress at Booting stage				
		Gy/plant	Gy/plant	STI	SSI	YSI	MP	Gy/plant	STI	SSI	YSI	MP
1	Dandea	1.7592	1.3545	1.757	0.654	0.770	1.557	0.82152	1.456	0.829	0.467	1.290
1	Mekelle4	1.48542	0.98784	1.396	0.952	0.665	1.237	0.5428	1.144	0.987	0.365	1.014
1	Hawii	1.17742	0.658684	1.036	1.252	0.559	0.918	0.33422	0.853	1.114	0.284	0.756
1	Mekelle3	1.55306	1.1866	1.546	0.670	0.764	1.370	0.60792	1.219	0.947	0.391	1.080
1	Medawalabu	1.25545	0.74034	1.126	1.166	0.590	0.998	0.38646	0.926	1.077	0.308	0.821
1	Shina	1.01587	0.5038	0.857	1.432	0.496	0.760	0.26595	0.723	1.148	0.262	0.641
2	Dandea	1.73143	1.33272	1.729	0.654	0.770	1.532	0.77787	1.416	0.857	0.449	1.255
2	Mekelle4	1.48083	0.94612	1.369	1.026	0.639	1.213	0.51568	1.127	1.014	0.348	0.998
2	Hawii	1.15022	0.59664	0.986	1.367	0.519	0.873	0.31892	0.829	1.124	0.277	0.735
2	Mekelle3	1.49295	1.14411	1.488	0.664	0.766	1.319	0.58368	1.172	0.947	0.391	1.038
2	Medawalabu	1.21345	0.70356	1.082	1.194	0.580	0.959	0.38019	0.899	1.068	0.313	0.797
2	Shina	1.0144	0.46284	0.834	1.545	0.456	0.739	0.2548	0.716	1.165	0.251	0.635
3	Dandea	1.63527	1.25256	1.629	0.665	0.766	1.444	0.77428	1.360	0.819	0.473	1.205
3	Mekelle4	1.37556	0.8925	1.280	0.998	0.649	1.134	0.51566	1.067	0.972	0.375	0.946
3	Hawii	1.0784	0.58625	0.939	1.297	0.544	0.832	0.3069	0.782	1.113	0.285	0.693
3	Mekelle3	1.46224	1.0199	1.401	0.860	0.697	1.241	0.57339	1.149	0.945	0.392	1.018
3	Medawalabu	1.15634	0.69903	1.047	1.124	0.605	0.928	0.37544	0.864	1.050	0.325	0.766
3	Shina	0.9255	0.46116	0.782	1.426	0.498	0.693	0.22126	0.647	1.184	0.239	0.573
Mean		1.3312783	0.8627308					0.475386				

Appendix 5.Mean performance of wheat genotypes under different water stress regimes in green house condition

WSR	Genotypes	PH	RWCg	RWCs	RWLg	LA cm2	Tiller	DF	DH	ELWR	IWCg
Booting	Dandea	34.83	67.98	81.22	14.45	11.017	4.45	60.33	52.00	48.47	2.031
	Mekelle4	31.67	65.26	79.27	18.82	12.137	4.33	64.00	57.67	42.76	1.737
	Hawii	32.17	53.85	79.45	22.5	10.55	3.78	58.67	48.33	35.72	1.333
	Mekelle3	34.5	66.89	82.73	17.63	13.523	4.00	60.67	54.33	41.6	1.821
	Medawalabu	37.17	60.29	77.36	23.78	9.753	3.67	56.67	50.67	35.44	1.404
	Shina	32.17	62.11	78.24	25.04	9.887	3.56	61.67	56.33	35.97	1.16
Control	Dandea	33.5	79.53	82.15	25.03	14.377	4.56	62.33	53.67	36.25	2.76
	Mekelle4	33.5	77.41	81.77	26.77	14.47	3.78	65.00	57.00	33.54	2.373
	Hawii	35.17	74.1	77.66	29.74	13.15	3.56	56.67	49.00	32.21	2.074
	Mekelle3	36.33	80.7	83.69	24.14	16.103	4.00	61.33	53.33	38.25	2.616
	Medawalabu	38	70.54	78.21	31.11	12.303	4.66	59.33	51.33	31.57	2.076
	Shina	31.83	71.88	77.69	31.69	12.237	3.89	71.67	57.33	32.68	1.827
Tillering	Dandea	42.67	72.03	70.8	18.24	12.81	4.22	73.67	67.67	42.51	2.469
	Mekelle4	36.67	68.35	71.85	20.8	13.473	4.00	71.67	64.00	38.94	2.243
	Hawii	36.33	61.07	63.75	23.66	12.393	3.00	73.33	66.33	35.4	1.661
	Mekelle3	40.67	71.05	80.88	19.67	14.62	4.00	72.67	63.67	41.16	2.334
	Medawalabu	36.67	60.26	52.33	24.62	11.69	4.11	76.67	69.67	34.23	1.847
	Shina	37	61.44	58.51	26.42	11.277	3.34	75.00	68.67	34.03	1.658

