**Agro-Morphological, Physiological and Yield Related Performances of Finger Millet [*Eleusine coracana* (L.) Gaertn.] (Poaceae) Accessions Evaluated for Drought Resistance under Field Condition**

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This is to certify that the thesis prepared by Awol Assefa, entitled: *Agro-Morphological, Physiological and Yield related Performance of Finger Millet [Eleusine coracana (L.) Gaertn] Accessions Evaluated for Drought Resistance under Field Condition* and submitted in partial fulfillment of the requirement for the Degree of Masters of Science in (Plant Biology and Biodiversity Management: Plant Physiology and Ecophysiology) complies with the regulation of the University and meet the accepted standard with respect to originality and quality.

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ABSTRACT

Agro-Morphological, Physiological and Yield Related Performance of Finger Millet [*Eleusine coracana* (L.) Gaertn.] Accessions Evaluated for Drought Resistance under Field Condition

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*This study was conducted on the understanding that a comprehensive study of the impact of drought stress and screening crop accessions for drought resistance is critical in evaluating the impact of climate change and climate variability on crop production. The study was conducted in Dhera Sub center of Kulumsa Agricultural Center, Oromia Regional State, from July 10- December 13, 2011; to screen drought tolerance of 96 finger millet accessions* (Eleusine coracana *L. Gaertn.*) *for their performance under severe drought condition. Data were collected for morphological trait and physiological measurement. Significant difference (P≤0.05) were recorded among accessions for selected physiological, morphological and yield related traits used for screening finger millet accessions for drought resistance. This implies there was variations among accessions collected from different agroecology for different target traits and provide opportunity to select accessions for different agroecology. (RWC), Chlorophyll Content Index (CCI) and yield related parameters, such as tillers number (TN), productive tillers (PT), seed weight per head and seed weight per plant. Based on high RWC, and CCI reading, higher root shoot ratio, green leaf number, productive tillers, ear length, ear* *number, grain yield per head and per plant. Based on the above parameters a total of 23 accessions were selected for their performance of drought stress tolerant and promoted to the next intensive physiological and yield evaluation. 238299, 238325, AAUFM-2, were the top three accessions which gave the highest grain yield per plant* (*84.5, 80 and 77.5(g)*, *respectively. Overall this research should be further utilized for improvement of finger millet for semi-arid area of Ethiopia.*

**Key words/phrases**: Finger millet, Drought stress, Accession, Morphological & Physiological traits

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# DEDICATION

This work is dedicated to my late father Ato Assefa Toib

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| | |
|---|---|
| EL: | Ear Length |
| EN: | Ear Number |
| GFU | Global Facilitation Unit |
| GLA: | Green Leaf Area |
| GLN: | Green Leaf Number |
| IBC: | Institute of Biodiversity Conservation |
| ICRISAT: | International Crop Research Institute in Semiarid Tropic |
| IPBGR: | International Plant Breeding and Genetic Resource |
| NRC: | National Research Council |
| NT: | Number of Tiller |
| PH: | Plant Height |
| PT: | productive Tiller |
| R: S: | Root Shoot Ratio |
| RDW: | Root Dry Weight |
| RWC: | Relative Water Content |
| SDW: | Shoot Dry Weight |
| CCI | Chlorophyll Content Index |
| TGLA: | Total Green Leaf Area |

# CHAPTER ONE

## 1. INTRODUCTION

### 1.1. Background of the study

Finger millet (*Eleusine coracana*) Poaceae ranks third in importance among millets in the world after pearl millet (*Pennisetum glaucum*) and foxtail millet (*Setaria italic*) (Upadhyaya *et al*., 2007). Millets are in the family of cereals grown globally with differential importance across continents and within regions of the world. They form a diverse group of small grains cultivated in diverse environments, mostly in the dry, semi-arid to sub-humid drought-prone agro ecosystems with an average annual rainfall at 800-1000 mm. Worldwide, there are nine species of millets with total production of 28.38 million tons, out of which 11.36 million tons (40%) are produced in Africa. The crop is mostly produced in mixtures (intercropped, double-cropped or relay-cropped) with other cereals like sorghum, legumes and oil crops such as groundnuts cowpeas (*Vigna unguiculata*), pigeon peas (*Cajanus cajan*) and sesame (*Sesamum indicum*), and root crops mostly cassava (*Manihot esculenta*) (Obilana, 1996).

The crop originated in Africa and has been cultivated for thousands of years in the highlands of Uganda and Ethiopia. It was introduced to India at a very early date, probably over 3000 years ago. Though finger millet is reported to have reached Europe at about the commencement of the Christian era, however its utilization is restricted mostly to eastern Africa and India (Sally and Katrien, 2004).

Finger millet is a small grain crop, which is indigenous to East Africa, especially Uganda and Ethiopian highlands. It is cultivated in diverse eco-geographical areas worldwide and displays high genetic variability (Hilu and de Wet, 1976), indicating that it can be improved through breeding. According to Holt (2000), the crop has wide adaptability, probably due to its C4 photosynthetic nature. In Africa, smallholder farmers grow finger millet with area allocated to the crop varying from country to country. In eastern Africa, finger millet is produced in Uganda, Kenya, Tanzania, Rwanda and Burundi (Obilana *et al*., 2002 cited in Oduori, 2005). Kenya and Uganda are among the leading producers of Finger millet in Africa and the rest of the world (Chrispu, 2008).

Finger millet is one of the important food crops in Ethiopia. It plays a significant role both as food grain and animal feed in areas where production of other cereals are reduced by marginal environments. As a result of increased drought and soil fertility degradation, a growing number of farmers are resorting to finger millet and thus the area allocated for this crop has significantly increased over the last ten years (Erenso Degu *et al*., 2009).

Finger millet (*dagussa*) is an indigenous food crop to Ethiopia and occupies an average 5% (228,000 ha) of the total area covered by cereal production and accounts for 4% of total cereal yield annually. It is an important crop in parts of Gojjam, Gonder, Wollega, Illubabur, Gamo-Gofa, Eastern Hararghe and Tigray. It also becomes an important crop in parts of the Ethiopian central rift valley including Arsi Negelle, Shashemene and Siraro Woredas (Chimdo Anchala, 2006).

Finger millet has a wide range of utility in Ethiopia. The grain is used for making traditional fermented liquors, *Tella* and *Areki*. The flour of finger millet alone or with mixture of teff (*Eragrostis tef*), Maize (*Zea mays*) and Barley (*Hordeum vulgare*) is commonly used for making *injera* and bread. Traditionally, porridge prepared from finger millet flour is believed to cure diarrhoea and malaria and the straw is used for animal feed and thatching roof (Kebere Bezaweletaw *et al*., 2007). The greatest value of finger millet is it can be stored for about ten years without damage by weevils, but with little bird damage, which makes it a perfect food grain commodity for famine prone areas (Erenso Degu *et al*., 2009; Adugna Asfaw *et al*., 2011).

The cereal is a staple food crop particularly in drought prone areas in the world where it is considered as an important component of food security. The grains are used for human consumption, the crop residues are excellent source of dry matter for livestock feed especially in dry season. Finger millet straw makes good fodder and contains up to 61 % total digestible nutrients (National Research Council, 1996).

Finger millets are hardy crops and quite flexible to a variety of agroclimatic adversities, like poor soil fertility and limited rainfall. In view of their superior adaptability (for example, compared to rice), they play an important role in supporting marginal agriculture, such as that commonly practiced in hilly and semi-arid regions of India (Ravi *et al*., 2010).

Finger millet can perform better under adverse soil and environmental conditions and can grow in areas close to the sea level (500 m a.s.l.). It is endowed with important nutrients than other crops. Despite all these agronomic qualities, finger millet has been neglected from the main stream international and national crop improvement research programs compared to other cereals like maize, rice and wheat (Kebere Bezaweletaw *et al*., 2007). One of the major constraints to finger millet production is underestimation of its importance within the society due to the cultural influence (National Research Council, 1996).

Owing to its wide range of adaptation, the crop is cultivated from sea level upto about 2,400 meters above sea level in parts of India, Nepal and Eastern Africa including Ethiopia. Finger millet prefers warm climate with a mean temperature of 26-29$^0$ C for optimum growth and crop yield declines as temperature drops below 20$^0$ C. The minimum temperature required for germination is 8-10$^0$ C. On top of that, the crop is generally drought tolerant but highly sensitive to frost (Gangaiah, 2010).

Finger millet grains are rich in minerals particularly iron, calcium and protein (7-14%) particularly methionine. However, the growth and production of finger millet is constrained by different biotic and abiotic factors. According to the National Research Council (1996), finger millet productivity is often constrained by blast disease, *Striga* weed, lodging, poor soils and drought. It is generally agreed that finger millet blast disease caused by the fungus *Pyricularia grisea* (a close relative of rice blast) is the most serious disease of finger millet.

Drought has much consequence on agricultural income particularly in marginal or degraded areas as a result growth and production is highly affected due to low soil fertility, less moisture and soil structure. In Amhara region for example, in addition to the alarming increasing of population growth, drought and erratic rainfall have been the main causes of food insecurity (Asnake Mekuriaw, 2002).

Rainfall and temperature are important determinants of crop harvests, and unfavorable realizations of either the amount or the temporal distribution of rainfall triggers food shortages and famine.  Ethiopia is known to be a country vulnerable to climate change with the least capacity to respond. For instance, according to the World Bank (2007), Climate change is projected to reduce yields of wheat staple crop by 33 % in Ethiopia. This amounts to a serious threat to food security and to the achievement of major developmental goals.

The development of drought resistant cultivars depends on the identification of traits that can be used in a breeding and selection program. For most crops, there is need to evaluate those traits that are inherent in drought stress resistant genotypes and are based on a plantøs morphology, physiology and anatomy (Eureka, 2000). Finger millet biodiversity constitutes an ecological advantage for millions of small scale and traditional farmers in Sub Saharan Africa, playing a vital role in their agricultural systems, and food security, livelihood and cultural identity. However the crop is neglected and its production is declined at the national and international level, particularly in the case of the West African millets (Gari, 2001).

