International Master Programme at
the Swedish Biodiversity Centre

Master's thesis
No. 61
Uppsala 2009

# Agronomic evaluation of Ethiopian barley (*Hordeum vulgare* L.) landrace populations under drought stress conditions in low-rainfall areas of Ethiopia

**Kiflu Tarekegn Abera**

**Supervisors**

**Dr. Jens Weibull,**

**Dr. Dereje Assefa,**

CBM Swedish
Biodiversity Centre

CBM MASTER THESES SERIES

# Abstract

Drought is the main factor limiting the yield of barley (*Hordeum vulgare* L.) in drought prone areas of Ethiopia because rainfall is scarce, unevenly distributed and temperatures are high during grain filling period. A field experiment was conducted to evaluate the yield performance and some agronomic traits of 20 barley landrace populations and three long-term checks (Bentu, Aruso and Saesa-a) for drought tolerance at Endayesus, Mekelle, Tigray. The design used was randomized complete block with three replications. In addition to the field experiment, a filter paper experiment was carried out to observe early root development so as to relate the fastest root growth with the overall field performance of the varieties. Accession numbers 235238, 235264 and 237320 significantly differed from the other varieties including the check varieties in attaining 50 percent heading and 75 percent maturity ($P<0.01$). Similarly, accession numbers 235238, 235259, 231191 and 235299 significantly out yielded all the other varieties including the two checks) at the 0.01 level of probability. Varieties also significantly differed in their thousand seed weight, a trait known to have positive correlation with yield. Accordingly, accession numbers 235299, 235264, 235238, 223191, 237327, 235285 and 235259 had the highest thousand seed weight. Bivariate correlation analysis revealed strong positive correlation of root length with grain yield and harvest index. Similarly, harvest index with grain yield, thousand seed weight with grain yield, and with productive tillers had positive correlations. Overall, accession numbers 235238, 235264 and the local check, Saesa-a have significantly proven superiority over the others in their overall performance in the field and also consistently demonstrated the fastest root development in the filter paper experimentation. The strong positive correlation of root length with thousand seed weight, harvest index and grain yield in combination with other agronomic performances in the field could be used as selection criteria for drought tolerance.

Key words: Barley, *Hordeum vulgare*, landraces, drought tolerance

# Contents

**Introduction** 6

**Literature review** 9

**Materials and methods** 16

Study area 16

Planting material used 18

Field trial 19

Filter paper experiment 19

**Results** 21

Field evaluation 21

Root growth test 25

Bivariate correlations 25

Cluster analysis 26

Ordination 29

**Discussion** 32

**Conclusion** 35

**Acknowledgements** 37

**References** 38

**Appendix 1 Collection passport data for the experimental variables** 42

**Appendix 2 Bivariate correlation analysis** 43

# Introduction

Globally, barley (*Hordeum vulgare* L.) ranks fourth among cereal crops in both yield and acreage, after wheat, rice and maize (CSA 2004). It is one of the oldest crops in Ethiopia cultivated and known as early as 3000 BC (Hailu and van Leur 1996). At national level, it is the third most important crop after sorghum and teff which is cultivated in wider ranges of environments, from as high as 3000 meters above sea level (m.a.s.l.) to low-rainfall areas including low lands with altitudes up to 1500 m.a.s.l. Belg barley (barley production carried out under the small rains received in Feb/March-April/May) is produced in parts of Wello, Shewa and Bale. Barley grain is used as a major food item; while the straw is used in the building of house walls together with mud, also for roof thatching and as fodder for domestic animals. In most of the Ethiopian highlands, barley accounts for over 60 percent of the total plant food of the inhabitants (Zemede 1989). The long history of cultivation, the wider agro-ecological and cultural diversity in the country has resulted in a large number of landraces of the crop, which can adapt to various environmental conditions.

According to Orlov (1929), Huffnagel (1961) and Westphal (1975), Ethiopian barley landraces were believed to have moderate yield, big kernel size, high tillering capacity, and large 1000-grain weight and high percentage of protein content. Awns contribute substantially to spike photosynthesis and longer awns are a possible selection criterion for drought-prone areas (Martin et al. 1976). Almost all of Ethiopian barley landraces are awned (Personal observation). Other authors, such as Onwueme and Sinha (1991) have also reported that barley as the most drought and salt-resistant of the small cereals, both during germination and later stage of growth. According to Hailu and Fekadu (1987), Ethiopian indigenous barley and farmers' indigenous knowledge associated with it has never been seriously considered by the modern sector of the country's agriculture. Such conditions necessitated execution of research on local landraces to come up with genotypes endowed with adaptive traits to drought stress conditions.

The country has been described as one of the world's richest genetic resource centres in terms of plant genetic diversity in general and crop diversity in particular by the Russian botanist N. I. Vavilov in the 1920s (Vavilov 1951). The diversity is principally attributed to the socio-economic, cultural diversity and complex topography. The conditions generally held to be important to or essential for the building up of a vast genetic diversity are all found in Ethiopia. Under such diverse and favourable conditions, crops such as durum wheat, field bean, lentil, field pea, chick pea, sunflower, barley and others were first brought to domestication from elsewhere and all these crops in general and barley in particular has developed immense variation in adaptation and economic traits in the Ethiopian region (IBCR 2001). However, due to recurrent droughts, changes in land use, use of high-input improved varieties and degradation of the natural habitats, the diversity of many of the crops in general and barley in particular is facing challenges.

Drought is one of the major production constraints that reduce crop yields in low-rainfall areas where many of the world's resource-poor farmers live (Ceccarelli et al. 1991). According to (Ribaut et al. 1997) as cited by Altinkut et al. (2003), the seriousness of drought problem is not only in arid and semi-arid regions, but also in places where total precipitation is high, but with uneven distribution over the entire growing season. Barley is a typical cereal crop that can do well in marginal, low-input and drought stressed environments than other cereal crops (Ceccarelli et al 1991). According to Shephard *et al.* 1987 in Shakhatreh et al. (2001) and Ceccarelli *et al.* (1991), a major feature of barley adaptation to low rainfall and high temperature is its early ear emergence. Early emergence of ear is a desirable agronomic trait which makes it early enough to ensure that pollination and grain filling take place before heat and drought stresses become too severe. In low-rainfall areas (receiving <250 mm of annual precipitation) of the Middle East (Acevedo et al., 1991) and in most of the low lands and highlands of Ethiopia receiving low amount of rainfall, barley is traditionally the dominant one and crop of best alternative choice.

Low-rainfall areas are characterized by a high year-to-year variability in the amount of rain they receive. Almost half of the area where barley is grown is a high-risk area, where crop failures are common, affecting resource-poor farmers who have little or no other options. Consequently, the development of barley genotypes that have greater stability and the ability to produce substantially higher yields in the presence of drought stress is the most economic solution. In the same way, small holder farmers living in arid and semi-arid agro-ecological zones of Ethiopia, frequently encounter food insecurity. They lack crop varieties that can cope with the small amount of annual rainfall they receive which is inadequate in amount and erratic in distribution. Barley landraces of native origin are believed to have good adaptation to those harsh agro-ecological and climatic conditions. However, many of the native barley landraces that co-evolved with biotic and abiotic stresses for many years in those drought-prone areas are currently decreasing in frequency of occurrence mainly due to recurrent drought resulting in famine, changes in land use, use of high input-improved varieties and degradation of their natural habitats (Zemede 1989). In response to such research question, not much research work has been conducted to screen varieties with adaptive traits and carryout restoration programmes to address problems of resource-poor farmers in drought-stressed agroecosystems.

The Institute of Biodiversity Conservation (IBC) has collected and conserved more than 17 000 accessions of barley landraces in the cold storage since the establishment of its gene bank in 1976. Despite the availability of tremendous diversity in this crop, plant breeders have yet insufficiently utilized the genetic diversity to generate cultivars with useful traits as a result of limited information. Evaluations of barley landraces for agro-morphological characters, disease, and drought resistance traits carried out by various researchers in the country have provided indicative information regarding regional differentiation in trait expressions. However, full information related to drought tolerant traits on Ethiopian barley landraces is very much limited.

The objective of this research project was therefore to contribute its share towards the on-going food security programmes by way of alleviating the recurrent chronic food shortages and improve the livelihoods of the resource-poor, small-scale farming communities in dry land parts of Ethiopia. The specific objectives of the research project were: 1) to evaluate the agronomic performance of different barley landraces under environments receiving low amount of annual rainfall with erratic distribution and experiencing very high evapotranspiration, 2) to come up with barley landraces which can better tolerate drought stress and give higher and stable yields to the farming communities, and 3) to identify genotypes possessing resistance genes against biotic and abiotic stresses that can serve as sources of gene pool for the on-going hybridisation programmes in the country.

To this effect, 175 landrace populations, collected from drought prone areas of the country, were acquired from the gene bank of the Ethiopian Institute of Biodiversity Conservation (EIBC). These materials were then subjected to preliminary screening trial under irrigated conditions during the 2007/2008 dry season. From the preliminary screening trial, 20 out of 175 landrace populations that demonstrated good performance on easily observable phenotypic traits such as earliness, uniformity, number of productive tillers, number of seeds per spike, tolerance to biotic and abiotic stresses, grain yield, biological yield etc. were selected and advanced to the main experiment carried out during July through October 2008 cropping season.

# Literature review

Domestication of barley took place prior to 7000 B.C. in the region of the near east known as "Fertile Crescent." The Fertile Crescent according to Ceccarelli (2007) includes parts of Jordan, Lebanon, Syria, Southern Turkey, Iraq, and Western Iran. Evidence suggests that the most important of the early cereals was barley, and the archaeobotanical material from the region clearly shows that the first barleys were two-rowed (Harlan and Zohary 1966). The wild progenitor of cultivated barley, *Hordeum vulgare* species *spontaneum*, is still widely distributed along the Fertile Crescent where, particularly in the driest areas, it can be easily identified from a distance because of its height. It is likely that *Hordeum spontaneum* contributes to the evolutionary processes of barley landraces through a continuous introgression of genes.

Recognized as one of the world's most ancient food crops, barley has been an important cereal crop since the early stages of agricultural innovations 8,000 to 10,000 years ago (Asfaw 2007). According to ibid, barley, throughout history has undergone continuous manipulation in an effort to optimize its use for human consumption and animal feed. The author further indicated that barley has been used as a model organism in experimental botany, the plant of choice because of its short life cycle and morphological, physiological, and genetic characteristics. At global level, barley ranks fourth among cereal crops in both yield and acreage, after wheat, rice, and maize (Munck 1992). However, with advances in food production and agriculture, major dietary shifts from barley to rice and/or wheat have resulted in the decline in barley consumption, with the exception of certain societies - particularly those relying on traditional, small-scale agricultural systems, in which its use as human food has continued to the present (Asfaw 2007).