WSR= Water Stress regimes ELWR=excised leaf water retention, IWCg,= initial water content at grain filling stage, , RWCg= relative water content at grain filling stage and RWCs=relative water content at stem elongation RWLg= rate of water loss at grain filling stage, PH= plant height DF= days to flowering, DH= days to heading, Tiller= number of tiller per plant, LA= Leaf Area,

Appendix 6. Mean performance of yield and yield component of wheat genotypes under different water stress regimes in green house condition

WSR	Genotype	seed/spike	IWCs	Spike len	1000seedwt	Gy/plant	MP	SSI	STI	YSI
Booting	Dandea	25.67	4.06	7.33	24.5	0.79	1.1	0.79	2.02	0.56
	Mekelle4	18.67	4.16	7.57	18.8	0.43	0.77	1.08	1.41	0.39
	Hawii	16.67	3.91	6.6	14.29	0.31	0.57	1.12	1.06	0.37
	Mekelle3	21.33	4.38	8.1	20.46	0.57	0.91	0.96	1.67	0.46
	Medawalabu	16	3.73	5.73	16.13	0.35	0.62	1.07	1.14	0.4
	Shina	13.67	3.83	6.34	14.49	0.27	0.52	1.15	0.96	0.35
Control	Dandea	33	3.99	9.23	37.15	1.41	1.41	0	2.6	1
	Mekelle4	28.67	3.98	9.57	32.99	1.1	1.1	0	2.03	1
	Hawii	26.33	3.51	8.47	29.07	0.84	0.84	0	1.55	1
	Mekelle3	31	4.29	10.33	34.99	1.25	1.25	0	2.3	1
	Medawalabu	25.33	3.74	7.4	29.89	0.88	0.88	0	1.63	1
	Shina	24.33	3.57	7.27	26.92	0.77	0.77	0	1.42	1
Tillering	Dandea	27	3.31	5.16	32.75	0.98	1.23	0.7	2.26	0.74
	Mekelle4	21	3.52	5.97	25.47	0.7	0.9	0.96	1.66	0.64
	Hawii	20	3.11	4.5	19.85	0.52	0.68	1	1.26	0.62
	Mekelle3	22	3.81	6.3	28.96	0.75	1.02	0.99	1.87	0.63
	Medawalabu	19.33	2.94	3.47	22.14	0.55	0.72	1	1.32	0.62
	Shina	16.33	3.12	4.33	16.27	0.4	0.58	1.29	1.08	0.51

SSI= stress susceptibility index, STI= stress tolerance index, YSI= yield stability index, MP= mean productivity ; WSR= Water Stress regimes, Gen= Genotypes, Gy/plant= grain yield per plant, 1000seedwt= 1000 seed weight

Appendix 7. Computed drought tolerance index based on the grain yield of studied wheat genotype under different water stress regimes in green house condition