In Ethiopia, where agriculture is the foundation of the countryøs economy, the importance of finger millet in general and drought resistance in particular in relation to climate variability, especially unpredictable rainfall and recurrent drought cannot be overstated. The purpose of this research was thus, exploration and screening of promising finger millet accessions adapted to low moisture content, promotion and recommendation of these accessions for further studies.

## 1.2. Objectives of the studies

### 1.2.1. General Objective

Evaluation of growth and physiological performance in relation to drought tolerance under field condition drought tolerance in finger millet accessions collected from different agroecological zones of the Ethiopia.

### 1.2.2. Specific objectives

- To evaluate variations among finger millet accessions in morpho-physiological performance under field condition
- Compare the physiological response mechanism to drought for different finger millets accession, and
- To identify growth and physiological traits that can be used in screening for drought tolerance among finger millet accessions.

# CHAPTER TWO

## 2. LITERATURE REVIEW

### 2.1. Origin and geographic distribution of finger millet

The crop is originated in Africa and has been cultivated for thousands of years in the highlands of Uganda and Ethiopia. It was introduced to India at a very early date, probably over 3000 years ago. Though finger millet is reported to have reached Europe at about the beginning of the Christian era, its utilization is restricted mostly to eastern Africa and India (Sally and Katrien, 2004). Africa is home to an enormous diversity of wild grasses, particularly in arid ecosystems and savannas. Some of such wild grasses have evolved into the cultivated millets through an extensive process of domestication and crop improvement during the last millennia. Wild millets comprise a diverse range of wild grasses that are related to the cultivated millets, including wild millet relatives and wild millet-like grasses (Gari, 2001).

finger millet is thought to have originated from Uganda or neighboring Ethiopian highlands where wide diversity of the genus Eleusine exists (Hilu *et al*., 1979). Eleusine species occupy diverse habitats, ranging from open, dry places to under-covers of forests from sea level to highlands and it is grown extensively in the semi-arid regions of Africa and India. Cytogenetical, morphological, flavonoid chemistry, and chloroplast and ribosomal DNA evidence indicates that finger millet evolved directly from the wild *E. africana* (Hilu and Johnson, 1991).

Finger millet was introduced to South Asia from its center of origin by sea probably in the third millennium B.C., especially India where it has gained importance and is called ñragiò (Hilu *et al*., 1979). The crop is cultivated in diverse ecogeographical areas where Eleusine displays high variability in vegetative, floral and seed morphology (Hilu and de Wet, 1976). Hilu and de Wet (1976) identified three ecogeographical races: (i) African highland race cultivated in East African highlands, (ii) lowland race grown in the lowlands of Africa and South India, and (iii) Indian race with its centre of distribution in Northeast India. The African highland race is the most primitive and is the precursor of the lowland race (Hilu and de Wet, 1976), which was subsequently introduced to southern India that developed into a secondary center of diversity, resulting in the Indian race (Chrispu, 2008).

Finger millet was domesticated about 5000 BC in Eastern Africa (possibly Ethiopia) and introduced into India as a crop 3000 years ago (Hilu *et al*., 1976). There are some more countries, namely, Uganda, Rwanda, Zaire, Kenya, Eritrea, Somalia, China, and Myanmar where finger millet is a common crop (Upadhyay, 2006).

## 2.2. Production of finger millet

Finger millet is grown in more than 25 countries in Africa and Asia. Uganda, India, Nepal, and China are the major finger millet producers of the world. In India, finger millet is a crop of the tropics and sub-tropics and can be raised successfully from sea level; from 500m to an altitude of 2,300 m on hill slopes, as well as plains. It grows best in moist climate. It is grown in areas with rainfall up to 1000 mm as well as in regions of higher rainfall and under irrigation (Gangaiah, 2010). It is grown on over 4 million ha worldwide and it is a primary food for millions in dry lands of east and central Africa, and southern India. The crop is productive in a wide range of environments and growing conditions spanning from the Himalayas in Nepal, India, and throughout the middle-elevation areas of Eastern and Southern Africa (Holt, 2000). Finger millet has an annual production of 4.5 million tons of grain, and Africa produces around 2 million tons. Though it was a predominant crop in Africa until recent decades, the cropøs production has declined significantly. Despite its importance as a food crop, many policy makers in countries that grow finger millet generally regard it as a poor personøs crop, and the scientific community has largely ignored it (www.worldwatch.org). The crop was grown on 194,000 ha in Nepal in 1990, 11000 ha in Sri Lanka in 1988, 227000 ha in Ethiopia in 1986 (Riley *et al*., 1993), and 1.68 million ha in India in 2001ï 2002 (CMIE, 2004 cited in Upadhyaya *et al*., 2005).

Finger millet is grown mainly by smallholder farmers covers an area of 65,000ha in Kenya and 500000 ha in Uganda. Demanding of finger millet is high and its popularity is spreading all over Kenya and hence opening up a large market. However the yield of finger millet on the farmersô farm is reported to be low about 15ï 16% of the potential yield. Reasons responsible for the low yields include use of unimproved cultivars and poor management practices (Oduori, 2005).

Table 1. Production of the most important African cereals (thousands of metric tons)

| Grains | Scientific name | World production | African Production | Major Producing countries |
|---|---|---|---|---|
| Sorgum | *Sorghum bicolor* | 58700 | 23282 | USA, Nigeria ,India, Mexico |
| Millets (total) | ---- | 29295 | 9557 | India, Nigeria, China, Niger |
| Peral millet | *Pennisetum glaucum* | 13351 | 7330 | Nigeria, Niger, Burkinafaso |
| Finger millet | *Eleusine coracana* | 3763 | 855 | India, China, Uganda, Nepal, |
| Teff | *Eragrostis tef* | Very low | 1063 | Ethiopia, S/Africa, Australia |

Source: (ICRISAT/FAO, 1996 cited in Slias and Kajuna, 2001)

According to the National Research Council (1996), blast disease, *Striga* weed, lodging, poor soils and drought are some of the constraints that need immediate research attention. It is generally agreed that five finger millet blast diseases caused by the fungus *Pyricularia grisea* (a close relative of rice blast) is the most serious disease of finger millet.

## 2.3. Nutritional value of Finger millet

The small millet grains are nutritionally superior and good source of quality protein, minerals, phytochemicals and vitamins. With appropriate processing and value added strategies, the millet grain can find a place in the preparation of several value added and health food products, which may result in high demand from large urban population and non-traditional users. Their good nutritional values including high levels of quality protein, ash, calcium, iron and zinc, which make millet nutritionally superior than most cereals (Obilana, 2001).

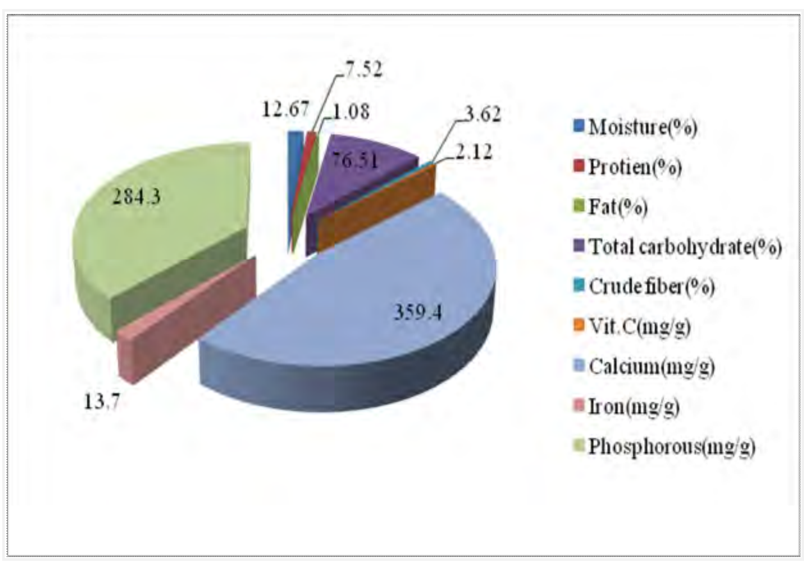


Figure 1.Nutritional composition of finger millet (Source: Desai *et al*., 2010)

Finger millet is widely cultivated in arid and semiarid region of the world. It serves as an important staple food for rural populations in developing tropical countries where calcium deficiency and anemia are widespread (Babu *et al*., 2010**).** Being rich in protein, iron and calcium, the grains contain high nutritional value special amino acids namely, tryptophan, cystine, methionine and total amino acids. Most of the time these amino acids are limited or lacking in many other cereals (McDonough *et al*., 2002).

Table 2. Nutritional composition of finger millet and other different grain

| Mineral(mg/100g) | Pearl millet | Finger millet | Teff | Fonio | wheat | Sorghum |
|---|---|---|---|---|---|---|
| Calcium | 37.0 | 344 | 159 | 44 | 30 | 27 |
| Copper | 9.8 | 0.5 | 0.7 | - | 1.1 | 2.4 |
| Iron | 114 | 9.9 | 5.8 | 8.5 | 4.0 | 6.6 |
| Manganese | 190 | 140 | 170 | - | 120 | 180 |
| Magnesium | 0.8 | 1.9 | 6.4 | - | 3.6 | 2.9 |
| Phosphorus | 339 | 250 | 378 | 177 | 400 | 520 |
| Potassium | 418 | 314 | 401 | - | 330 | 440 |
| Sodium | 15 | 49 | 47 | - | 16 | 14 |
| Zinc | 2.0 | 1.5 | 20 | - | 3.5 | 4.4 |

Source: National Research Council, 1996

Finger millet is a good source of diet for growing children. It provides the highest level of calcium, antioxidant property of phytochemicals which make it easily and slowly digestible, on the other hand it helps to control blood glucose levels in diabetic patient very efficiently. Therefore, finger millet is considered to be ideal food for diabetic individuals due to its low sugar content and slow release of glucose in the body (Desai *et al*., 2010).