The world has now"re-discovered" barley as food grain with desirable nutritional composition including some medicinal properties. Burger et al. 1981 and Anderson et al. 1991 (cited in Asfaw 2007) indicated that barley breakfast foods and snacks are increasingly available, as a result of recent research findings, which show that barley fibber contains beta-glucans and tocotrinols, chemical components known to lower serum cholesterol levels in the blood. Efforts to improve barley have demonstrated a preference for a limited number of modern, genetically uniform cultivars suited for high-input agriculture, to the neglect of the various farmers' varieties, or landraces on which a large sector of the human population has subsisted for millennia. However, these improved, high-input barley varieties have been found less adapted and yielding much lower than the landraces, especially in environments frequently experiencing drought stress and risks associated with stress (Asfaw 2007).

According to Orlov (1929), Huffnagel (1961) and Westphal (1975), Ethiopian barley landraces were believed to have desirable agronomic traits related yield and yield components. Awns contribute substantially to spike photosynthesis and longer awns are a possible selection criterion for drought-prone areas (Martin et al. 1976). Almost all of Ethiopian barley landraces are awned (Personal observation). Other authors, such as Onwueme and Sinha (1991) have also reported that barley as the most drought and salt-resistant of the small cereals, both during germination and later stage of growth. According to Hailu and Fekadu's (1987) findings, Ethiopian indigenous barley and farmers' indigenous knowledge associated with it has never been seriously considered by the modern sector of the country's agriculture.

Experiment conducted by Loss and Siddique 1994 as referred by Gonzalez et al. (2007) compared tiller survival in old and new drought tolerant varieties and have shown that older varieties over-produce tillers many of which fail to set grains while modern-drought tolerant varieties produce fewer tillers most of which survive and set seeds under drought stress conditions. Innes et al. 1984 in Reynolds et al. [2000. accessed 6 March 2009] demonstrated the benefit of abscisic acid (ABA) accumulation under drought conditions and it appears to pre-adapt plants to stress by reducing stomatal conductance, rates of cell division, organ size, and increasing development rate. However, high ABA can also result in sterility problems because high ABA levels may abort developing florets. Research works on leaf anatomical traits such as; waxiness, pubescence, rolling, thickness and posture by Richards 1996 as cited in Reynolds et al. [2000. Accessed 6 March 2009] have indicated that these traits decrease radiation load to the leaf surface. Lower evapotranspiration rate and reduced risk of irreversible photo-inhibition were also considered as additional benefits of these traits. However, these leaf anatomical traits may also be associated with reduced radiation use efficiency, which would in turn reduce yield under more favourable conditions.

Risk aversion in crop production is the prime survival strategy for subsistence farmers living in drought prone areas of the world, so also in Ethiopia. Notwithstanding this problem, both farmers and their governments aspire to capture as much as possible of the crop yield potential in order to increase production and fulfil their food and feed requirements (Sinebo 2005). Yield is considered as the total biological yield (grain + straw) because in most dry areas the barley crop is used for sheep grazing in the field or harvested for animal feed as hay. In Mediterranean type of climates, drought is the major factor limiting the yield of cereal crops because rainfall is scarce, unevenly distributed and temperatures are high during early vegetative stage and grain filling period (Gonzalez et al. 2007). According to Van Ginkel et al. (1998), Genotype x Environment interactions are considered most important in determining grain yield as these interactions could occur as a consequence of differential responses by genotypes to yearly variation in the quantity of rainfall or its distribution. However, high yield and drought adaptation are often based on different and, to some extent contradicting mechanisms. Traits related to drought resistance, such as small plant size, reduced leaf area and early maturity, can result in reduced total seasonal evapotranspiration. In the same way, Karamanos and Papatheohari 1999 as cited in Rizza et al. (2004) have reported that prolonged stomatal closure allows plants to limit water loss but also reduces dry matter production However, Fischer and Wood (1979) as cited in Ceccarelli et al. (1987) have found out that these traits are associated with a lower yield potential. Slafer and Araus 1998 in Rizza (2004) on the other hand, found out that assimilate accumulation in the stems before anthesis is advantageous if drought occurs during subsequent phases, but it could reduce spike weight at anthesis.

Traits related to drought resistance and to high yield potential should be alternatively favoured in cereal breeding programmes, based on the ideotype for a target area and a specific type of stress. According to some authors, such as Falconer 1990 as cited in Ceccarelli and Grando (1991), yield in low and high yielding environment can be considered as separate traits which are not necessarily maximized by identical alleles. (Falconer 1990 as cited by Ceccarelli et al., 1991) consequently reported that plant breeding strategies should be different when targeting stress and non-stress environments (Ceccarelli et al. 1991; Ceccarelli et al. 1998). Other authors such as Cativelli et al 1994, Braun et al 1997 and Sayri et al. 199) as referred by Rizza et al. (2004) also claim that selection under favourable conditions is required to select genotypes with good performance under both stress and non-stress conditions.

Different authors have suggested two varying breeding strategies for stress environments. An issue that has been thoroughly discussed in relation to breeding strategies for stress environments is whether breeding for stress environments should rely on selection under good environmental conditions and carry out subsequent yield testing in stress environments or on direct selection under stress conditions. Supporters of the first strategy assume that varieties that give good yields in favourable conditions will also yield relatively well in unfavourable conditions. Selection in favourable conditions is easier because genetic variation and heritability are higher in this case. This strategy also assumes that genotypes selected in stress environments will have a low yield potential in good environments. Although the argument for selection in favourable conditions has been supported by Roy and Murty 1970 in Ceccarelli et al. (1998), direct selection under stress conditions has been advocated by many scientists such as Aufhammer et al 1959, Burton 1964; Hagemann et al 1967; Johnson et al 1968; Hurd 1968, Boyer & McPherson 1975; Johnson 1980, Bidinger 1980, Richards 1982 and Buddenhagen 1983 as cited in

Ceccarelli (1987). According to Hurd 1971 as referred by Ceccarelli (1987), breeding programmes aimed at increasing yield under stressful environments should be based on selections carried out under stressed conditions. Hurd 1971) in Ceccarelli (1987) further stated that breeding for maximum yield in the most adverse years rather than for highest yield in good years is of paramount importance. Both Hurd 1971 and Fischer and Wood 1979 in Ginkel et al. (1998) agreed and suggested that breeding strategies for yield which change the allocation of resources within the plant might not be the optimal solution for buffering yield and yield components in drought situations.

A major problem in plant breeding is the disproportion between the limited number of selection sites and recommendations made to wide and different areas of cultivation. This problem has two fundamental facets. One is that the number of target environments in many cases greatly exceeds the number of selection environments, especially sites where selection in the early segregating material is conducted. The other problem is the relationship between selection and target environment in terms of soil, climate, agronomic practices and so on (Ceccarelli et al., 2001). In the same way, Falconer 1952 as cited by Ceccarelli et al. (2001) pointed out that direct selection in the target environment or in an identical one to the target environment is always the most efficient. The selection efficiency decreases as the selection environment becomes increasingly different from the target environment (Ceccarelli et al., 2001). Therefore, it is not surprising to see much more successes of plant breeding in favourable environments which have the greatest similarity to the research stations where selection is carried out. However, Byerlee and Husain 1993 as referred in Ceccarelli et al. (2001) have indicated that resource-poor farmers in unfavourable environments, without the means to modify their environment through application of water, herbicides, fertilizers and pesticides always suffer from low yields, crop failures and, in extreme cases, malnutrition and famine. Evidences from breeding by Hurd 1971 in Ceccarelli (1987) and quantitative genetics by Falconer 1990 as cited in Ceccaelli et al. (1991) have indicated that breeding for stressful conditions should rely up on selection in the presence of stress. Similarly, Ceccarelli and Grando (1989) indicated that in adapted barley germplasm the use of direct selection in the presence of stress increased selection efficiency for stress environments.

Based on the magnitude of genetic correlations between yields in stress and non-stress environments, and on the ratio of genetic variances in stress and non-stress environments, selection for tolerance to stress is expected to produce a negatively correlated response on mean yields in non-stress environments [Rosielle & Hamblin 1981 as cited in Ceccarelli et al. (1998)]. This conclusion, which is supported by the data of Langer et al 1979 as referred by Ceccarelli (1987), indicated that direct selection in stress environments will decrease yield in a non-stress environment unless genetic variances in stress environments are considerably greater than in non-stress environments and genetic correlations are close to 1. Shakhatreh et al. (2001) found out positive relationship between grain yield and the length of grain filling period in experiments conducted in the wettest location, negative relationship in the driest and non-significant at two intermediate locations, emphasizing the importance of selection in the target environment and the need to develop early-maturing genotypes as a way of withstanding drought and high temperatures during grain filling period. Shakhatreh et al. (2001) further reported the presence of a high and negative correlation coefficient between drought susceptibility index and grain yield at the driest site, whereas at the wettest site the correlation coefficient was lower and in some cases positive, indicating the existence of characters that are desirable under drought and undesirable under favourable conditions.

According to Ceccarelli (1987), the major problem with selection under stress environments is the variation of stress in the experimental field, and therefore the choice of breeding procedures and experimental designs is of paramount importance in attempting to reduce the environmental variation and thus increase heritability and repeatability. Other problems in field testing for stress tolerance, which are more difficult to remove without special field techniques, are the variation of stress from year to year, the different time of the growing season when the stress occurs, and the different types of stress, or combination of stresses, which occur (for instance, heat stress with or without moisture stress). Breeders dealing with field testing for stress tolerance must then be aware of such problems, because reliable results may not become available every year. Therefore, carefully selected sites (multi-location testing), representing ranges of stress conditions are essential for rapid progress in this regard.

Apart from environmental conditions, the final grain yield of barley is determined by the product of three components; the number of ears per $m^2$, the number of grains per ear and individual grain weight (currently expressed as 1000-grain weight). The duration of grain filling and the growth cycle also contribute greatly to crop yield (Garcia del Moral et al 1991 in Gonzalez et al. (2007). According to El Madidi et al. (2005), most farmers in the unfavourable areas of arid and semi-arid tropics use their own landraces that have gone through natural selection for centuries. According to these authors, farmers in such areas do not apply fertilizers, herbicides or insecticides and have little or no inclination to use improved varieties or high-input practices.

Because of its range of geographical distribution, barley has accumulated a vast array of genetic variability, which was maintained by landraces grown across all barley growing regions. Over the past 100 years, heterogeneous landraces have gradually been replaced by homogeneous pedigreed lines in industrialized countries while still continue to be widely grown in developing countries, particularly in harsh environments (El Madidi et al., 2005; Samarah, 2005). Shephard et al 1987 as referred by Shakhatreh et al. (2001) and Ceccarelli et al. (1991) reported that a major feature of barley adaptation to low rainfall and high temperature is its early ear emergence, a desirable agronomic trait, which makes it early enough to ensure that pollination and grain filling take place before heat and drought stress become too severe. Genotype-environment (G X E) interaction exists whenever the differences amongst a number of genotypes change with changes in the environment. Hence, the presence of high G X E interaction complicates breeding work as it makes it difficult to predict how genotypes selected under a given set of conditions will perform in a different set of environmental conditions (Ceccarelli 1989).