Block	Genotypes	Control	Water stress at Tillering stage					Water stress at Booting stage				
		Gy/plant	Gy/plant	STI	SSI	YSI	MP	Gy/plant	STI	SSI	YSI	MP
1	Dandea	1.451	1.193	2.434	0.474	0.822	1.322	0.922	2.184	0.647	0.635	1.186
1	Mekelle4	1.095	0.710	1.661	0.934	0.649	0.902	0.445	1.417	1.051	0.407	0.770
1	Hawii	0.900	0.581	1.364	0.943	0.646	0.741	0.334	1.136	1.115	0.371	0.617
1	Mekelle3	1.226	0.791	1.857	0.944	0.645	1.009	0.511	1.599	1.034	0.417	0.868
1	Medawalabu	0.968	0.621	1.463	0.955	0.641	0.795	0.440	1.297	0.967	0.454	0.704
1	Shina	0.786	0.375	1.069	1.393	0.476	0.581	0.248	0.952	1.213	0.316	0.517
2	Dandea	1.351	0.947	2.116	0.795	0.701	1.149	0.715	1.902	0.835	0.529	1.033
2	Mekelle4	1.101	0.625	1.589	1.151	0.567	0.863	0.404	1.385	1.123	0.366	0.752
2	Hawii	0.778	0.492	1.169	0.977	0.633	0.635	0.273	0.967	1.151	0.351	0.525
2	Mekelle3	1.251	0.762	1.853	1.040	0.609	1.006	0.548	1.656	0.995	0.438	0.900
2	Medawalabu	0.797	0.514	1.207	0.945	0.645	0.656	0.305	1.015	1.094	0.383	0.551
2	Shina	0.697	0.351	0.965	1.320	0.504	0.524	0.221	0.846	1.210	0.317	0.459
3	Dandea	1.426	0.988	2.222	0.816	0.693	1.207	0.720	1.975	0.877	0.505	1.073
3	Mekelle4	1.108	0.779	1.737	0.790	0.703	0.944	0.448	1.433	1.055	0.405	0.778
3	Hawii	0.843	0.497	1.233	1.090	0.590	0.670	0.319	1.069	1.102	0.379	0.581
3	Mekelle3	1.265	0.797	1.898	0.983	0.631	1.031	0.653	1.765	0.857	0.517	0.959
3	Medawalabu	0.884	0.518	1.291	1.103	0.586	0.701	0.316	1.105	1.139	0.358	0.600
3	Shina	0.833	0.466	1.196	1.171	0.560	0.650	0.355	1.093	1.018	0.426	0.594
	Mean	1.042	0.667					0.454				

SSI= stress susceptibility index, STI= stress tolerance index, YSI= yield stability index, MP= mean productivity, Gy/plant= grain yield per plant

Appendix 8. Analysis of Variance for all studied traits at field condition

Appendix 8. 1 Analysis of variance for agronomic traits

ANOVA for tiller number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.0795	0.0397	0.16	
WSR	2	1.6354	0.8177	3.20	0.053
Gen	5	4.2115	0.8423	3.29	0.016
WSR.Gen	10	5.3899	0.5390	2.11	0.052
Residual	34	8.6956	0.2558		

ANOVA for days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	26.333	13.167	2.18	
WSR	2	1244.333	622.167	103.19	<.001
Gen	5	164.889	32.978	5.47	<.001
WSR.Gen	10	111.444	11.144	1.85	0.089
Residual	34	205.000	6.029		

ANOVA for days to heading

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	29.148	14.574	2.17	
WSR	2	1394.926	697.463	103.62	<.001
Gen	5	237.037	47.407	7.04	<.001
WSR.Gen	10	164.185	16.419	2.44	0.026
Residual	34	228.852	6.731		

ANOVA for leaf area

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1.913	0.957	0.76	
WSR	2	17.997	8.998	7.17	0.003
Gen	5	15.947	3.189	2.54	0.047
WSR.Gen	10	10.326	1.033	0.82	0.609
Residual	34	42.652	1.254		

ANOVA for Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	4.148	2.074	0.32	
WSR	2	621.593	310.796	48.65	<.001
Gen	5	355.704	71.141	11.14	<.001
WSR.Gen	10	55.519	5.552	0.87	0.570
Residual	34	217.185	6.388		

Appendix 8.2 Analysis of variance for physiological traits

ANOVA for Initial water content at grain filling stage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.021154	0.010577	2.12	
WSR	2	5.175019	2.587510	517.43	<.001
Gen	5	12.029531	2.405906	481.11	<.001
WSR.Gen	10	0.078676	0.007868	1.57	0.157
Residual	34	0.170025	0.005001		