It is also sources of methionine amino acid, iron, and calcium and animal feed, the cultivation of finger millet is being pushed to the more marginal areas as well as the poor attitude to the crop is also a major constraint to finger millet production (National Research Council, 1996). Despite its important and nutritional value and loss of the wellbeing of the people of Africa and some part of the world, finger millet is one of underutilization species (Global Facilitation Unit, 2007). Finger millet is a neglected crop both scientifically and internationally. For example, there are 13,919 publications on wheat in the world, whereas there are only 1, 975 and 670 for sorghum and millet respectively. Most of the world even has never heard of it and those countries that grow the crop left to a ñfamine foodò or even worse ñbirdseedò. Despite its importance as food sources of methionine amino acid, iron, and calcium and animal feed, cultivation of finger millet is being pushed to the more marginal areas as well as underestimation of the society to the crop due to cultural influence are major constraints to finger millet production (National Research Council, 1996).

Drought is a natural hazard caused by an extended shortfall of precipitation that results insufficient water supplies to meet the needs of humans and the environment (Wilhite and Buchanan-Smith, 2005). Increased demand for finite water supplies has resulted from population growth; migration of people from rural to urban settings and from more humid to more arid environments; changes in land use are among other factors. Increased competition arising from increased demand has created greater and more complex impacts than ever experienced in the past, increasing vulnerability to drought and exacerbating the impacts of drought in the United States (Donald, 2007).

Drought is the most important limiting factor for crop production and it is becoming an increasingly severe problem in many parts of the world (Passioura, 1996). According to Isendahl and Schmidt (2006), the percentage of drought affected area in the world has doubled between 1970s and early 2000. It is a chronic problem worldwide that influences grain production and quality with increasing population and global climate change making the situation more serious (Hongbo *et al*., 2005).

Often drought is accompanied by relatively high temperatures, which promote evapotranspiration and hence could emphasize the effects of drought and thereby further reduce crop yields (Sabaghpour *et al*., 2006; Mafakheri *et al*., 2010). Drought is a global, social and economic problem. About 70% of the yield is reduced at the field condition as compared to optimum environmental condition is due to abiotic stress such as temperature and drought stress (Bruce *et al*., 2002; Anjum *et al*., 2011).

It is one of the most important constrain for crop production but improvement of drought tolerance is very difficult because of the set of mechanisms involved. Crop plants have developed many mechanisms to survive water deficit, including escape, tolerance, and avoidance of tissue and cell dehydration (Turner, 1986; Ludlow *et al*., 1990).

Drought affects almost all physiological and biochemical processes including water relations, nutrient acquisition, $CO_2$ fixation, etc. The drought induced malfunctions ultimately result in reduced germination, poor seedling establishment and hampered growth and development of plants (Hale and Orcutt, 1987). Drought stress progressively decreases $CO_2$ assimilation rates due to reduced stomatal conductance. It reduces leaf size, stems extension and root production and disturbs plant water relations and reduces water-use efficiency. It disrupts photosynthetic pigments and reduces the gas exchange leading to a reduction in plant growth and productivity (Anjum *et al.*, 2011). In turn, may differentially affect plant growth and production depending on many variables such as the extent of the stress, developmental stage of the crop, and the occurrence of other multiple environmental stress factors for example, high light irradiance and high temperatures (Kaiser, 1987).

Water shortage is one of the stress factors which has an adverse effect on the growth and development of plants; however, its effect on growth varies depending on the stage of development of plant. For example, drought stress caused a great reduction in grain yield and water use efficiency at ear emergence stage (Seghatoleslami *et al.*, 2008).

Inadequate water supplement in soil limits the productive potential of several plant species by provoking smaller growth during the vegetative period and the reproductive period (Sibel and Birol, 2007). Water deficit is one of the most common abiotic stress factor that have substantial negative impact in plant growth and development, it is one of the most limiting environmental factors affecting crop productivity (Pirzad *et al.*, 2011).

When water deficit occurs during a particular part of the total growing period of a crop, the yield response to water deficit can vary greatly depending on how sensitive the crop is at that growth period. In general, crops are more sensitive to water deficit during emergence, flowering and early yield formation than they are during early (vegetative, after establishment) and late growth periods (Kaiser, 1987). Plants differ in their resistance to water stress because of difference in phenological, morphological, biochemical and molecular adaptive mechanism. Genetic differences in drought tolerance offer the unique opportunity to compare changes in metabolic process in plants under water stress that might be involved in drought tolerance (Balch *et al*., 1996).

One of the most well-known responses to drought stress is stomatal closure and the subsequent increase of resistance to $CO_2$ diffusion in leaves. Avoidance of stress includes rapid phenological development, increased stomatal and cuticular resistance, changes in leaf area, orientation and anatomy, among others (Morgan, 1984; Jones, 1992). Plants tolerate drought by maintaining sufficient cell turgor to allow metabolism to continue under increasing water deficits (Zlatev, 2005).

Global climate change is now recognized as a major new factor that must be considered in assessing future drought hazard. Climate has changed many times over earthộs history, and climate will continue to change in the future. The current pace of global climate change, which is unprecedented in recorded human history, is likely to significantly influence future drought hazard (National Research Council, 2007). Despite the complexity of the coupled and interacting phenomena, there exists broad scientific agreement that global climate change will affect temperature, precipitation, evaporation, transpiration of water by plants, surface water flow, and groundwater recharge. In particular, there is high confidence that global climate change will lead to higher average temperatures nearly everywhere (Dettinger, 2005).

**2.4. Effects of drought on plant growth and development**

Plant growth and productivity is adversely affected by natureφs anger in the form of various biotic and abiotic stress factors. Water deficit is one of the major abiotic stresses, which adversely affects crop growth and yield. These changes are mainly related to altered metabolic functions, one of those is either loss of or reduced synthesis of photosynthetic pigments. This results in declined light harvesting and generation of reducing powers, which are a source of energy for dark reactions of photosynthesis. These changes in the amounts of photosynthetic pigments are closely associated to plant biomass yield (Jalee *et al*., 2009).

Water deficit is the most important of abiotic stresses often encountered by the plants. Its effects are severe in semi-arid environments where droughts are unpredictable and cause genotypes of sunflower. Water deficit affects nearly all the plant growth processes. However the stress response depends upon the intensity, rate, and duration of exposure and the developmental stage of crop growth (Brar *et al*., 1990).

Plants grown in arid and semi-arid environments are exposed to a long period of water stress, have evolved a serious of adaptation mechanisms which confer tolerance to the water stress. A reduction in photosynthetic rate, for example, is associated with stomatal closure due to a change from water status in the leaf. This is one example that is observed where plants are grown under water stress condition (Chartzoulas *et al*., 1999).

Plants can resist drought by either dehydration avoidance or by dehydration tolerance. Drought resistance in terms of the physiology involved interacts with the magnitude and the timing of the stress. Timing here refers to the stage of plant development when stress occurs. For example, drought resistance has serious injury on plant at different developmental stages such as during germination and grain filling in the field (Blum, 2005).

The plant employed different strategies throughout individual survival strategy by drought conditions. One of the strategy of plants in drought stress environment is minimization of leaf surface area as the result the amount of water lost in the form of evapotraspiration is also minimum (Alireza *et al*., 2009).

## 2.5. Effects of water stress on plant physiological processes

### 2.5.1. Relative water content

Relative water content (RWC), one of the useful indicators of the water status of the plants is essential because it expresses the relative amount of water, which the plant requires to reach full saturation (Gonzalez and Ganzalz, 2001). Leaf water content is a useful indicator of plant water balance, since it expresses the relative amount of water present on the plant tissues (Kramer, 1983). Drought resistant cultivars should maintain greater relative water content compared to susceptible ones. This character might be an adaptive feature that certain plant species have developed under water stress conditions (Ahmadi and Siosemarideh, 2005). Physiological response of plant in response to deficit irrigation varies, however irrigation deficit reduced relative water content, chlorophyll content and protein contents (Moaveni, 2011).

The relative water content rate in plants with high resistance against drought is higher than others. In other words, plant having higher yields under drought stress may have high water content. The accumulation of osmolyte compounds in the cells, as a result of water stress is often associated with a possible mechanism to tolerate the harmful effect of water shortage (Pirzad *et al*., 2011).

### 2.5.2. Chlorophyll content (greenness) of the leaves

Plant growth is controlled by several factors; of which water deficit is one of the abiotic factors that adversely affects the growth and development of plant. A small decrease in the availability of water to a growing plant immediately reduces its metabolic and physiological functions. Drought stress induced a significant decrease in metabolic factors such as the decrease in chlorophyll contents and increase accumulation of proline in canola (*Brassica napus*) (Gibon and Larher, 2000).

One possible reason for similarity or dissimilarity of photosynthetic activity can lie in the constitution of the photosynthetic apparatus in general and in the chlorophyll content in particular (Maqsood, and Ali, 2007). It is also one of the most obvious characteristics of plants are the green color of leaves, which is caused by the presence of the chlorophyll (Chl) pigments (Markwell and Blevis, 1999). According to Abdalla and El-Khoshiban (2007), chlorophyll content diminished progressively with exposure and intensity of water stress, but the reduction is more severe in susceptible genotypes.

### 2.5.3. Effects of water stress on biomass production

Drought stress is a very important limiting factor at every stage plant growth and establishment. It affects both elongation and expansion growth (Anjum *et al*., 2003). Food productivity is decreasing due to detrimental effects of various biotic and abiotic stresses; therefore minimizing these losses is a major area of concern to ensure food security under changing climate. Environmental abiotic stresses, such as drought, extreme temperature, cold, heavy metals, or high salinity, severely impair plant growth and productivity worldwide. Drought is one of the most important environmental stresses that severely impair plant growth and development, limits plant production and the performance of crop plants, more than any other environmental factor (Shao *et al.*, 2009).