Water stress is one of the major yield-reducing factors by causing physiological and biochemical effects on plants leading to serious problems in many parts of the world where barley, wheat, and other small-grained cereals form the staple diets (Altinkut et al., 2003). The same authors indicated that the same situation holds true not only in arid and semi-arid regions, but also in places where total precipitation is high, but unevenly distributed over the growing period. They further asserted that the effects of water stress on leaf physiology could be mediated by the production and accumulation of toxic reactive oxygen intermediates generated during water stress which in turn can bring about a serious challenge to a number of cellular functions. For instance; chlorophyll destruction, serious disorganization of chloroplast fine structure, and enzyme inactivation can be due to these toxic oxygen forms. According to Sinclair and Ludlow 1985 as cited in Teulat et al. (2003), Relative Water Content (RWC) is related to cell volume, as it may closely reflect the balance between water supply to the leaf and transpiration rate, when measured on the flag leaf. The potential value of RWC for breeding under drought stress conditions has been demonstrated by Schonfeld et al 1988 as cited by Teulat et al. (2003). These authors also reported that RWC is inherited quantitatively and controlled by genes with additive effects. Although difficult to measure, Hurd 1968 in Ceccarelli (1998) has shown that high Relative Leaf Water Content (RLWC) during grain filling as an indicating ability of the plant to extract water. A root system that can extract whatever water is available in the soil profile is clearly drought adaptive.

Jones et al. (2003) reported that several studies carried out in arid and semi-arid regions have shown that increased application of phosphorus fertilization greatly improved water use efficiency. This finding was supported by Payne et al (1992) as referred by Jones et al. (2003), in which they indicated that phosphorus application may partially overcome the direct and indirect effects of water stress on phosphorus uptake and diffusion to the roots. Other authors such as Saneoka et al 1990 and Singh and Sale 2000 have also found out that root growth and potential root hydraulic conductance to increase with the application of higher phosphorus levels, assuming that increased root growth would lead to a greater volume of soil explored and hence a greater potential reservoir of soil water. They also indicated the possibility of phosphorus enabling the plant to better withstand drought stresses due to its role in energy storage and protein formation. However, this fact would not hold true under very extreme drought conditions, because water rather than phosphorus would likely become more limiting factor, as low water content might decrease phosphorus diffusion rates. Singh and Sale 2000 in Jones et al. (2003) also reported that drought tolerance in barley has been increased with increased application of phosphorus fertilizer. Similarly, Radriquez et al 1996 in ibid has reported that increased application of phosphorus fertilizer significantly increased shoot dry matter of barley.

# Materials and methods

## Study area

The experiment was conducted in Northern Ethiopia, at Endayesus, Mekelle (Tigray Regional State). The experimental site located 13°28' N and 39°29' E, 8 kms east of Mekelle town has an altitude of 1950 m a.s.l. (meters above sea level). The site (Figure 1) has a unimodal type of rainfall which commences in the second week of July ceasing in the first week of September. However, in very rare cases, rains can commence in the beginning of July and cease in mid September resulting in good harvests. This experimental site receives an average annual rainfall of 300 mm which is classified as one of the drought-prone areas of the country by the Ethiopian meteorological service.

Figure 1 The location of the study area

### Climatic conditions of the season

Daily rainfall, minimum and maximum temperature data for the months of July, August and September 2008 were obtained from the nearby higher learning institution, Mekelle University (Figure 2a-2c). The total amount of rainfall received in the season was 328.2 mm of which 109.6, 185.3 and 33.3 mm rain was recorded for the months of July, August and September respectively. The rainfall received this season exceeded the annual average by about nine percent. However, it was erratic in distribution and increased in amount from July to August and drastically decreased in September. On the other hand, the daily mean temperatures for July, August, September and October remained more or less constant. Daily mean temperature of 27, 26, 26, and 26.5°C, was recorded for the months of July, August, September and October respectively (Figures 1a-1c).

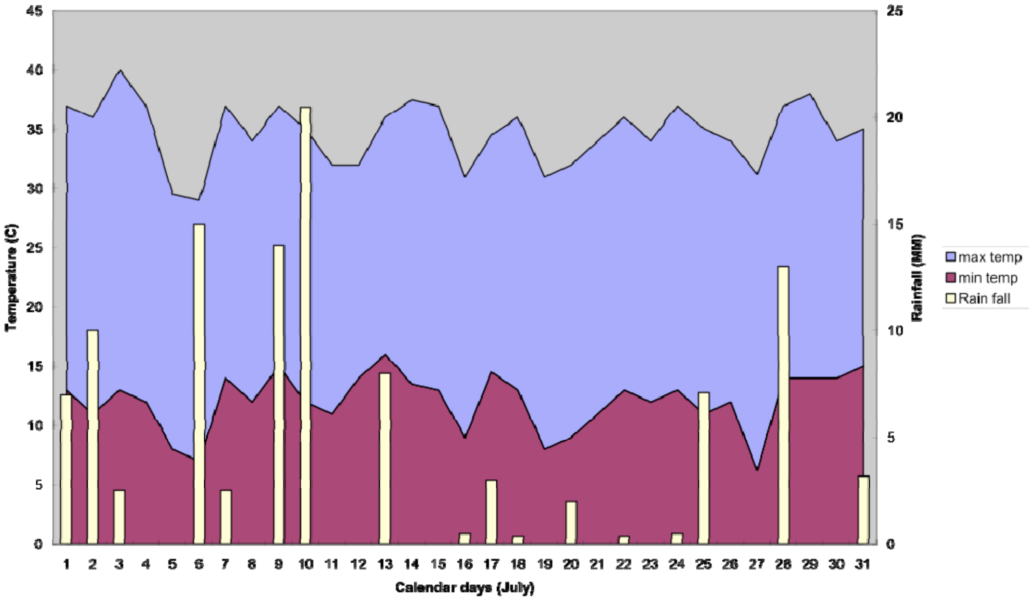

Figure 2a. Daily rainfall, maximum and minimum temperatures for the month of July 2008, Endayesus, Mekelle

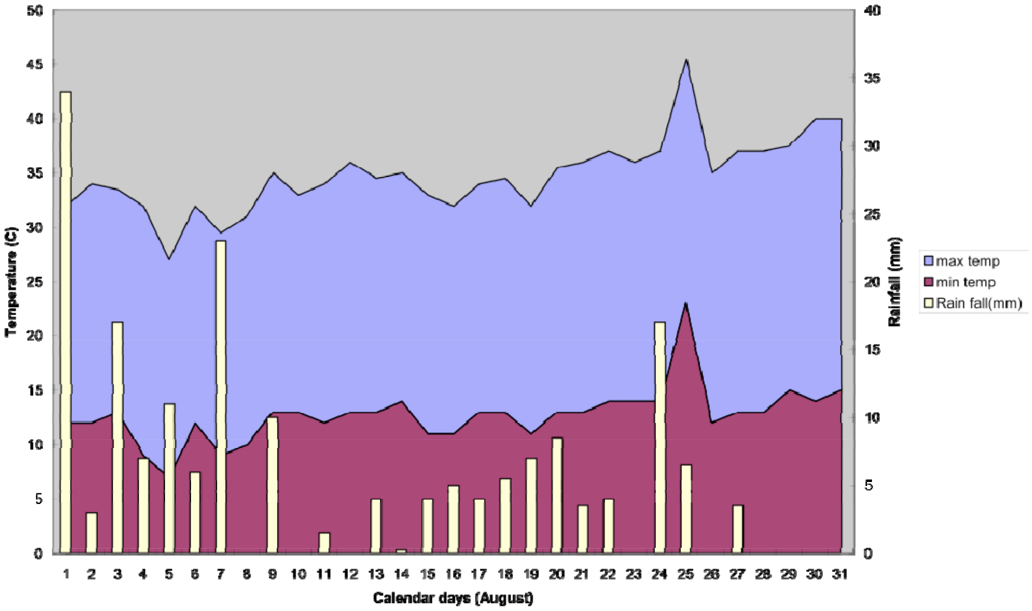

Figure 2b Daily rainfall, maximum and minimum temperatures for the month of August 2008, Endayesus, Mekelle

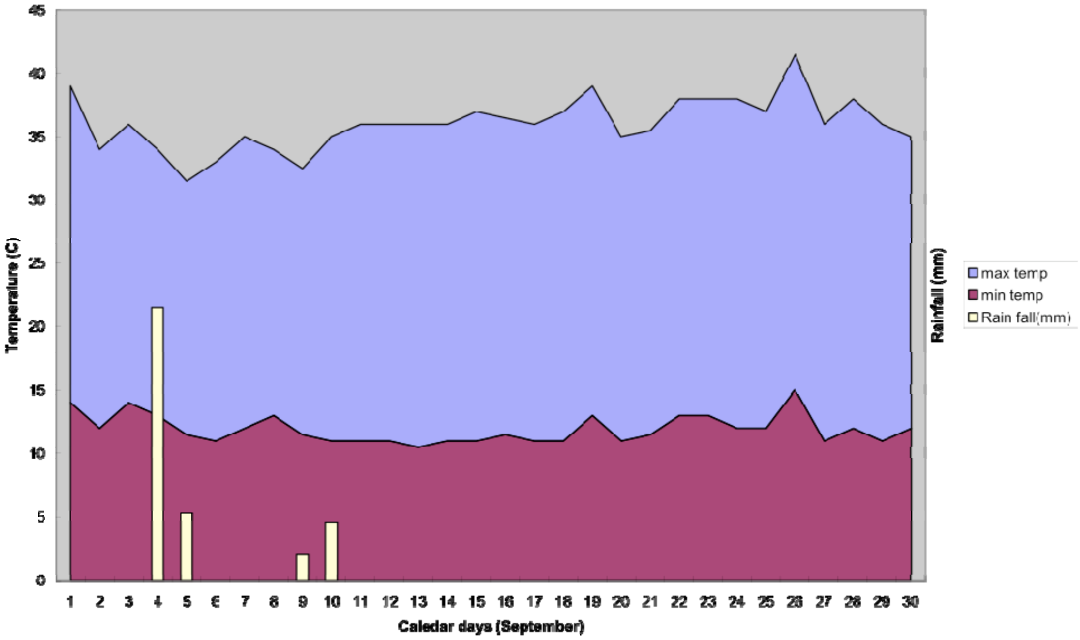

Figure 2c Daily rainfall, maximum and minimum temperatures for the month of September 2008, Endayesus, Mekelle

## Planting material used

Before conduction of the actual experiment in the rainy season under natural conditions, 175 landrace accessions collected from various geographical ranges, mostly from drought prone areas of Ethiopia have been acquired from the cold storage of the Institute of Biodiversity Conservation. These materials were planted in the off-season under irrigated conditions as a preliminary screening trial and selection has been carried out on easily observable phenotypic traits such as yield, earliness, uniformity, tolerance to biotic and abiotic stresses, etc. Accordingly, it was possible to select 20 landrace accessions that were in turn promoted to the rainy season (July/October 2008) rainy season field experiment. At the same time, seed multiplication for the main experiment has also been taken care of simultaneously. This activity has been undertaken in the months of December 2007 – May 2008. Accordingly, 20 different farmers' barley landrace populations which were selected from the off-season preliminary screening trial including another three long-term checks (one from ICARDA, one national and one local checks), in total 23 varieties have been used as experimental variables (Appendix 1). However, variety number 20 (accession number 221300) was discarded from the experiment since it was unable to flower and set seeds with the available soil moisture. Hence, the number of experimental varieties has been reduced to 22.