ANOVA for Initial water content at stem elongation stage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.007180	0.003590	0.40	
WSR	2	6.694478	3.347239	375.47	<.001
Gen	5	14.492776	2.898555	325.14	<.001
WSR.Gen	10	1.683691	0.168369	18.89	<.001
Residual	34	0.303106	0.008915		

ANOVA for excised leaf water retention

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	31.602	15.801	2.68	
WSR	2	27.767	13.883	2.35	0.110
Gen	5	1082.893	216.579	36.72	<.001
WSR.Gen	10	57.325	5.732	0.97	0.485
Residual	34	200.536	5.898		

ANOVA for relative water content at grain filling stage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1.6797	0.8399	3.64	
WSR	2	3647.3842	1823.6921	7910.39	<.001
Gen	5	1875.7643	375.1529	1627.25	<.001
WSR.Gen	10	23.4131	2.3413	10.16	<.001
Residual	34	7.8385	0.2305		

ANOVA for rate of water loss

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	16.344	8.172	2.65	
Gen	5	4902.024	980.405	317.94	<.001
WSR	2	833.696	416.848	135.18	<.001
Gen.WSR	10	50.028	5.003	1.62	0.142
Residual	34	104.843	3.084		

ANOVA for relative water content at stem elongation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	3.624	1.812	0.80	
Gen	5	949.189	189.838	83.30	<.001
WSR	2	2061.848	1030.924	452.38	<.001
Gen.WSR	10	32.500	3.250	1.43	0.211
Residual	34	77.482	2.279		

Appendix 8.3. Analysis of variance for yield and yield components

ANOVA for spike length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.2578	0.1289	0.71	
WSR	2	46.2061	23.1030	127.23	<.001
Gen	5	48.7028	9.7406	53.64	<.001
WSR.Gen	10	5.5547	0.5555	3.06	0.007
Residual	34	6.1739	0.1816		

ANOVA for Seed per spike

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	4.0370	2.0185	2.58	
WSR	2	2042.7037	1021.3519	1304.03	<.001
Gen	5	861.4815	172.2963	219.98	<.001
WSR.Gen	10	32.4074	3.2407	4.14	<.001
Residual	34	26.6296	0.7832		

ANOVA for grain weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	11.7836	5.8918	17.38	
WSR	2	1962.1679	81.0840	893.73	<.001
Gen	5	1028.7811	05.7562	606.88	<.001
WSR.Gen	10	32.3238	3.2324	9.53	<.001
Residual	34	11.5273	0.3390		

ANOVA for grain yield per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.024578	0.012289	9.08	
WSR	2	6.612753	3.306377	2441.95	<.001
Gen	5	3.075457	0.615091	454.28	<.001
WSR.Gen	10	0.122469	0.012247	9.05	<.001
Residual	34	0.046036	0.001354		

Appendix 8.4. Analysis of variance for drought tolerance indices

ANOVA for stress tolerance index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.040407	0.020204	11.09	
WSR	2	2.105267	1.052634	577.70	<.001
Gen	5	4.006898	0.801380	439.81	<.001
WSR.Gen	10	0.038990	0.003899	2.14	0.048
Residual	34	0.061951	0.001822		

ANOVA for stress susceptibility index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.006774	0.003387	2.75	
WSR	2	12.894451	6.447225	5243.62	<.001
Gen	5	0.960412	0.192082	156.22	<.001
WSR.Gen	10	0.791213	0.079121	64.35	<.001
Residual	34	0.041804	0.001230		

ANOVA for yield stability index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.0006916	0.0003458	1.92	
Gen	5	0.1786891	0.0357378	198.89	<.001
WSR	2	3.8918681	1.9459340	10829.74	<.001
Gen.WSR	10	0.1017768	0.0101777	56.64	<.001
Residual	34	0.0061093	0.0001797		

ANOVA for mean productivity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.031730	0.015865	11.09	
Gen	5	3.146467	0.629293	439.81	<.001
WSR	2	1.653188	0.826594	577.70	<.001
Gen.WSR	10	0.030617	0.003062	2.14	0.048
Residual	34	0.048648	0.001431		

Appendix 9. Regression analysis under Normal condition

Regression analysis

Response variate: Gy/plant
Fitted terms: Constant + 1000seedwt + IWCs + RWCg + RWLg + Seed/spike + spike length

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	6	1.1111473	0.18519121	8046.36	<.001
Residual	11	0.0002532	0.00002302		
Total	17	1.1114004	0.06537650		

Percentage variance accounted for 100.0
Standard error of observations is estimated to be 0.00480.