Plant experiences drought stress either when the water supply to roots becomes difficult or when the transpiration rate becomes very high. Available water resources for successful crop production have been decreasing in recent years. Furthermore, in view of various climatic change models scientists suggested that in many regions of the world, crop losses due to increasing water shortage will further aggravate its impacts (Anjum *et al.*, 2011). Biomass production reduces down when the moisture content from the soil drops. However in most of the time the tolerant genotype had less reduction in biomass than the susceptible one in response to drought stress (Salem, 2003). Irrigation clearly enhances greater biomass allocation to the shoot and leaves by increasing the above ground to below ground dry matter ratio. The fact that water stress can reduce not only biomass production, but also shifts in partitioning within the plant and usually an increased biomass partitioning to below ground organs (Bota *et al*., 2004).

### 2.5.4. Impact of water stress on yield and yield components

The effects of drought stress on morphology of the plants are reduction of meristematic cell division and subsequent massive expansion of the young cells. Under severe water deficiency, cell elongation of higher plants can be inhibited by the interruption of water flow from the xylem to the surrounding cells. The impact of drought stress on crops are reduction of plant height, Stem diameter, leaf area reduction due to the suppression of the leaf, leads to reduction in photosynthesis, rate of senescence is increasing rapidly, reduction in productive tiller (Anjum *et al*., 2011). One of the common effects of drought stress on crop plants is reduction in fresh and dry biomass production (Zhao *et al.,* 2006).

The growth, development and spatial distribution of plants are severely limited by a variety of environmental stresses. Among the different environmental problems faced by crop plants, water stress is considered to be the most serious one (Boyer, 1982). The effect of water deficit on growth, developments and yield depends upon time, intensity and duration of water deficit (Jaleel *et al*., 2009). It is necessary to know such effects of water deficit at different stages of crop growth in order to develop crop management strategies to minimize the risk in maize production (Sah and Zamora, 2005).

### 2.6. Mechanisms of drought resistance in plants

Drought stress is one of the most widespread environmental stresses, which affect growth and productivity of plant. It reduces many physiological and biochemical and molecular response on plant, so that plants develop tolerance mechanism to the external environment (Tas and Tas, 2007). It is the most significant limiting factor for agriculture worldwide, which can cause serious losses of yield and productivity in most crops in arid and semi arid regions. The degree of these effects depends on its impact on the plant physiological, biochemical as well as molecular process. One of the major environmental constraints that reduce the productivity and stability of crops is water stress (Waseem *et al*., 2011).

Adaptations to water deficit in plants involve the reduction of cell dehydration by avoidance (leaf shedding, leaf rolling and low stomatal conductance) or tolerance through osmotic adjustment (Turner, 1979). There are different mechanisms of drought stress in plants.

According to different scenarios predicted by intergovernmental panel on climate change, it is expected that there will be a reduction in precipitation and rising evapotranspiration rate. The supposed need to gain further studies on drought stress tolerance crops and understanding of their morphological, physiological and molecular adaptation mechanisms is very crucial, so as to alleviate the current problems and production of crop yields under drought conditions (Lawlor and Tezara, 2009).

## 2.7. Types of drought coping mechanisms

Adaptation to water stress in plants involve the reduction of cell dehydration by avoidance (leaf shedding, leaf rolling and low stomatal conductance) or tolerance through osmotic adjustment (Turner, 1979). There are different mechanisms of drought stress tolerance in plant. One of these adaptations mechanisms are to drought stress like, develop more root system, which able to absorbed much water from the deepest part of the soil, thick leaf, small leaf area and thick cuticle, stomatal regulation, ABA accumulation, stomatal closure, rapid accumulation of proline, glycinebetaine early þowering, smaller plant, small leaf area, or limited tillering (Blum, 2005).

### 2.7.1. Drought escape

Plants are adapted to drought environments either through escape, avoidance, or tolerance mechanisms. Drought escape is a particularly important strategy of matching phenological development. With the period of soil moisture availability to minimize the impact of drought stress on crop production in environments where the growing season is short and terminal drought stress predominates (Turner, 1986). Drought escape is defined as the ability of a plant to complete its life cycle before supply of water soil is depleted or before the moisture content of the soil drops and form dormant seeds before the onset of dry season. These plants are known as drought escapers (Mooney *et al*., 1987). Plants that escape drought exhibit a high degree of developmental plasticity, being able to complete their life cycle before physiological water deficit occur. Escapes strategies rely on successfully reproduction before the onset of severe of stress (Chaves *et al*., 2003).

### 2.7.2. Drought avoidance

It is the ability of plants to maintain relative high tissue water potential despite shortage of soil moisture. Drought avoidance is performed by maintenance of turgor through roots grow dipper in the soil, stomatal control of transpiration and by reduction of water loss through reduced epidermal i.e. reduced surface by small and thicker leaves. Adaptation to water stress involves the reduction of cell dehydration by either avoidance of stress. Some examples of, leaf shedding, leaf rolling, changing the leaf angle, production of more root that shoot to absorb water from the deepest part of the soil and low stomatal conductance to water vapor as the result plants to reduce activities like transpiration and become dormant in the face of extreme water deficit (Morgan, 1984; Osmond *et al*., 1987).

### 2.7.3. Drought tolerance

Drought tolerance is the ability of crops to grow and productive under water deficit condition. A long term drought stress effects on plant metabolic reactions in association with plant growth stage, intensity of the stress factor and water holding capacity of the soil and physiological aspects of the plants (Moaveni *et al*., 2011). Plants respond to declining water potential through several mechanisms such as accumulation of compatible solutes within cells that is osmotic adjustment (Jones, 1992)

# CHAPTER THREE

## 3. MATERIALS AND METHODS

### 3.1. Finger millet accessions

A total of 96 finger millet (*Eleusine coracana*) accessions were included in the experiment of which occupies 50 and 44 were collected by Bioinnovate Africa project from Tigray and Institute of Biodiversity Conservation (IBC) from different part of Ethiopia, respectively. Additional two improved cultivars, namely Tadesse and Boneya, which were released by Melkassa and Bako Agricultural Research Centers respectively, were included in the study. We included accessions collected from semi-arid area with low altitudinal ranges. Details of the accessions used in the study area are shown in Appendix 1.

## 3.2. Description of experimental site

The field investigation was conducted at Dhera, (Sub Center of Kulumsa Agricultural Research Center) found in Oromia Regional State (Fig. 2), 117 km from Addis on the main road to Assela located between 08$^{0}$ 19Ŋ06.3ŊŊN latitude 039$^{0}$ 19Ŋ0.74ŊŊE longitude at the altitude of 1677 m a.s.l.

Physicochemical properties of the soil from the study area were analyzed in Ecophysiology laboratory, Addis Ababa University. The soil pH and electrical conductivity was 6.8 and 9.8 dS/m, respectively. Total nitrogen and organic carbon content was 0.05% and 1.4%, respectively, indicted the soil was deficient with nitrogen and carbon content. The soil particle size was composed of Clay, Sand and Silt with percentage of 8, 51.5 and 40.5, respectively. Based on this data, the soil was characterized as sandy-loam d rived from the soil triangle chart.

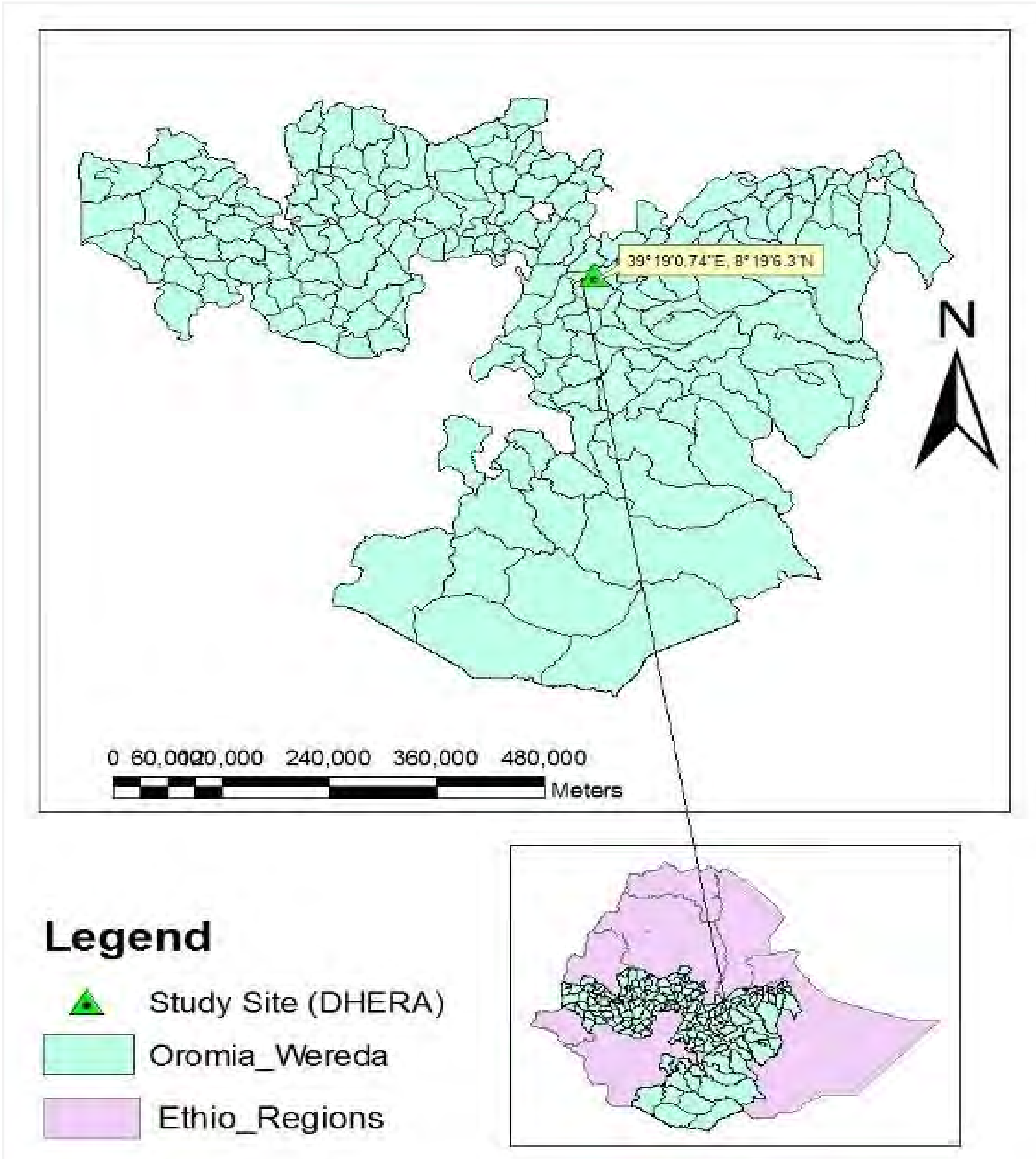


Figure 2. Map of the study area

### 3.3. Climate of the study area

Five years average data rainfall (834mm), maximum and minimum temperature ($30.8^0$ C and $5.2^0$ C, respectively indicated in Figure 3 and Table 3. The maximum temperature was recorded from October, November, December and March, whereas the minimum temperature was in January and February. Maximum rainfall was recorded starting from June to the beginning of September.