Altogether, thirteen quantitative traits were recorded and subjected to one-way ANOVA: total number of days from planting to 50 percent heading/flowering, number of days to 75 percent maturity, plant height, awn length and spike length in cm, seeds per spike and productive, tillers in number, biological yield and grain yield in gm/plot, thousand grain weight in gms, leaf area index of the flag leaf in cm$^2$, harvest index in percentage, and grain filling period in days were the characters or traits studied.. Moreover, mean root length in cm recorded at three different intervals (one week, two weeks and three weeks after planting) was also studied in a filter paper experiment in the laboratory.

## Field trial

The experimental design employed was Randomized Complete Block Design (RCBD) in three replications. Each experimental unit consisted of 2.4 m$^2$ plot area with four rows of two meters length (Figure 3). The spacing between rows of a treatment was 30 cm and 40 cm between plots of different treatments. Sowing took place on the 7th of July as the rains started a bit late in the season. ANOVA was used to determine the significance levels between treatments means. Treatment mean separation for different quantitative traits was compared using Student's t Test (Gomez and Gomez, 1984). For statistical analysis, all the necessary data and samples were collected from the two central rows. For qualitative traits such as waxiness and anthocyanine, the data was recorded as presence or absence, hence difficult to measure the intensity or amount of wax or anthocyanine on the plant part/s. Therefore, no statistical analysis was carried out for all qualitative characters in this experiment except for the quantitative ones (Table 1).

Figure 3. Experimental plots (Photo: K. T. Abera).

## Filter paper experiment

In addition to the field experiment, four seeds were sampled from each of the 22 varieties and then planted on filter paper in two replications in the laboratory, Department of Dryland Crop and Horticultural Sciences, Mekelle

University. They were planted on 28 November 2008. The seedlings grown in the Petri dishes were regularly watered uniformly after every third day and closely monitored and protected against fungal pathogens growth. In the mean time, data on root length measurements have been recorded on the seventh, 14th and 21st days after planting to relate the outcome with (the ones that would have overall good field performance) drought tolerant varieties grown under natural rainfed conditions in the field.

Table 1 Parameters recorded

| Parameter | |
|---|---|
| Number of days to 50 % seedling emergence | Seeds per spike* |
| Stand count (number of plants/plot) | Waxiness presence or absence on stem and leaf |
| Number of days to 50 % heading* | Anthocynine presence or absence on stem, leaf and auricle |
| Plant height in cm* | Biological yield in g/plot* |
| Leaf diseases' score (0-9 scale) | Grain yield in g/plot* |
| Number of effective tillers/plant* | Harvest index (in percentage)* |
| Leaf area index (LAI) of the flag leaf* | 1000 grain weight (TSW)* |
| Number of days to 75% maturity* | Early root development, in cm, (7, 14 and 21 days after planting on Petri dishes)* |
| Grain filling period in days* | Row number (2, 6 or irregular) |
| Awn length in cm* | Lemma colour |
| Spike length in cm* | Seed Color |

* Agronomic traits on which statistical analysis has been carried out

# Results

## Field evaluation

The varieties exhibited different mean performances for the traits studied (Table 2). Days to 50 percent heading ranged from 53 to 70 with average of 58 days, while days to maturity had an average of 92 days, with a range of 84 to 96 days. Awn length ranged from 10 to 15.3 cm .(with average of 12.5 cm) while seeds per spike had a range of 24 to 65, averaging 28 seeds per spike; and grain yield from 125.0 to 342.7 gm (10.41-28.56 q/ha), with an average plot yield of 279.5 grams (23.33 q/ha). Similarly, thousand seed weight ranged from 27.0 to 57.6 gms, averaging 49.6 gms; harvest index ranging from 29.9 to 50.2 percent (averaging 44.8 percent) and mean root length over the three weeks period ranged from 13.5 to 21.3 cm averaging 18.1 cm. ANOVA carried out on the 14 quantitative traits revealed highly significant differences among varieties for total number of days from planting to 50 percent heading and 75 percent maturity, awn length, number of seeds per spike, grain yield per plot, thousand seed weight, harvest index and mean root length at the 0.01 level of probability (Table 3). It has also shown significant differences among varieties for plant height, spike length, number of productive tillers, biological yield, leaf area index and grain filling period at the 0.05 probability level (Table 3).

Based on the analysis of variance (Table 3), attempts were made to separate trait mean performance of the varieties using student's t-test based on Gomez and Gomez (1984). Accordingly, the local check Saesa-a, accession numbers 235238, and 235264, the International check, Bentu from ICARDA and accession number 237320 were among the earliest varieties that took 53 to 56 days to attain 50 percent heading. Similar trend was observed on accession numbers 235238, 237320, 235264, 235299, and the local check-Saesa-a, for days to maturity except for Bentu which ultimately aligned itself with the latest maturing group (took 94 days to attain 75 percent maturity). The local check, Saesa-a, accession numbers 235238, 235264 and accession number 237320 that had similar number of days to heading matured significantly much earlier than the other varieties (matured within 84 to 87 days after planting). These materials were capable of efficiently utilizing whatever moisture was available in the soil, set seeds and matured early enough before moisture and temperature stresses became too severe. These landrace populations are considered as candidate varieties to moisture stress areas because of their adaptive traits to such harsh growing conditions.

Table 2 Mean quantitative data for the 14 agronomic traits studied

| *Variety No.* | *Var names/ accession number* | ***Mean quantitative data*** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | DTH in numb | DTM in numb | PLH n cm | AWL in cm | SPL in cm | SPS in numb | PTI in numb | BIY in gm | GRY in gm | TSW in gm | LAI in cm$^2$ | HI in % | GFP in days | RTL in cm |
| 1 | 219902 | 64 | 94 | 79,6 | 13,0 | 9,2 | 27 | 13 | 699,0 | 238,3 | 44,7 | 14,6 | 34,1 | 30 | 17,0 |
| 2 | 219941 | 58 | 91 | 75,6 | 13,0 | 9,5 | 26 | 13 | 575,0 | 252,7 | 43,5 | 18,6 | 43,4 | 33 | 17,5 |
| 3 | 221711 | 64 | 94 | 72,0 | 13,3 | 8,9 | 25 | 11 | 505,7 | 173,3 | 47,3 | 16,9 | 34,9 | 30 | 17,2 |
| 4 | 223191 | 58 | 89 | 71,3 | 12,6 | 10,0 | 26 | 14 | 509,3 | 308,3 | 53,4 | 15,3 | 44,5 | 31 | 18,6 |
| 5 | 234311 | 57 | 90 | 76,3 | 12,6 | 9,9 | 26 | 11 | 499,0 | 218,3 | 49,6 | 19,8 | 43,3 | 33 | 19,7 |
| 6 | 234335 | 57 | 88 | 80,0 | 13,0 | 9,6 | 26 | 14 | 608,7 | 264,0 | 51,2 | 15,3 | 43,4 | 31 | 19,1 |
| 7 | 234342 | 58 | 89 | 83,6 | 13,3 | 10,2 | 26 | 14 | 652,7 | 291,7 | 45,0 | 12,4 | 44,6 | 32 | 19,1 |
| 8 | 235238 | 55 | 84 | 76,6 | 12,1 | 9,2 | 25 | 14 | 703,0 | 334,7 | 53,7 | 14,7 | 45,6 | 29 | 10,0 |
| 9 | 235259 | 56 | 87 | 73,3 | 12,6 | 9,5 | 26 | 12 | 693,3 | 325,0 | 52,5 | 15,1 | 47,7 | 31 | 20,1 |
| 10 | 235264 | 56 | 84 | 76,3 | 12,6 | 9,7 | 25 | 12 | 609,7 | 286,3 | 57,3 | 10,5 | 46,9 | 28 | 21,3 |
| 11 | 235273 | 59 | 90 | 84,3 | 13,3 | 9,4 | 26 | 12 | 757,7 | 282,0 | 49,0 | 22,4 | 38,2 | 31 | 19,4 |
| 12 | 235285 | 57 | 87 | 72,6 | 12,6 | 9,6 | 24 | 14 | 786,3 | 283,0 | 52,5 | 13,3 | 37,5 | 30 | 18,0 |
| 13 | 235299 | 56 | 86 | 79,3 | 13,0 | 9,8 | 25 | 12 | 617,7 | 296,0 | 57,6 | 15,8 | 47,9 | 30 | 18,5 |
| 14 | 237320 | 56 | 84 | 74,3 | 12,3 | 9,4 | 25 | 13 | 611,3 | 256,0 | 46,3 | 12,2 | 42,5 | 28 | 19,1 |
| 15 | 237327 | 56 | 87 | 75,3 | 13,0 | 9,6 | 26 | 12 | 587,0 | 251,7 | 53,1 | 15,7 | 43,6 | 31 | 18,5 |
| 16 | 237349 | 57 | 90 | 69,6 | 12,3 | 9,6 | 25 | 13 | 565,7 | 251,3 | 48,9 | 14,9 | 45,3 | 33 | 19,2 |
| 17 | 3609 | 59 | 88 | 72,3 | 11,3 | 8,9 | 46 | 10 | 361,7 | 131,0 | 27,0 | 12,5 | 40,0 | 29 | 13,5 |
| 18 | 64255 | 63 | 91 | 75,3 | 15,3 | 11,6 | 28 | 10 | 439,7 | 125,0 | 42,2 | 17,7 | 29,9 | 29 | 15,6 |
| 19 | 232662 | 70 | 96 | 70,3 | 11,6 | 8,4 | 56 | 7 | 571,0 | 204,7 | 37,6 | 12,5 | 37,2 | 26 | 14,8 |
| 20* | 221300 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 21 | Aruso | 58 | 93 | 78,6 | 11,0 | 10,1 | 26 | 12 | 502,7 | 184,7 | 48,2 | 19,5 | 37,0 | 34 | 17,0 |
| 22 | Bentu | 56 | 92 | 67,0 | 10,0 | 8,9 | 65 | 9 | 544,0 | 259,7 | 33,7 | 12,5 | 44,7 | 37 | 16,2 |
| 23 | Saesa-a | 53 | 85 | 72,0 | 12,6 | 9,1 | 24 | 12 | 673,7 | 342,7 | 50,0 | 12,1 | 50,2 | 32 | 19,6 |

* Variety number 20 (Accession number 221300) has been discarded from the experiment for its inability to flower and set seeds with the available soil moisture