Estimates of parameters

Parameter	estimate	s.e.	t(11)	t pr.
Constant	-0.817	0.103	-7.90	<.001
1000seedwt	0.03987	0.00142	28.13	<.001
IWCs	0.02771	0.00699	3.97	0.002
RWCg	0.00593	0.00124	-4.77	<.001
RWLg	-0.001688	0.000581	-2.91	0.014
Seed/spike	0.03218	0.00126	25.44	<.001

Appendix 10. Regression analysis for water stress at tillering stage

Regression analysis

Response variate: Gy/plant
Fitted terms: Constant + %1000seedwt + PH + RWLg + IWCs + Seed/spike + spike length

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	6	1.551471	0.2585785	1922.42	<.001
Residual	11	0.001480	0.0001345		
Total	17	1.552950	0.0913500		

Percentage variance accounted for 99.9
Standard error of observations is estimated to be 0.0116.

Estimates of parameters

Parameter	estimate	s.e.	t(11)	t pr.
Constant	-0.7402	0.0772	-9.59	<.001
1000seedwt	0.03096	0.00276	11.21	<.001
PH	0.00286	0.00108	2.66	0.022
RWLg	-0.002407	0.000844	-2.85	0.016
IWCs	0.0476	0.0169	2.82	0.017
Seed/spike	0.02308	0.00316	7.30	<.001
Spike length	-0.01666	0.00458	-3.63	0.004

Regression analysis

Response variate: STI
Fitted terms: Constant +1000seedwt + DF + RWLg + IWCs + IWCg

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	5	1.668428	0.3336856	707.36	<.001
Residual	12	0.005661	0.0004717		
Total	17	1.674089	0.0984758		

Percentage variance accounted for 99.5
Standard error of observations is estimated to be 0.0217.

Estimates of parameters

Parameter	estimate	s.e.	t(12)	t pr.
Constant	0.101	0.147	0.69	0.504
1000seedwt	0.05729	0.00376	15.24	<.001
DF	-0.00482	0.00151	-3.18	0.008
RWLg	-0.00443	0.00175	-2.54	0.026
IWCs	0.1532	0.0335	4.57	<.001
IWCg	0.1820	0.0527	-3.45	0.005

Appendix 11. Regression analysis for water stress under booting stage

Regression analysis

Response variate: Gy/plant

Fitted terms: Constant +1000seedwt + DH + ELWRg + IWCs + RWCg + RWCs + Seed/spike + spike length

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	8	0.6039918	0.07549897	3449.07	<.001
Residual	9	0.0001970	0.00002189		
Total	17	0.6041888	0.03554052		

Percentage variance accounted for 99.9

Standard error of observations is estimated to be 0.00468.

Estimates of parameters

Parameter	estimate	s.e.	t(9)	t pr.
Constant	-0.3951	0.0863	-4.58	0.001
1000seedwt	0.02321	0.00121	19.20	<.001
DH	-0.002753	0.000866	-3.18	0.011
ELWRg	0.00258	0.00140	1.84	0.100
IWCs	0.05947	0.00955	6.23	<.001
RWCg	0.00546	0.00116	-4.72	0.001
RWCs	0.00318	0.00151	2.11	0.065
Seed/spike	0.01226	0.00139	8.85	<.001
Spike length	0.01042	0.00376	2.78	0.022

Regression analysis

Response variate: STI

Fitted terms: Constant + 1000seedwt + Seed/spike

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	1.052442	0.5262211	1234.88	<.001
Residual	15	0.006392	0.0004261		
Total	17	1.058834	0.0622844		

Percentage variance accounted for 99.3

Standard error of observations is estimated to be 0.0206.

Estimates of parameters

Parameter	estimate	s.e.	t(15)	t pr.
Constant	-0.2322	0.0278	-8.36	<.001
1000seedwt	0.03074	0.00372	8.27	<.001
Seed/spike	0.02754	0.00349	7.90	<.001