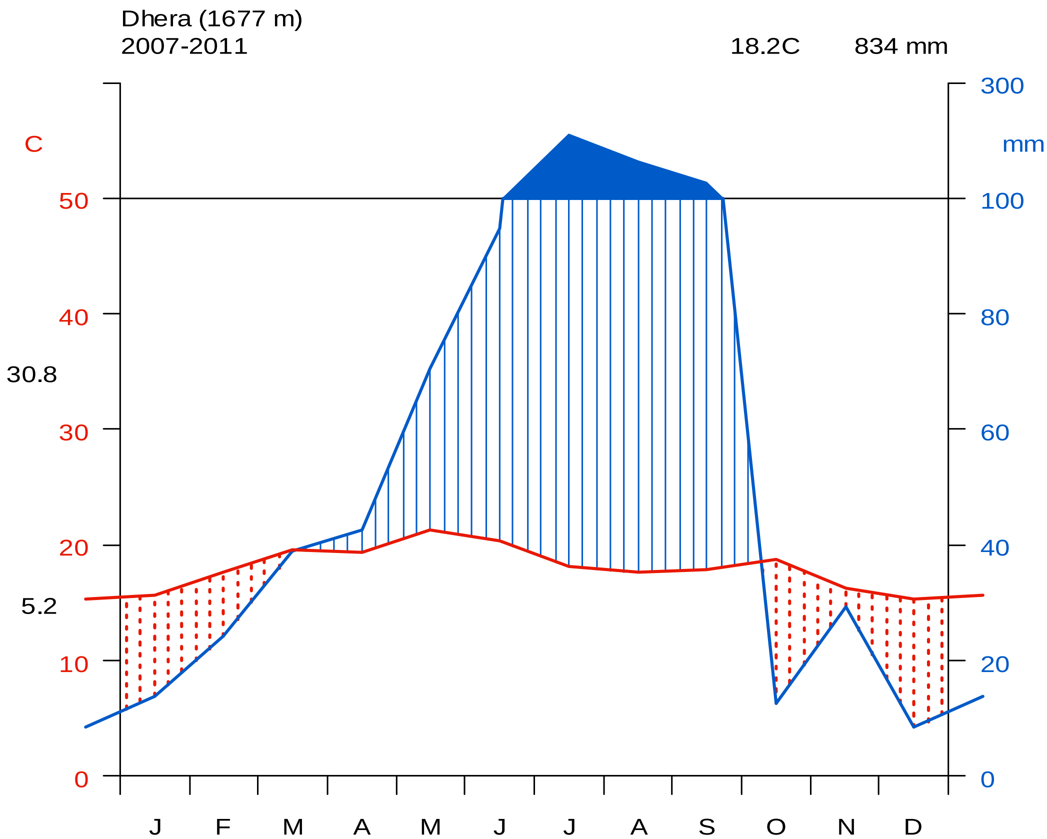


Figure 3. Klimadiagram showing five years mean rainfall (mm), maximum and minimum temperature ($^{0}$C) of the study area (2007-2011)

Table 3. The monthly mean maximum and minimum temperature ($^{0}$C) and rainfall (mm) during the study period

| | July | August | September | October | November | December |
|---|---|---|---|---|---|---|
| Rainfall | 135.6 | 107.4 | 133.6 | 0.0 | 35.4 | 0.0 |
| Max. Temperature | 27.9 | 26.4 | 25.5 | 28.4 | 26.0 | 18.3 |
| Min. Temperature | 16.0 | 15.9 | 14.3 | 12.1 | 13.6 | 7.2 |

### 3.4. Experimental design

The experimental was designed with Randomized Complete Block Design (RCBD) with two replications. To minimize the effect of soil variation on different treatments, both replications were folded to hold 48 accessions with block size of 2 m x36 m (72 $m^2$). In each plot accessions were planted in three rows of 2 m length with 75 cm distance between rows. For plot management and data collection 1.5 m path was left between each

All the seeds of 96 accessions used in the study were planted on July 10, 2011 on the basis of 15kg/ha and about 1-2 cm deep in the soil surface and finally covered with thin soil layer. Accessions from 1- 48 were placed in the first block of the first replication, while the second block contained from 49-96 accessions and the same pattern was also followed for the second replication with randomization.

Thinning and fertilizer application was carried out following the procedure described by Upadhyaya (2007), after three weeks the crop were thinned with 10 cm in each accession for each row and finally adjusted to remain 10 crop stands per row. Eventhough finger millet is a hardy crop; moderate fertilizer application enhances its agronomic performance. Hence, nationally recommended fertilizers were applied at the rate of 100 kg $ha^{-1}$ of DAP (Nitrogen = 18% and Phosphate = 46%) as a basal dose, and 100 kg $ha^{-1}$ of urea (nitrogen = 46%) as top dressing.

### 3.5. Sampling strategy and analysis

#### 3.5.1. Soil sampling

Soil sampling procedure was carried out following Mason (1992). Sampling was done to represent the study area following ŏZô scheme on the study plot 7 samples from each plot and a total of 21 samples were taken and composite sample was made for laboratory analysis. Three replicas of each laboratory analysis were carried out and later mean value of the three readings was taken.

### 3.5.2. Soil Texture and pH analysis

Soil texture (particle size) was determined using hydrometer of mechanical analysis method following the procedure by Juo (1978). The solution was measured using both hydrometer and thermometer.

Soil pH and electrical conductivity was analyzed following Juo (1978) using pH meter (pH-100 Digital controller, India), and conductivity meter (Model SX713, Conductivity/TDS/ Salinity/Resistivity meter, China), respectively.

### **3.5.3. Determination of Total Nitrogen**

Total Nitrogen was determined following the Macrokjeldhal method described by Van Schouwenberg and Walinge (1973). The method is structured in three successive steps:

i. ***Digestion***: In this process organic and inorganic nitrogen are converted to $NH_4SO_4$ with the digestion mixture of concentrated $H_2SO_4$, Potassium sulphate ($K_2SO_4$) and cupric sulphate ($CuSO_4.5H_2O$) was used to raise the temperature and as catalysts respectively.

ii. ***Distillation***: After transferring the digested mixture from the digester to the distillation apparatus, 40% NaOH (w/v) was used to raise the pH of the mixture and the ammonia was liberated and condensed finally received by 2% $H_3BO_3$ (w/v).

iii. ***Titration***: Ammonium borate mixture will be titrated using 0.1N $H_2SO_4$, finally the amount of 0.1N $H_2SO_4$ (v/v) consumed to change the color from light green to pale or violate. Percentages of total nitrogen in the soil and plant samples were calculated using the following formula.

$$\% N = [(a-b) * N x0.014 * mcf *100]/S \text{-------------------------------} 1$$

Where a = titrant volume for sample, b = titrant volume of for blank, N = normality of $H_2SO_4$ (0.1) S= Dry weight of sample; 0.014= molecular equivalent of nitrogen, mcf= moisture correction factor of the sample.

### 3.5.4. Determination of organic carbon

Organic carbon was determined following the method of Walkey (Magdoff *et al*., 1996). From 0.1-2 g of soil that passed with 2 mm sieve and transferred to 500 ml Erlenmeyer flask including two blanks. Both for the sample and the blank, 10 ml of 1N $K_2Cr_2O_7$ and 20 ml concentrated $H_2SO_4$ was added in the fume cupboard and swirl the flask and allow to stand on pad for 30 minutes, then 200 ml distil water was added and allowed to cool, finally 10 ml and 0.5 ml concentrated orthophosphoric acid and barium diphenlamine sulphonate indicator, respectively was added before titration. Both the sample and the blank were titrated using 0.5N ferrous sulfate solution until the color changes to purple or blue and the indicator was added drop by drop until the color flashes to light green. The percentage of the organic carbon was calculated using the following formula.

$$\% C = [N* (V1-V2)* 0.39*mcf]/S \text{---------------------------------------} 2$$

Where: N= normality of ferrous sulfate solution (from blank titration) i.e. N= ($NK_2Cr_2O_7$ x $VK_2Cr_2O_7$ ) / V $FeSO_4$ , V1= ml ferrous sulfate solution used for blank, V2= ml ferrous sulfate solution used for sample, S= weight of air dry sample in gram, 0.39= $3x10^{-3}$ x 100% x1.3 (3=equivalent weight of carbon), mcf= moisture correction factor

### 3.5.5. Individual plant sampling strategy for morphological and physiological measurements

According to International Board for Plant Genetic Resources (IBPGR, 1985) plant descriptor for finger millet, five finger millet stands were selected from each plot. The selected five individual plants were used for morphological measurements (plant height, green leaf number, green leaf area), physiological measurements such as RWC, CCI, biomass and yield related parameters (above ground and below ground biomasses) and grain yield biomass per head and per plant (tiller number, number of productive tillers, ear number and ear length).