Table 3 ANOVA table for all the agronomic traits analyzed

| | | Mean square | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | df | DTH | PLH | AWL | SPL | SPS | PTI | BIY | GRY | TSW | LAI | HI | DTM | GFP | RTL |
| Vars | 21 | 41.512** | 58.263* | 3.16179** | 1.169 $^{ns}$ | 363.069** | 10.362* | 31719.6* | 10766.6** | 164.071** | 26.831* | 80.723** | 35.311** | 16.171* | 11.22** |
| Rep. | 2 | 3.470 | 95.697 | 0.601 | 2.209 | 18.727 | 38.288 | 20900.0 | 9686.6 | 6.590 | 84.626 | 13.315 | 17.106 | 8.591 | |
| Error | 42 | 1.930 | 27.395 | 0.423 | 0.492 | 4.330 | 4.859 | 13521.5 | 3412.5 | 12.580 | 14.516 | 16.866 | 7.471 | 6.496 | |
| Total | 65 | | | | | | | | | | | | | | |

Statistically significant differences were observed among varieties in their awn length. Exceptionally, accession number 64255 had the longest awns from all the varieties including the control varieties. It had an average awn length of 15.3 cm (Table 2). Awn length is alleged having a positive contribution for drought tolerance (S. Grando personal communication). Martin et al. (1976) also confirmed that awns function in transpiration and photosynthesis and as a depository for mineral water. On the contrary, Bentu, Aruso, accession numbers 3609, 235238 and 232662 had the shortest awn lengths ranging from 10.0 to 12.1 cm (Table 2). Highly significant difference was also distinctly observed among varieties in their number of seeds per spike ($P<0.01$). Bentu, accession numbers 232662, and 3609 were significantly different from each other in their number of seeds per spike and have clearly manifested their superiority over the other varieties by ranking first, second and third respectively. These varieties had 65, 56 and 46 seeds per spike according to their ranking (Table 2). Similarly, varieties have revealed highly significant variation in their yielding potential ($P<0.01$). The local check Saesa-a, accession numbers 235238, 235259, 223191, 235299 were some of the best landrace populations, yielding 342.7 gms, 334.7 gms, 325.0 gms, 308.3 gms and 296.0 gms per plot respectively. Sinebo (2005) also confirmed Saesa-a's high yielding potential in his experiment.

With regard to thousand seed weight, which is known to have positive correlation with yield, varieties displayed highly significant differences in this trait ($P<0.01$). Accordingly, accession numbers 235299, 235264, 235238, 223191, 237327, 235285, and 235259 had the highest thousand seed weights of 57.6 gms, 57.3 gms, 53.7 gms, 53.4 gms, 53.1 gms, 52.5 gms and 52.5 gms respectively. It can be observed that all these varieties were also among the top yielding varieties in addition to having heavier thousand seed weight trait, confirming the presence of positive correlation of thousand seed weight with grain yield and vice-versa. As far as harvest index is concerned, varieties significantly differed from each other ($P<0.01$). The local check Saesa-a, accession numbers 235299, 235259, 235264, 235238, 237349, and the international check Bentu were among the varieties with the highest harvest index percentages of 50.2, 47.9, 47.7, 46.9, 45.6, 45.3 and 44.7 respectively while accession numbers 64255, 219902, 221711 and the national check Aruso had the lowest harvest index percentages ranging from 29.9 to 37.0 (Table 2). At the same time, it can be noticed that accession numbers 235299, 235264, and 235238 with the highest percentage of harvest indices were among the top yielding and with the highest thousand seed weight. According to Gonzalez et al. (1999), harvest index and the number of ears per $m^2$ were considered as the key traits in the selection process to increase yield in drought conditions.

## Root growth test

The other important agronomic trait was root length data obtained from a filter paper experiment over a period of three weeks after planting. Average of the root length recorded three times at seven days interval was subjected to ANOVA. Highly significant differences were observed among varieties in their root development over the three weeks period (Table 3). Accordingly, accession numbers 235264, 235259, 234311, the local check Saesa-a, 235273, 237349, 237320, 234335, 234342 and 235238 had significantly faster root development over the stated period as compared with the others. On average, roots of these varieties attained a length of 21.3 cm, 20.1 cm, 19.7 cm, 19.6 cm, 19.4 cm, 19.2 cm, 19.1 cm, 19.1 cm, 19.0 cm and 19.0 cm over the three weeks growth period respectively (Table 2). However, there was no significant difference in root length within this group. In this laboratory experiment, accession numbers 3609, 232662, 64255, ICARDA's check variety Bentu and accession number 219902 had the shortest root development (ranging from 13.5 to 17.0 cm) over the stated growth period.

In summary, accession numbers 235238, 235264, and the local check, Saesa-a had an overall good performance in the experimental field under natural growing conditions and have also consistently demonstrated the fastest root development in the laboratory filter paper experimentation.

## Bivariate correlations

Bivariate correlation analysis was run on the fourteen agronomic traits (Appendix 2). The analysis revealed a significant and positive correlation of root length with thousand seed weight ($r=0.83$), grain yield ($r=0.74$) and also with harvest index ($r=0.63$). Similarly, days to maturity with days to heading ($r=0.79$), harvest index with grain yield ($r=0.76$), grain yield with biological yield ($r=0.75$), thousand seed weight with grain yield ($r=0.63$) and thousand seed weight with productive tillers ($r=0.64$) had strong positive correlations. On the contrary, however, significant and negative correlations were found for productive tillers with number of seeds per spike ($r= -0.77$), harvest index with days to heading ($r= -0.75$), root length with number of seeds per spike ($r= -0.66$), days to maturity with harvest index ($r= -0.63$), seeds per spike with awn length ($r= -0.63$), root length with days to heading ($r= -0.62$) and root length with days to maturity ($r= -0.61$) and grain yield with days to heading ($r= -0.60$). As indicated in the bivariate correlation analysis above, root length had strong positive correlations with thousand seed weight, grain yield and harvest index. The strong positive correlation of root length with thousand seed weight, harvest index and grain yield in combination with the overall field performance of the varieties could be used as selection criteria for drought tolerance.

Descriptive statistics was also run by categorizing the 22 varieties in to three groups based on earliness/days to heading (54-58, 59-63 and ≥ 64 days) for groups 1, 2 and 3 respectively (Table 5). The mean and the standard deviation for all agronomic traits of the varieties in the three categories are shown in table 5.

Table 5 Descriptive Statistics: DTH, DTM, PLH, AWL, SPL, SPS, PTI, BIY, GRY, TGW, LAI, HI, GRP (Based on DTH, 3 earliness groups)

*Report*

| var | | DTH | DTM | PLH | AWL | SPL | SPS | PTI | BIY | GRY | TGW | LAI | HI | GRP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Mean | 56.6 | 87.8 | 75.2 | 12.5 | 9.6 | 28.3 | 12.6 | 623.4 | 279.5 | 49.6 | 14.5 | 44.8 | 31.2 |
| | Std. Deviation | 1.17 | 2.74 | 4.26 | 0.80 | 0.35 | 10.59 | 1.44 | 73.65 | 35.96 | 6.17 | 2.57 | 3.02 | 2.31 |
| 2 | Mean | 59.7 | 90.5 | 76.4 | 12.7 | 9.9 | 30.5 | 11.4 | 514.2 | 206.2 | 43.96 | 17.5 | 37.7 | 30.7 |
| | Std. Deviation | 1.9 | 1.89 | 5.29 | 1.73 | 0.98 | 8.90 | 1.78 | 148.54 | 84.97 | 10.29 | 3.80 | 5.24 | 2.23 |
| 3 | Mean | 66.1 | 94.9 | 74.0 | 12.8 | 8.8 | 36.10 | 10.2 | 591.9 | 205.4 | 43.20 | 14.7 | 35.4 | 28.8 |
| | Std. Deviation | 3.6 | 1.56 | 5.01 | 0.85 | 0.40 | 17.51 | 3.03 | 98.33 | 32.51 | 5.02 | 2.20 | 1.61 | 2.14 |
| Total | Mean | 58.6 | 89.4 | 75.3 | 12.60 | 9.6 | 29.9 | 11.9 | 594.3 | 252.7 | 47.5 | 15.2 | 4.9 | 30.78 |
| | Std. Deviation | 3.8 | 3.44 | 4.41 | 1.02 | 0.62 | 10.99 | 1.85 | 102.82 | 59.91 | 7.40 | 2.99 | 5.18 | 2.32 |

## Cluster analysis

Clustering was made to categorize agronomic traits into components for the sake of understanding the share components contribute to major variations in the study.

Characters were standardized to mean 0 and variance = 1, prior to running multivariate analysis, in order to avoid the possible impact of different magnitude of units of the thirteen different characters. The standardized data of the thirteen quantitative traits was then used as an input for the cluster analysis. An agglomerative, hierarchical classification technique with incremental sum of squares sorting strategy and squared Euclidean distance measure was used (Ward, 1963) for clustering the 22 landrace populations. The dendrogram obtained from the cluster analysis grouped the 22 populations in to five clusters (Figure 4). Cluster I comprised six populations characterized by relatively intermediate in heading and maturity, long stature, intermediate spike length, lower number of seeds per spike, better in tillering capacity, biological and grain yield as well as thousand seed weight, large in leaf area index and with intermediate grain filling period (Figure 4 and Table 2).

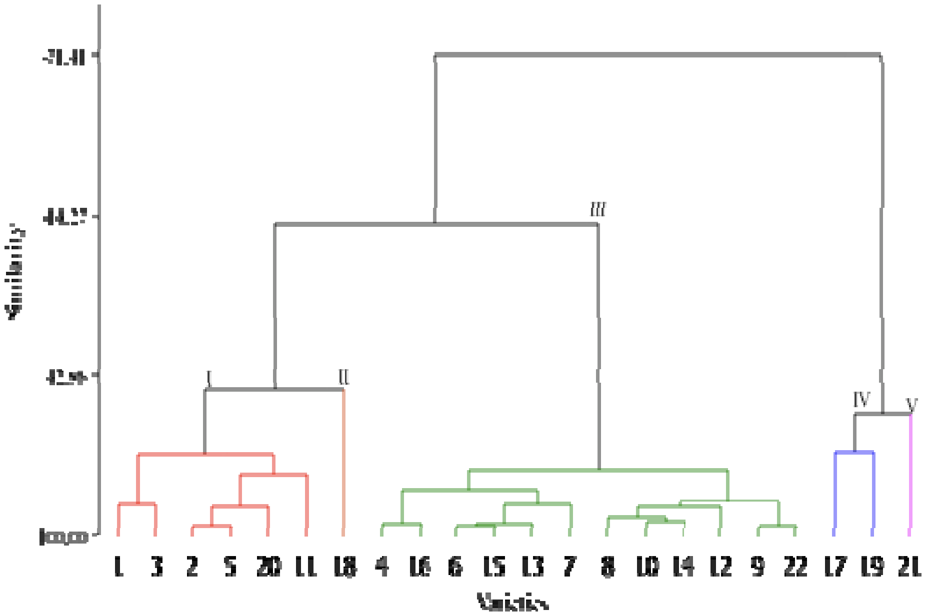

Figure 4 Cluster based on all morphological characters standardized to mean 0 and standard deviation = 1. NB: The numbers indicated in each cluster represent serial numbers for the corresponding accession numbers. Example: number 8 in cluster III represents accesion number 235238, number 10 represents accession number 235264 and so on .For more details se appendix 1.