## 3.6. Field Data collection for morphological and physiological measurements

The observations were recorded on five randomly selected plants at 50 % flowering in each replication and later averaged to be used for statistical analysis. All field managements were undertaken following standard agronomic practices. Data on measured parameters were scored from five plants randomly sampled from each accessions and replication following International Board for Plant Genetic Resources Descriptors for Finger millet (IBPGR, 1985).

### 3.6.1. Morphological parameters

Morphological parameters, plant height, total number of tillers and productive tillers, number of green leaves, total green leaves area, finger number and finger size were taken as per the IBPGR descriptor. Moreover, physiological data was also scored from five plants randomly sampled from each accession and replication.

The data collection approach was stratified into three. The first measurement was made at the time of germination for accession (Appendix 2) and then followed by physiological measurements (chlorophyll content and relative water content) at 50% of flowering. The second data recording of agronomic measurement was carried out at 50% physiological maturity while, the last measurement was focused in collecting data related to yield and yield related data (dry shoot weight, dry root weight, grain yield per head and yield per plant).

***Plant height***

Based on IBPGR (1985), descriptor for finger millet, five randomly selected plants were measured for its height. Plant height was measured starting from the base of the ground to the tip of the plant (Vurayai *et al*., 2001) using measuring tape for five randomly selected accessions for each accession in both replications.

***Green Leaf number and green leaf area***

Green leaf was counted from five randomly selected plants for all the 96 accessions. Green leaf area was taken using a ruler and green leaf area (GLA) was calculated using the formula below.

$$GLA = (C*L*W) \text{ ----------------------------------------------------- } 3$$

Leaf length was measured from the base of the leaf to the tip of the leaf (L) and, width was measured from the widest part of the leaf (W), 0.79 is the correction factor (C) obtained from scanning 15 leaf samples using leaf area meter (Area meter, Am100 Bio Scientific Ltd, UK). The mean value was taken from the fifteen plant measurements and this measurement was used to calculate correction factor which became 0.79, based on the formula below total green leaf area (TGLA) can be calculated:

$$TGLA= \Sigma (C*L*W) \text{ --------------------------------------------- } 4$$

Figure 4. Measurement of plant height and ear length using meter

***Tiller and productive tillers***

Number of basal tillers other than mother plant was counted per plant. Moreover, the numbers of tillers with fertile heads for five randomly individual plants were recorded for each accession per replication.

***Finger number and Finger size***

The number of fingers was counted from the five tagged plants from each accession per replication, while the finger size was measured using a ruler from base to the tip of longest spike (finger) in the main tiller.

***Grain yield per head and per plant***

The panicle from each head was trashed from each tagged plants and the seed was kept in the laboratory and seed weight was taken every other day until we attained a constant seed weight. Finally seed weight per head and per plant was determined using top load balance (Adam Equipment Co. Ltd. Milton, UK).

***Biomass determination***

Five randomly selected plants were used to determine the biomass. The plant was uprooted and the biomass was divided into shoot and root. The shoot was dried immediately whereas the root was washed using tap water and dried in the oven at $70^0$ C for 24 hours (Schutt labtechnik, Rudolf-Wissell, Gottingen, Germany); and dry weight was taken using triple beam balance (Florham park, USA).


Figure 5. Different accessions with different root biomasses

### 3.6.4. Physiological measurements

***Determination of Relative Water Contents***

Three fresh leaf samples from five randomly selected finger millet accessions were collected from the flag leaf and trimmed 2 $cm^2$. Fresh weight was taken using analytical balance (Denver Analytical Instruments, Colorado, USA) and floated on the Petri dish using distil water for 24 hours (Fig. 6), and turgid weight was taken again using analytical balance. The leaf sample was subsequently oven-dried (Schutt Labtechnik, Rudolf-Wissell, Gottingen, Germany) to a constant weight at $70^0$ C.

Relative water content was calculated using the formula;

$$RWC= [(FW – DW)/ (TW – DW)] *100 \text{--------------------------------} 5$$

Where, FW= Fresh weight, DW= dry weight, TW= Turgid weight

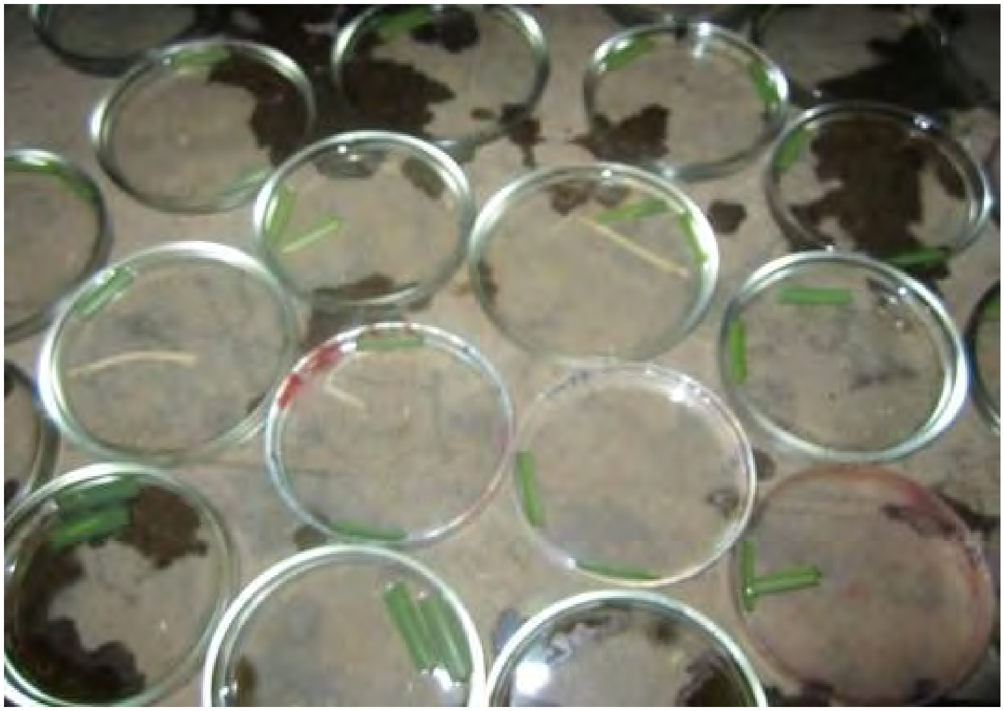

Figure 6. Leaf samples floated on Petri dish using distil water to get turgid weight.

***Chlorophyll content measurements***

Triplicate of Chlorophyll Content Index (CCI) reading was measured from each of the six leaves sampled from ninety six accessions in replication (Fig. 7) following Felix *et al*. (2002). Chlorophyll content index (leaf greenness) was measured using chlorophyll content meter, CCM-200 plus (Opti-Sciences, Inc. 8 Winn Avenue Hudson, USA). The ration of absorption of the light emitted from the instrument at two wave lengths (931nm/653nm) is the bases for the measurement of chlorophyll content index. The leaf light absorption characteristics at two wavelengths are affected by leaf chlorophyll content and the measured value provides an indication of the relative amount to total chlorophyll present in the leaves. The value was calculated according to the amount of light absorbed by the leaf (2x3 mm) into two wave length regions.

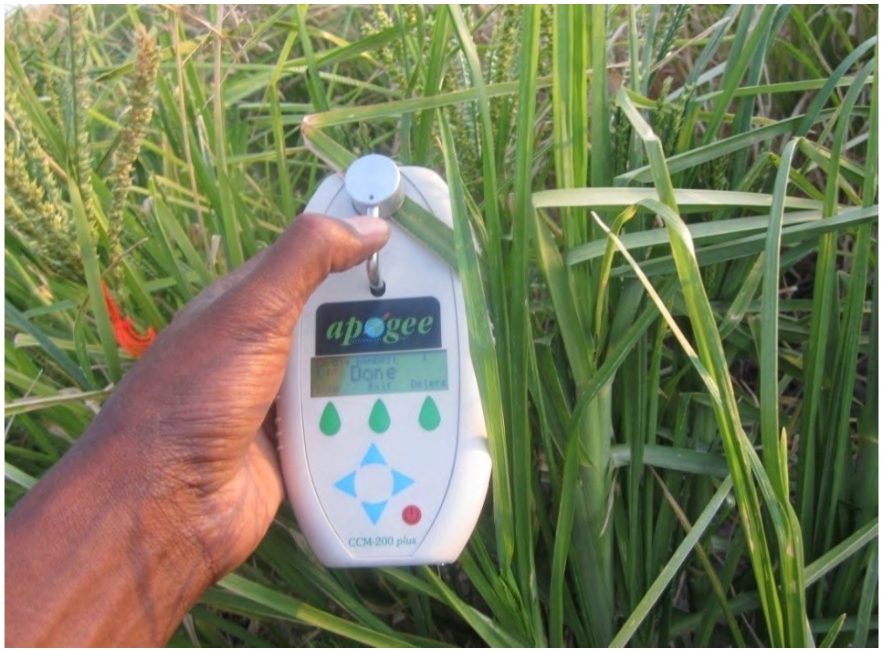


Figure 7. Measurement of chlorophyll content using chlorophyll content meter (CCM 200 plus).