Members in cluster III were twelve in total and this cluster was the largest one in this study. It is characterized mainly by earliness (both earliness in heading and maturity) and with intermediate grain filling period. Populations in this cluster showed the highest yielding capacity in terms of grain and biological yield. The straw yield is as equally important as the grain yield as it helps to bridge the dry season feed shortage gap for their draught animals and their cattle in general. The seed weight and harvest index of these members were also better than the rest of the populations in this particular study (Figure 4 and Table 2). Cluster IV comprised only two members which were characterized by an intermediate stature and spike length, low tillering capacity, low grain yield and biological yield. However, members in this cluster had reasonable harvest index after cluster III (Figure 4 and Table 2). Cluster V comprised only one outlying genotype, Bentu acquired from ICARDA/Syria which was the earliest heading, however, latest maturing with the lowest number of productive tillers, thousand grain weight and leaf area index, but with good harvest index (45 percent) and with the longest grain filling period (Table 2 and Figure 4)

The distance between clusters were assessed by the so called Mahalanobis's distance ($D^2$) such that the values calculated between pairs of clusters (Table 5) were considered as Chi-square values and were tested for significance using P-1 degrees of freedom, where 'P' is the number of characters used in the study (Singh and Chaudhary, 1985). The larger the $D^2$ value between two clusters was considered, as the populations in the two groups were highly divergent populations for the characters under study. The $D^2$ value has a paramount importance for breeding and enhancement work of the crop in addition to the breeder's phenotypic observations on agromorphological traits (Yemane and Fassil, 2002). For example, members of cluster III were the most outstanding varieties in most of the characters studied (Figure 4 and Table 2), except for the number of seeds per spike. This limitation can be improved by crossing the lines in cluster III with members of cluster IV as the calculated $D^2$ value was so high enough showing that the populations are highly diverged and improvement would be possible by intercrossing the respective groups (Table 5). Since populations in clusters V and I have the highest divergence, members from these clusters can also be crossed to incorporate genes responsible for earliness, high numbers of seeds per spike and grain yield in to populations in cluster I (Figure 4 and Table 5). Similarly, Clusters III and V have got the largest $D^2$ value indicating the presence of greatest divergence between the populations; hence members of cluster III could be intercrossed with members of cluster V to come up with varieties of intermediate maturity with high number of seeds per spike (Figure 4 and Table 5). Furthermore, the lateness in heading and maturity of members in cluster II could be likewise improved by crossing the lines with members of cluster III, as they are the earliest maturing types (Table 5 and Figure 4). However, the breeder can also use his own visual phenotypic observations to combine desirable traits from different populations to develop an improved variety.

Table 5 Mahalonobis distance (squared distance between groups)

| *Clusters* | *1* | *2* | *3* | *4* | *5* |
|---|---|---|---|---|---|
| 1 | 00.00 | 271.51 | 06.57 | 1185.64 | 3476.60 |
| 2 | 271.51 | 00.00 | 284.43 | 1129.59 | 3345.92 |
| 3 | 06.57 | 284.43 | 00.00 | 1210.67 | 3477.56 |
| 4 | 1185.64 | 1129.59 | 1210.67 | 00.00 | 766.14 |
| 5 | 3476.60 | 3345.92 | 3477.56 | 766.14 | 0.00 |

## Ordination

Principal Component Analysis (PCA) was performed as a data reduction tool to summarize the information. A total of 13 principal components were extracted, though the first four principal components with eigenvalues greater than 1 were considered significant for this particular study. A summary of the composition of variables in the first four components, eigenvalues and percentage variance are given (Table 6).The first two component scores were plotted to aid visualization of the overall variability among the populations (Figure 5). The first four components explained 82.38 percent of the total variation and the first and second components explained 37.45 and 23.22 percent of the total variation respectively (Table 6).

Table 6 Discriminant analysis

| *Principal Component* | *Eigenvalues* | % variance |
|---|---|---|
| 1 | 4.86787 | 37.445 |
| 2 | 3.01858 | 23.22 |
| 3 | 1.62202 | 12.477 |
| 4 | 1.20158 | 9.2429 |

Component 1 was highly associated, in the negative direction, with days to heading and maturity and number of seeds per spike, where as in the positive direction, it was associated with productive tillers, grain yield and thousand grain weight (Figure 5). Genotypes in the left side of axis 1 (PC1) that belong to Cluster I, II and IV have a strong association with days to heading and maturity as well as number of seeds per spike (Figure 5). They were of late maturity types having large number of seeds per spike. However, genotypes 2 and 11 from Cluster I were exceptions that were mapped in the positive direction of axis I, unlike the result obtained from the discriminate analysis (Figure 5). Both of these populations were collected from similar altitude of 1700 m a.s.l. from Central and Eastern Zones of Tigray Regional State respectively. Genotypes 1 and 3 in this group were also observed to have extra-glumes, an agronomic trait alleged to having positive contribution to drought tolerance (Stefania - Personal communication)

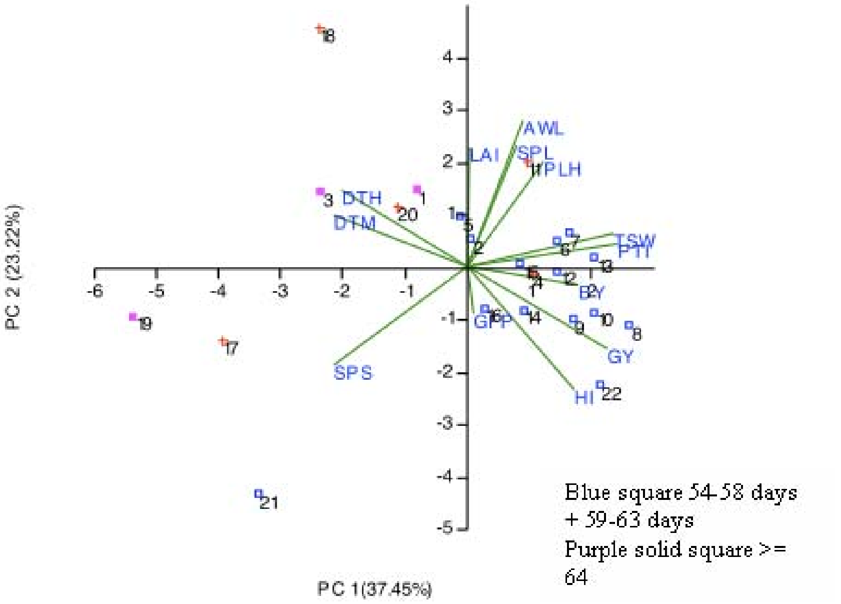

Figure 5. PCA based on earliness group (Days to heading) NB: Blue open Squares represent 54 to 58 days + sign represents 59 to 63 days Purple solid squares represent equal or greater than 64 days

On the other hand, genotypes located in the positive direction of the first axis (PC 1) were all members of Cluster III and they showed a strong association with yield and yield components such as productive tillers, grain yield and thousand grain weight. Those members of Cluster III were of early maturity type (Table 2). The second principal component showed an association with characters such as awn and spike length as well as leaf area index in the positive direction and with harvest index in the negative direction. The outlying genotype (Cluster II) and some members of Cluster I and III mapped in the positive direction of PC 2 have a positive association with awn length, spike length and leaf area index (Figure 5). On the other hand, all members of Cluster IV (negative direction of axis 2) showed a strong positive association with harvest index, a trait of paramount importance for crop breeding programme.

In summary, the PCA showed that members of cluster III were of early maturity types and showed strong association with yield and yield components such as productive tillers, thousand seed weight and grain yield. Accession numbers 235238, 235264, Saesa-a, 235299 and 235259 which demonstrated an overall better performance in the field trial and faster root development in the filter paper laboratory experiment were members of cluster III in the PCA. The result obtained from the PCA is in agreement with the results of ANOVA on the varieties' traits analysed. The aforementioned landrace accessions and the local check, Saesa-a had an overall better performance than the remaining members of cluster III and members of all other clusters (Table 7). Hence, they are considered as candidate genotypes for Endayesus, Mekelle (Tigray regional state) and other similar target environments.

Table 7 Varietal performances across traits with highly significant differences (P<0.01)

| *Var. No.* | *Acc/var Name* | *Agronomic traits* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | dth | dtm | awl | sps | gry | tsw | hi | rtl | T.tally | Rank |
| 1 | 219902 | | | | | | | | | 0 | Last |
| 2 | 219941 | | | | | | | | | 0 | Last |
| 3 | 221711 | | | | | | | | | 0 | Last |
| 4 | 223191 | | | | | √ | √ | | | 2 | 8 |
| 5 | 234311 | | | | | | | | √ | 1 | 10 |
| 6 | 234335 | | | | | | | | √ | 1 | 10 |
| 7 | 234342 | | | | | | | | √ | 1 | 10 |
| 8 | 235238 | √ | √ | | | √ | √ | √ | √ | 6 | 1 |
| 9 | 235259 | | | | | √ | √ | √ | √ | 4 | 5 |
| 10 | 235264 | √ | √ | | | | √ | √ | √ | 5 | 2 |
| 11 | 235273 | | | | | | | | √ | 1 | 10 |
| 12 | 235285 | | | | | | √ | | | 1 | 10 |
| 13 | 235299 | | √ | | | √ | √ | √ | | 4 | 4 |
| 14 | 237320 | √ | √ | | | | | | √ | 3 | 6 |
| 15 | 237327 | | | | | | √ | | | 1 | 10 |
| 16 | 237349 | | | | | | | √ | √ | 2 | 8 |
| 17 | 3609 | | | | √ | | | | | 1 | 10 |
| 18 | 64255 | | | √ | | | | | | 1 | 10 |
| 19 | 232662 | | | | √ | | | | | 1 | 10 |
| 20 | Aruso | | | | | | | | | 0 | Last |
| 21 | Bentu | √ | | | √ | | | √ | | 3 | 6 |
| 22 | Saesa-a | √ | √ | | | √ | | √ | √ | 5 | 2 |

# Discussion

The varieties differentiated as having good agronomic performance were members of cluster III. The result obtained from the PCA is in agreement with the results of ANOVA regarding the agronomic traits analysed. The observed strong positive correlation of root length with yield and yield components in combination with the overall field performance of the varieties, could be used as selection criteria for drought tolerance. However, Farmers' participation in the entire process of selection for drought tolerance is of paramount importance which should be given top priority.

Drought incidences before the 1980s were more or less concentrated in the northern and eastern regions of Ethiopia. Currently, however, the number of drought affected areas is dramatically increasing even in areas that used to be productive regions in the western and southern parts covering about 60 percent of the country's land mass (Anonymous, 1985). Taye (1996) reported on incidences of famine in Ethiopia since the last four decades. He further indicated that most of these incidences took place due to partial or total crop failures, which occurred as a result of shortage of rainfall. In addition to the low crop yields or total failures due to drought, currently the population of Ethiopia is growing at a rapid rate. According to the Ethiopian Statistical Authority (CSA, 2007, accessed 14 March 2008), the country's population grew by more than 20 million people in 13 years time, reaching almost 74 million in between 1994 and 2007. Hypothetically, if the population continues to grow with the current growth rate of 2.6 percent per annum, Ethiopia will have 27 million more people to feed in the year 2025.

Moreover, due to the impact of global warming and climate change, many areas that used to receive adequate amount of rain water for crop production have turned out semi-arid or in some cases arid. Such situation is sending signals for urgent remedial action. In other words, resource-poor farmers living in these marginal agro-ecosystems urgently need crop varieties with adaptive traits to low moisture and high temperature stresses. These farmers solely relying on crop landraces adapted to their agro-ecosystems do not have tendency towards using improved varieties that require high external input, as moisture is limiting factor rather than improved varieties or other external inputs. In this regard, accession numbers 235238, 235264, 235299, 235259 and the local check, Saesa-a which have demonstrated good overall performance in this particular study would be candidate varieties to address the problem of resource-poor farmers provided that the varieties consistently display their suitability (in future experimentation with temporal and spatial replications) to low moisture and high temperature stressed growing conditions. These varieties were originally collected from southern zone of Tigray from altitudinal ranges of 1510-2210 m a.s.l. This trend implies the opportunity of coming across varieties endowed with adaptive traits to low rainfall areas, provided that further research with full involvement of small-scale farmers is conducted on materials previously collected from drought prone areas and currently conserved *ex-situ* in the Ethiopian gene bank. The local check Saesa-a`s top yielding potential was confirmed in an experiment conducted by Sinebo (2005).

The current agricultural policy of the Ethiopian government is rural cantered-agriculture based and is very much aware of the felt needs of the farmers. Since it has been difficult to get good harvests from crops that are less efficient in their water-use during recurrent droughts, the government has fully realized that barley as a crop of best alternative choice in such areas. Governmental and Non-governmental organizations have created conducive conditions for all rounded rural development programmes. Technical and financial assistances from GOs and NGOs for rural development are already in place. To cite an example in this respect, the Global Environmental Facility (GEF) of the United Nations Environment Programme (UNEP) has been financing the *On-farm* Conservation and sustainable utilization of Ethiopian Cereal, Root and Tuber Crops Project from 1990-2005. Consequently, community seed banks have been established to take care of the sustainability of seed supply system of cereal crops, including barley. Many of the barley landraces have been collected and conserved in the gene bank of the Ethiopian Institute of Biodiversity Conservation. Although their co-evolutionary process has been arrested, diversity of the crop barley is still there, as the country is the centre of diversity for barley. Therefore, it can be concluded that there is bright prospect for the enhancement and wider use of barley in drought prone areas of the country.

According to Acevedo et al. (1991) and Van Oosterom and Acevedo (1992), in areas of the Mediterranean receiving low amount of rainfall, traits found useful for the evaluation of barley genotypes for drought tolerance and high yield are growth vigour, days to 50 percent heading, days to 75 percent maturity, harvest index, peduncle length, plant height and straw yield. However, much variability has been observed for these traits among indigenous barley landraces (ibid). For environments in which drought stress becomes progressively more severe (i.e. terminal drought environments), there are two physiological requirements. First, matching of crop phenology with the available moisture in the soil, i.e. crop landraces should mature early enough before complete exhaustion of soil moisture. Secondly, growth and development should be maximized when conditions are most favourable (Fischer, 1981). Good seedling vigour and vigorous tillering leading to a rapid attainment of full ground cover contribute to higher yield through increased water use efficiency, since good ground cover reduces evaporative water loss from the soil and increases the amount of water available for transpiration. Early heading, short grain filling period and early maturity enable the plant to escape damaging terminal drought.

In addition to the above mentioned traits, physiological responses such as osmotic adjustment could have contributed to drought tolerance of crop landraces (Bohnert et al., 1995). Osmotic adjustment, as a process of active accumulation of compatible osmolytes in plant cells exposed to water deficit may enable tolerant landraces to have a continued leaf elongation, though at reduced rates; stomatal and photosynthesis adjustments; maintained root development and soil moisture extraction; delayed leaf senescence and better dry matter accumulation and yield reduction in stressful environments.

Therefore, drought tolerance should be the major goal of barley breeding programmes in drought affected areas of Ethiopia and of course, farmers have to be fully involved in the entire breeding process for drought tolerance. Ceccarelli et al. (2001) had involved farmers from Syria, Tunisia and Morocco in their experiments aimed at varietal selection for drought stress tolerance in the farmers' respective countries. In this particular study, some important traits of barley adaptive to terminal drought-stressed environments of Ethiopia have been identified. However, improvement of drought tolerance is probably one of the most difficult tasks (Altinkut et al., 2001). Various environmental factors and their interaction, and also complex physiological responses to drought have retarded the development of suitable cultivars for drought-prone environments. Unpredictability of drought conditions in the field and the diversity of tolerance strategies developed by the plants further complicate attempts made to understand drought tolerance (Teulat et al., 1997). An extensive study of the Quantitative Trait Loci (QTL) controlling the genetic variation has provided new breeding methodologies with molecular marker assisted selection. Molecular marker assisted selection in combination with field evaluation of plant traits based on conventional breeding under different environmental conditions has given better understanding of drought tolerance.

# Conclusion

It can be concluded that, accession numbers 235238, 235264, and the local check, Saesa-a had an overall good performance in the experimental field under natural growing conditions and also have consistently demonstrated the fastest root development in the laboratory filter paper experimentation. These accessions have out yielded the other two checks as well. Although, not as good as the best performers mentioned above, accession numbers 235299 and 235259 also have manifested reasonably good agronomic performance in the field experiment under natural conditions in addition to having faster root development under laboratory conditions. As indicated in the bivariate correlation analysis above, root length had strong positive correlations with yield and yield components such as harvest index, thousand seed weight and grain yield. (Appendix 2). The strong positive correlation of root length with thousand seed weight, grain yield and harvest index in combination with the overall field performance of the varieties could be used as selection criteria for drought tolerance.

However, since these results are obtained from one year's experimental data, it is only after verifying the consistency and stability of the performance of these varieties across few more similar sites and for a minimum of two more years that reliable and commendable recommendations can be made. Direct and full involvement of the local farmers (Figure 6) in the whole process of plant breeding and on-farm verification of the materials for stress tolerance should be given top priority.

Figure 6. Traditional agriculture in Ethiopia

Finally, once the materials are selected and verified both on research station and on-farm with full involvement of farmers living in target environments. Restoration of the landraces to their original habitats (where they coevolved and developed adaptive traits to biotic and abiotic stresses) should be the next urgent step that should be undertaken.

# Acknowledgements

This MSc programme in general and the thesis research in particular was made possible by the financial assistance from the Swedish international development agency (Sida) and also close supervision and guidance from the Swedish Biodiversity Centre (CBM), hence I am grateful for both of these institutions. My sincere thanks should also go to Dr. Dereje Asefa and Ato Yemane Tsehaye (both from Mekelle University) for their assistance in identification and acquisition of experimental land and valuable technical guidance throughout the field research period.

I would at the same time like to thank the Ethiopian Institute of Biodiversity Conservation for allowing me to pursue the Masters programme and also paying my salary for the entire study period. I am also grateful to my supervisor, Dr. Jens Weibull whose continued assistance and support made the completion of this study possible. In particular, I would like to thank him for his crucial and concrete suggestions starting from the initiation of the research proposal up to the final write-up of this manuscript for his constructive criticism and indispensable guidance and also for generously offering his time and knowledge. His deep concern and interest in my work will always be remembered. Last but not least, I would like to thank my wife and children for their patience and encouragement during my stay for the studies here in Sweden.

# References

Acevedo, E., C. Raufurd P.Q., Austin, R.B. and Perez-Marco, P. 1991. Traits associated with high yield in low-rainfall environments. Journal of Agricultural Sciences. 116, 23-36.

Allen, F.L., R.E. Comstock & D.C. Rasmusson 1978. Optimal environment for yield testing. Crop Sci.18: 747-751.

Altinkut, A., Kazan, K., and Gozukirmizi, N. 2003. AFLP marker linked to water-stress-tolerant bulks in barley (Hordeum vulgare L.). Genetics and Molecular Biology. 26.1. pp. 77-82.

Altinkut, A., Kazan, K., Ipekci, Z. and Gozukirmirzi, N. 2001. Tolerance to paraquat is correlated with traits associated with water stress tolerance in segregating F2 populations of barley and wheat. Euphytica, 121 (1): 81-86.

Asfaw, Z. [Accessed, 5 December 2007]. Barleys of Ethiopia. [http://www.idrc.ca/en/ev-98727-201-1-DO_TOPIC.html]. International Development Research Centre Books, Chapter 4 of GENES IN THE FIELD. pp. 1-28

Atlin, G.N. & K.J. Frey 1990. Selecting oat lines for yield in low-productivity environments. Crop Sci. 30:556-561.

Anonymous. 1985. Consultant report on special program of actions for the improvement of food situation and rehabilitation of agriculture in Africa.

Bohnert, H.J., D.E. Nelson and R.G. Jensen 1995. Adaptation to environmental stresses. Plant Cell7: 1099-1111.

Ceccarelli, S. [Accessed 5 December 2007]. Barley land races from the Fertile Crescent: a lesson for plant breeders. [http://www.idrc.ca/en/ev-98727-201-1-DO_TOPIC.html]. International Development Research Centre Books, Section III Chapter 3 of GENES IN THE FIELD. pp. 1-26.

Ceccarelli, S., S. Grando, and A. Impiglia 1998. Choice of selection strategy in breeding barely for stress environments. *Euphytica* 103:297 – 318.

Ceccarelli, S. 1989. Wide adaptation. How wide? *Euphytica* 40:197-205.

Ceccarelli, S. and S. Grando 1989. Efficiency of empirical selection under stress conditions in barley. J. Genet. And Breed.43:25-31.

Ceccarelli, S., and S. Grando. 1991. Environment of selection and type of germplasm in barley breeding for low-yielding conditions. *Euphytica* 57:207-219.

Ceccarelli, S., Acevedo, E. and S.Grando 1991. Breeding for yield stability in unpredictable environments: single traits, interaction between traits, and architecture of genotypes. **In**: Shakhatreh, Y. (Eds.). Selection of barley lines for drought tolerance in low-rainfall areas. J. Agronomy and Crop Science 186. pp. 119-127. ISBN: 0931-2250

Ceccarelli, S. 1987. Yield potential and drought tolerance of segregating populations of barley in contrasting environments. *Euphytica* 36:265-270.

Ceccarelli, S. and Grando, S. 2000. Barley landraces from the Fertile Crescent: a lesson for plant breeders. **In**: Stephen, B.B. *Genes in the field. On-Farm Conservation of Crop Diversity.* Section III, Chapter 3. pp. 1-26. Canada, Lewis Publishers. ISBN 1-55250-327-5.

Ceccarelli, S., Grando, S., Bailey, E., Amri, A., El-Felah, M., Nassif, F., Rezgui, S. and Yabyaoui, A. 2001. Farmer participation in barley breeding in Syria, Morocco and Tunisia. *Euphytica* 122:521-536.