Table 4. List of parameters taken during the study period

| Characters | Abbreviation |
|---|---|
| Plant height | PH |
| Number of tillers | NT |
| Number of productive tillers | NPT |
| Number of Green Leaves | NGL |
| Green Leaves area | GLA |
| Total Green Leaf area | TGLA |
| Number of ears | EN |
| Length of ears | EL |
| Yield per head | YPH |
| Yield per plant | YPP |
| Relative water content | RWC |
| Chlorophyll Content Index (CCI) | CCI |
| Root to Shoot ratio | R:S |

### 3.6.5. Data analysis

All the collected data were subjected to the analysis of variance (ANOVA), using SPSS Software (Version 16, SPSS Inc., Chicago USA). Means of each measured data were separated using Tukeyǿs range test at the 95% level of probability to test the significance of the treatments .The graph and plots were generated using Sigmaplot version 11, Systat Software, Inc. Software óRô version 2.11.1 was used to draw Dendrogram (cluster analysis) as well as Klimadiagram for temperature and rainfall data from the study area.

# CHAPTER FOUR

## 4. RESULTS

### 4.1. Descriptive statistics of the measured parameters

Descriptive statistics of the all the 96 accessions for the measured parameters such as plant height, tiller number, productive tillers, green leaf number, green leaf area, ear number and ear length, seed weight per head, seed weight per plant, dry shoot weight and dry root weight tabulated as follows (Table 5).

Table 5. Descriptive statistic of the 96 accessions at critical value 0.05, mean Standard deviation and Standard error of the parameters for randomized complete block design for

| Accession | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| PH | 96 | 72.23 | 15.007 | 1.532 |
| TN | 96 | 14.10 | 3.269 | 0.334 |
| PT | 96 | 10.10 | 3.737 | 0.381 |
| GLN | 96 | 3.71 | 2.436 | 0.249 |
| GLA | 96 | 24.22 | 16.753 | 1.710 |
| TGLA | 96 | 102.16 | 89.872 | 9.172 |
| EN | 96 | 9.22 | 2.617 | 0.267 |
| EL | 96 | 8.97 | 2.085 | 0.213 |
| DRW | 96 | 4.07 | 0.93 | 0.095 |
| DSW | 96 | 65.44 | 15.30 | 1.56 |
| R:S | 96 | 0.064 | 0.0195 | 0.002 |
| RWC | 96 | 12.67 | 2.157 | 0.220 |
| CCI | 96 | 12.67 | 2.157 | 0.947 |
| RWC | 96 | 74.90 | 9.56 | 0.945 |
| YPH | 96 | 2.70 | 1.42 | 0.144 |
| YPP | 96 | 138.97 | 90.52 | 9.24 |

Where N= number of accession, PH= plant height, TN= tiller number, PT= productive tiller, GLA= Greenleaf number, GLA= green leaf area, TGLA= total green leaf area, EN= ear number, EL= ear length, RWC= relative water content, CCI= designated for chlorophyll measurements, RWC = relative water content, GYPH= grain yield per head and GYPP= grain yield per plant

### 4.2. Plant height

The first tallest 20 finger millet accessions are indicated in Table 10 along with other parameters. Accordingly, Accession 230107, AAUFM-10, 230106, 230110, 230108, 230109, 230103, AAUFM-47, 208440 and AAUFM-17 were the top ten accessions having the highest plant height in descending order, whereas 242111, 238325, AAUFM-28, 242622, AAUFM- 33, 235140, AAUFM-41, AAUFM-37, 215982 were 215985 are the lowest bottom ten accessions in descending order. Analysis of variance (ANOVA) shows there was a significant ($P \leq 0.05$) difference between accessions. Plant height had significant correlation with yield per head and yield per plant. Moreover significant positive correlation with $r^2 = 0.430$ and $r^2 = 0.331$ was also observed with number of productive tillers and ear numbers, respectively.

### 4.2. Green leaf number and total green leaf area

Variation among accessions have been observed in internode length and number, as a result some accessions tend to have several leaves, while others were observed to have few internodes as a result they are maintaining small number of leaves. In addition, some accessions maintain their green leaves for longer time, while others senesced quickly. Ten accessions namely, 215851, 242132, AAUFM-15, AAUFM-47, 237475, 238300, AAUFM-44, 237465, 241618, 234159, 230110 were observed to have highest number of green leaves in descending order. Analysis of variance showed that there is a significant ($P \leq 0.05$) difference between the accessions.

Total green leaf area is the product of the number of green leaves and the number of green leaf area of a plant. The analysis of variation shows that there is a significant difference between the accessions ($P \leq 0.05$). The correlation coefficient indicated on Table 10, shows that there is a highly positive significant correlation ($r^2 = 0.669$ and $r^2 = 0.767$) with green leaf number ($r^2 = 0.669$) and total green leaf area ($r^2 = 0.767$) per plant.

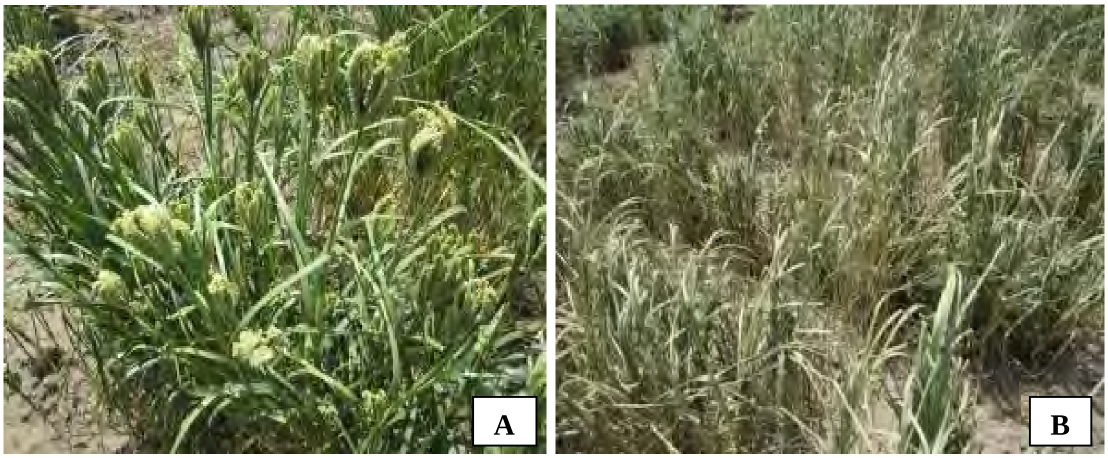


Figure 8. Tadesse, nationally released variety (A); Accessions (242120, 242132, and 242135) (B) which were susceptible to drought stress.

Some of the accessions collected from part of Tigray and Eritrea tended to be early maturing before the moisture content of the soil dropped. Accessions particularly collected from Eritrea and part of Tigray such as accessions; 230102, 230103, 238299, 208440, 230106, 230107, 230108 and 100002 can be cited as early maturing accessions with five and half months time. In contrast, some accessions were observed to be very late maturing; these are 238325, AAUFM-41, AAUFM-53 and 216046 with prolonged maturity time as long as additional one more months after from the early matured ones.

Table 6. Mean ± S.E values of green leaf number; mean green leaf area and total green leaf area per plant in descending order for ten accessions

| Accession | Green leaf number | Accession | Green leaf area ($cm^2$) | Accession | Total green leaf area ($cm^2$) |
|---|---|---|---|---|---|
| 215851 | 10.8(1.6)$^{a}$ | AAUFM-19 | 144.2(3.4)$^{a}$ | AAUFM-36 | 542.1(0.4)$^{a}$ |
| 242132 | 10.2(1.2)$^{b}$ | AAUFM-36 | 125.1(2.4)$^{a}$ | AAUFM-19 | 528.6(1.1)$^{b}$ |
| AAUFM-15 | 10.0(1.6)$^{b}$ | 238310 | 36.5(2.9)$^{ab}$ | 215851 | 300.3(0.6)$^{bc}$ |
| AAUFM-47 | 9.4(0.4)$^{c}$ | 241618 | 32.3(3.8)$^{ab}$ | 241618 | 245.2(0.5)$^{c}$ |
| 237475 | 8.4(2.0)$^{c}$ | AAUFM-29 | 30.2(3.4)$^{ab}$ | AAUFM-15 | 228.9(0.4)$^{c}$ |
| 238300 | 8.2(1.0)$^{c}$ | 230110 | 30.0(3.5)$^{ab}$ | 230110 | 219.7(0.4)$^{d}$ |
| AAUFM-44 | 8.0 (1.1)$^{c}$ | AAUFM-39 | 29.2(1.5)$^{bc}$ | AAUFM-44 | 217.3(0.4)$^{e}$ |
| 237465 | 7.6(0.6)$^{d}$ | 215989 | 28.8(3.5)$^{bc}$ | 234159 | 217.1(0.9)$^{e}$ |
| 211618 | 7.6(1.5)$^{d}$ | 238325 | 28.8(0.2)$^{bc}$ | AAUFM-47 | 207.9(0.2)$^{f}$ |
| 234159 | 7.6 (1.2) | 234159 | 28.6 (.5) | 238300 | 204.7(0.6)$^{f}$ |

From the top ten accessions 215851, AAFUM-19, AAUFM-36, 241618, 230110 and AAUFM-15 had the highest value at least with two variables such as green leaf number and green leaf area or green leaf area and total green leaf area (Table. 6). For instance, accession AAUFM-19 was observed to have the highest green leaf area and the second highest in total green leaf area, while accession AAUFM -36 had the second highest with green leaf area and first highest with total green leaf area. Moreover, accession 215851 was the highest with green leaf number but third with total green leaf area.

## 4.4. Physiological measurement

### 4.4.1. Chlorophyll content (greenness of the leaves)

There is a significance difference of CCI reading between the accessions ($P \leq 0.05$). Except positive correlation with green leaf area and relative water content, there was no correlation so far observed with other parameters. The following ten accessions showed the highest CCI readings, AAUFM-14, AAUFM-44, AAUFM-24, 215965, AAUFM-23, AAUFM-12, AAUFM-33, 235782, AAUFM-5 and 215985, while the following ten accessions were observed to show the lowest CCI readings; namely 215990, AAUFM-36, 235140, AAUFM-37, AAUFM-49, 242111, 100002, 216046, AAUFM-26 and 215982.