Central Statistical Authorithy of Ethiopia 2004. Results on area, production and yield of major crops by sector and season. Agricultural sample survey. Statistical bulletin 74. Addis Ababa, Ethiopia.

EL Madidi, S., Diani, Z., and Aameur, F.B. 2005. Variation of agro-morphological characters in Moroccan barley landraces under near optimal and drought conditions. Genetic Resources and Crop Evolution 52:831-838.

Evans, L.T., J. Bingham, P.Johnson, and J.Sutherlands 1972. Effects of awns and drought on the supply of photosynthate and its distribution within wheat ears. Ann. Appl. Biol. 70:67.
Fischer, R.A. 1981. Optimizing the use of water and nitrogen through breeding of crops. Plant and soil. 58:249-278.

Gomez, K.A. and Gomez, A.A. 1984. *Statistical Procedures for Agricultural Research* (2nd ed.). John, Wiley and Sons, Toronto, Canada. Pp. 188-192.

Gonzålez, A., Martin, I. and Ayerbe, L. 2007. Responses of barley genotypes to terminal soil moisture stress: phenology, growth, and yield. *Australian Journal of Agricultural Research.* 58:29-37.

Gonzalez, A., Martin, I., and Ayerbe, L. 1999. Barley yield in water stress conditions.The influence of precocity, osmotic adjustment and stomatal conductance. Field Crops Research. Volume 62 Issue 1. pp. 1-15.

Hailu and Fekadu 1987. Barley breeding in Ethiopia. Rachis barley and wheat newsletter 6 (2):13-15.

Hailu, G. and van Leur 1996. Barley research in Ethiopia: Past work and future Prospects. Proceedings of the first barley research review workshop, 16-19 October 1993, Addis Ababa: IAR/ICARDA. Addis Ababa, Ethiopia.

Harlan, J.R. 1971. Agricultural origins; centres and concentres. Sci.**174:** 468-474. Harlan, J.R. and D. Zohary 1966. Distribution of wild wheats and barleys, Science 153:1074-1080.

Huffnagel, H.P. 1961. Agriculture in Ethiopia. Food and Agriculture Organization of the United Nations, Rome.

IBCR. 2001. Institute of Biodiversity Conservation and Research. Twenty-five years of Biodiversity Conservation and Utilization and Future Plan of Action. May 2001. Addis Ababa, Ethiopia.

Innes, P., R.D. Blackwell, and S.A. Quarrie 1984. Some effects of genetic variation in drought-induced abscisic acid accumulation on the yield and water-use of spring wheat. J. Agric. Sci. Camb. 102:341.

Jones, C.A., Jacobson, J.S., and Wraith, J.M. 2003. The effects of phosphorus fertilization on drought tolerance of malt barley. Western Nutrient Management Conference. Vol. 5:88-92.

Ketata, H. 1987.Actual and potential yield of cereal crops in moisture-limited environments. **In**: Shakhatreh, O., Kafawin, O., Ceccarelli, S. and Saoub, H. (Eds). Selection of barley lines for drought tolerance in low-rainfall areas. J. Agronomy & Crop Science. 186:119-127.

Martin, J.H., Warren, H.L. and David, L. 1976. *Principles of field crop production*. (3rd Ed.). Macmillan Publishing Co. Inc. New York, USA. Pp. 503-510.

Munck, L. 1992. The contribution of barley to agriculture today and in the future, Barley Genetyics VI (2): 1099-1110.

Orlov, A.A. 1929. The barley of Abyssinia and Eritrea.-Bulletin of Applied Botany, genetics and breeding 20:283-345. In Russian with English summary.

Qualset, E.O. 1975. Sampling germplasm in a centre of diversity: An example of disease resistance in Ethiopian barley. In Crop Genetic Resources for Today and Tomorrow, O.H. Frankel and J.G.Hawkes (eds.).EBP 2. Cambridge: Cambridge

Reynolds, M., Skovmand, B., Trethowan, R. and Pfeiffer, w. 2000. (Accessed 6 March 2009). Evaluating a Conceptual Model for Drought Tolerance. Pp. 49-53.

Samarah, N.H. 2005. Effects of drought stress on growth and yield of barley. Agron. Sustain. Dev.Vol. 25. Pp. 145-149.

Saneoka, H., K. Fugita and S.Ogata 1990. Effect of phosphorus on drought tolerance in *Chloris gayana Kunth* and *Coix lacryma*-jobi L. Soil Sci. Plant Nutr. 19:29-39.

Shakhatreh, Y., Kafawin, O., Ceccarelli, S. and Saoub, H. 2001. Selection of barley lines for drought tolerance in low-rainfall areas. J. Agronomy and Crop Science 186:119-127.

Sinebo, W. 2005. Trade off between yield increase and yield stability in three decades of barley breeding in a tropical highland environment. Field Crops Research 92. pp. 35-52.

Singh, R.K. and Chaudhary, B.D. 1985. Biometrical methods in quantitative genetic analysis. Kalyani publishers, New Delhi.

Talame, V., Ozturk, N.Z, Bohnert, H.J and Tuberosa, R. 2007. Barley transcript profiles under dehydration shock and drought stress treatments: a comparative analysis. Journal of Experimental Botany, vol. 58, No.2. pp.229-240.

Taye, B. 1996. SAFGRAD's approach to enhancing the generation of suitable technologies for increasing food production in drought stress areas. **In**: J.M. Menyenga., B. Taye and A.., B. Taye and A.Youdeowel (Eds.). Food grain production in semi-arid Africa. Proceedings of International drought symposium held at the Kenyan conference. Nairobi, Kenya, 19th to 23rd May 1986.

Teulat, B., MOnneveux, P., Wery, J., Borries, C., Souyris, I., Charrier, A. and This, D. 1997. Relationship between water content and growth parameters under stress in barley: QTL study. New Phytol. 137. 99-107.

Van Ginkel M, Galhous DS, Gebeyehu G, Miranda A, Tian-you C, Pargas Lars R, Trethowan RM, Sayre K, Crossa J, Rajaram, S. 1998. Plant traits related to yield of wheat in early, late, or continuous drought conditions. *Euphytica* 100:109-121.

Van Oosterom, E.J. and Acevedo, E. 1992. Adaptation of barley (*Hordeum vulgare* L.) to harsh Mediterranean environment. Morphological traits.Euphytica, 62:1-14.

Vavilov, N.I. 1951. The Origin, Variation, Immunity and Breeding of Cultivated Plants. *Chron. Bot.* 13:1-366..

Ward, J.H. 1963. Hierarchical grouping to optimise an objective junction. J. Am. Stat. Assoc. **58:** 236-244

Westphal, E.1975. Agricultural systems in Ethiopia. Agric. Res. Rep. 826. Wageningen.

Yemane, T. and Fassil, K. 2002. Morphological diversity and geographic distribution of adaptive traits in finger millet (*Elusine coracana* (L) Garten.Subsp. Coracana (Poaceae) populations from Ethiopia. *Ethio.J.Biol.Sci.*, 1 (1): 37-62.

Zemede A. 1989. Relationship between spike morphology, hordeins and altitude within Ethiopian barley, *Hordeum vulgare* L. (Poaceae). Hereditas, 110:209-303.

# Appendix 1 Collection passport data for the experimental variables.

| *Treatment number* | *Accession number* | *Administrative region* | *Zone* | *Altitude m.a,s.l* |
|---|---|---|---|---|
| 1 | 219902 | Tigay | Central | 1920 |
| 2 | 219941 | Tigay | Central | 1700 |
| 3 | 221711 | Tigay | Southern | 1980 |
| 4 | 223191 | Tigay | Eastern | 1930 |
| 5 | 234311 | Tigay | Eastern | 2090 |
| 6 | 234335 | Tigay | Central | 1800 |
| 7 | 234342 | Tigay | Western | 1820 |
| 8 | 235238 | Tigay | Southern | 1710 |
| 9 | 235259 | Tigay | Southern | 2210 |
| 10 | 235264 | Tigay | Southern | 1850 |
| 11 | 235273 | Tigay | Eastern | 1700 |
| 12 | 235285 | Tigay | Southern | 1730 |
| 13 | 235299 | Tigray | Southern | 1860 |
| 14 | 237320 | Tigray | Southern | 1510 |
| 15 | 237327 | Tigray | Southern | 1560 |
| 16 | 237349 | Tigray | Southern | 1840 |
| 17 | 3609 | SNNP | Bench-Maji | 1500 |
| 18 | 64255 | SNNP | Semen Omo | 1500 |
| 19 | 232662 | Oromia | Western Hararghe | 2500 |
| 20* | 221300 | SNNP | Hadiya | 2500 |
| 21 | Aruso | Oromia | Oromia | |
| 22 | Bentu | ICARDA/Syria | Syria | |
| 23 | Saesa-a | Tigray | Tigray | |

* Treatment number 20 (Accession number 221300) has been discarded from the experiment for its extreme lateness and its inability to set seeds and mature with the already available moisture.

# Appendix 2 Bivariate correlation analysis

| | DTH | PLH | AWL | SPL | SPS | PTI | BIY | GRY | TSW | LAI | HI | DTM | RTL | GFP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DTH | 0 | | | | | | | | | | | | | |
| PLH | -.058 | 0 | | | | | | | | | | | | |
| AWL | .155 | .429* | 0 | | | | | | | | | | | |
| SPL | -.155 | .369 | .619** | 0 | | | | | | | | | | |
| SPS | .345 | -.512* | -.627** | -.474* | 0 | | | | | | | | | |
| PTI | -.544** | .447* | .274 | .286 | -.766** | 0 | | | | | | | | |
| BIY | -.238 | .353 | .124 | -.182 | -.350 | .488* | 0 | | | | | | | |
| GRY | -.600** | .127 | -.062 | -.159 | -.307 | .589** | .750** | 0 | | | | | | |
| TSW | -.423* | .328 | .365 | .293 | -.761** | .639** | .521* | .625** | 0 | | | | | |
| LAI | .111 | .414 | .306 | .345 | -.321 | .006 | -.072 | -.234 | .148 | 0 | | | | |
| HI | -.750** | -.093 | -.275 | -.184 | -.116 | .360 | .254 | .756** | .411 | -.338 | 0 | | | |
| DTM | .792** | -.132 | -.082 | -.114 | .451* | -.539** | -.325 | -.574** | -.512** | .323 | -.628** | 0 | | |
| RTL | -.623** | .318 | .234 | .176 | -.656** | .660** | .564** | .742** | .825** | .027 | .628** | -.608** | 0 | |
| GFP | -.432* | -.102 | -.370 | .080 | .112 | .075 | -.099 | .114 | -.079 | .299 | .273 | .209 | .101 | 0 |

** Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).
Note: DTH-Days to heading; PLH- Plant height; AWL-Awn length; SPL-Spike length; SPS-Seeds per spike; PTI-Productive tillers; BIY-Biological yield; GRY-Grain yield; TSW-Thousand seed weight; LAI-Leaf area index; HI-Harvest index; DTM-Days to maturity; RTL-Root length; and GFP-Grain filling period