### 4.4.2. Relative water content

. Analysis of variance indicated relative water content was significantly different between accessions ($P > 0.05$). Relative water content (RWC) positively correlated with root shoot ration, yield per head and per plant as well as with CCI reading, while dry root weight showed a strong significant correlation at $r^2 = 0.905$ with RWC. Three accessions namely 215985, AAUFM-6 and 215989 showed the highest RWC with 100 %, 98.6 % and 93.7 %, respectively.

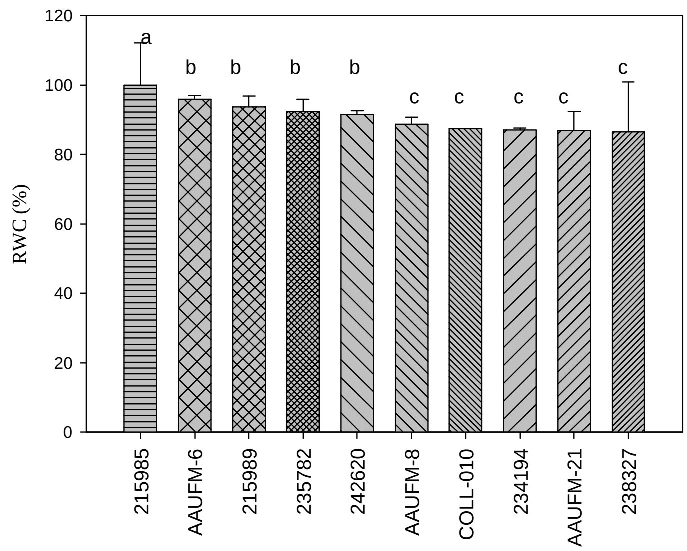


Figure 9. The first top ten accessions in relative water content

However, the first three accessions that showed the lowest RWC read were 242132, 215965 and 238299 with 48.7 %, 49.2 % and 56.3 %, respectively.

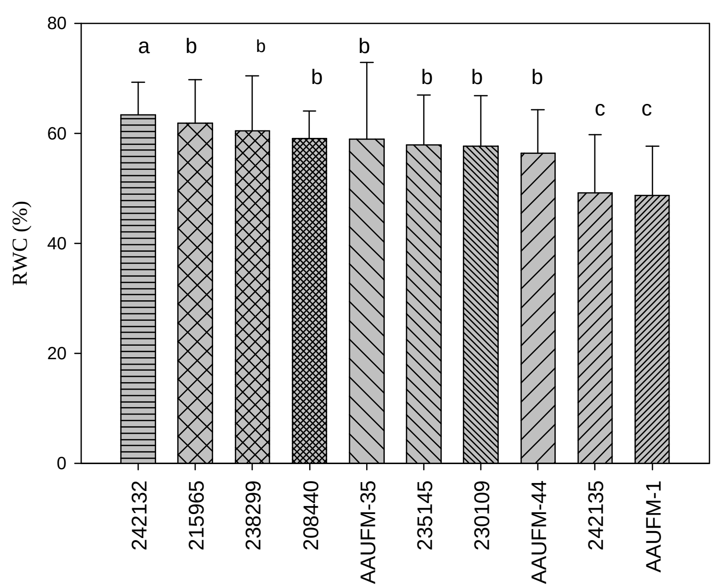


Figure 10. The bottom ten accessions in relative water content

### 4.5. Yield and yield components

#### 4.5.1. Number of tillers and productive tillers

There was significant difference among accessions tiller number while productive tillers showed significant ($P \leq 0.05$) difference. Productive tillers were had a strong significant correlation with tiller number and plant height. Moreover, tillers number showed strong correlation with grain yield per plant at $r^2 = 0.259$. Accessions with highest and lowest number of tillers and productive tillers are summarized in Table 7 and Table 8, respectively.

Accessions collected from moisture rich areas particularly from northwest Ethiopia, produced more tillers, however the number of productive tillers were lower.

Table 7. Mean value ± S.E. of accessions with the highest tillers number and productive tillers

| Accession | Tiller Number | Accession | Productive tillers |
|---|---|---|---|
| AAUFM-1 | 23.3 (3.4)$^{a}$ | AAUFM-20 | 18.9 (0.3)$^{a}$ |
| AAUFM-20 | 22.3 (0.3)$^{a}$ | 230103 | 18.7 (1.4)$^{a}$ |
| 230105 | 21.2 (2.5)$^{ab}$ | AAUFM-17 | 17.3 (0.9)$^{b}$ |
| 215989 | 20.1 (1.3)$^{b}$ | AAUFM-38 | 17.1 (0.9)$^{b}$ |
| 230103 | 19.7 (1.6)$^{b}$ | 230102 | 16.9 (0.6)$^{b}$ |
| AAUFM-38 | 19.3 (1.6)$^{b}$ | AAUFM-2 | 16.9 (0.0)$^{b}$ |
| 225892 | 19.2 (1.5)$^{b}$ | 230105 | 16.6 (2.3)$^{b}$ |
| 238300 | 19.1 (1.4)$^{b}$ | 242624 | 15.3 (1.7)$^{c}$ |
| AAUFM-11 | 19.0 (2.6)$^{b}$ | 238334 | 15.3 (0.6)$^{c}$ |
| AAUFM-29 | 18.8 (2.6)$^{b}$ | AAUFM-4 | 14.3 (0.9)$^{c}$ |

Table 8. Mean value ± S.E. of accessions with lowest tiller number and productive tillers

| Accession | Tiller number | Accession | productive tillers |
|---|---|---|---|
| AAUFM-5 | 11.1 (1.1)[a] | 235140 | 5.0 (0.8)[a] |
| 230109 | 10.6 (0.2)[a] | 242111 | 4.9 (1.9)[a] |
| BONEYA | 10.4 (1.9)[a] | AAUFM-41 | 4.8 (0.6)[a] |
| AAUFM-7 | 10.2 (0.4)[a] | AAUFM-33 | 4.7 (1.0)[a] |
| TADESSE | 9.7 (0.7)[ab] | AAUFM-37 | 3.9 (0.9)[ab] |
| AAUFM-8 | 9.4 (1.6)[b] | 215985 | 3.6 (1.1)[b] |
| 234158 | 9.1 (2.0)[bc] | AAUFM-24 | 3.5 (0.5)[b] |
| 242135 | 8.8 (0.9)[bc] | 100002 | 3.4 (0.2)[b] |
| 238325 | 7.5 (2.6)[c] | 238334 | 1.3 (0.6)[b] |
| AAUFM-24 | 5.9 (1.4)[d] | 215982 | 0.3 (0.1)[c] |

**4.5.2. Grain yield per head and per plant**

The amount of grain yield per head and grain yield per plant depends on the number of ear number, ear size and productive tillers. The following twenty accessions showed the highest grain yield per head, these are: AAUFM-7, TADESSE, 238325, AAUFM-43, AAUFM-2, AAUFM-30, 230109, AAUFM-42, AAUFM-50, AAUFM-44, BONEYA, 238299, 235145, AAUFM-21, 230103, AAUFM-4, 8234158, AAUFM-5, AAUFM-10, and AAUFM-24. Moreover; the following accessions showed the highest grain per plant; these were 238299, 238325, AAUFM-2 AAUFM-30, AAUFM-44, AAUFM-38, AAUFM-21, 230103, AAUFM-36, AAUFM-18, TADESSE, AAUFM-42, 215965, AAUFM-10, AAUFM-48, AAUFM-50, 242616, AAUFM-4, 230109, AAUFM-5. Analysis of variance showed grain yield per head and grain yield per plant varied significant ($P \leq 0.05$) between accessions.

Correlation coefficient (Table 13) revealed that grain yield per head and per plant showed strong correlation with plant height, productive tillers, number of tillers and productive tillers at 0.01.

Grain yield per plant showed highly significant correlation with plant height, number of tillers, number of productive tillers and the yield per head. Strong positive correlation was observed among grain yield per plant and grain yield per head at $r^2 = 0.733$. Moreover, grain yield per head had significant correlation with plant height, productive tillers, ear number and the greenness of the leaf (CCI). Six accessions (238325, AAUFM-2, AAUFM-30, AAUFM-44, TADESSE, AAUFM-42), had the highest amount of seed yield per head and total seed weight per plant in gram (Table 9).

Table 9. The top ten accessions raked with their grain yield per head and per plant

| Accessions | Grain yield/head (g) | Accessions | Grain yield/plant (g) |
|---|---|---|---|
| AAUFM-7 | 5.40(0.3)[a] | 238299 | 84.50(3.4)[a] |
| TADESSE | 4.64(1.4)[ab] | 238325 | 80.00(0.3)[ab] |
| 238325 | 4.00(0.9)[b] | AAUFM-2 | 77.50(2.5)[b] |
| AAUFM-43 | 4.00(0.9)[b] | AAUFM-30 | 75.20(1.3)[b] |
| AAUFM-2 | 4.00(0.6)[b] | AAUFM-44 | 72.00(1.6)[c] |
| AAUFM-30 | 3.85(0.0)[b] | AAUFM-38 | 70.50(1.6)[c] |
| 230109 | 3.74(2.3)[c] | AAUFM-21 | 67.00(1.5)[cd] |
| AAUFM-42 | 3.74(1.7)[c] | 230103 | 65.49(1.4)[cd] |
| AAUFM-50 | 3.73(0.6)[c] | AAUFM-36 | 64.50(2.6)[cd] |
| AAUFM-44 | 3.60(0.9)[d] | AAUFM-18 | 63.50(2.6)[d] |
| AAUFM-19 | | AAUFM-50 | |

## 4.7. Biomass and root related traits

### 4.7.1. Aboveground and belowground biomass

The highest dry shoot biomass was observed by accessions 230109, 242111, AAUFM-40 and AAUFM-2, whereas AAUFM-8, AAUFM-49, AAUFM-48, and 238334 had the least dry shoot biomass. Moreover; Accessions 215965, 242616, AAUFM-42, 242624 had the highest dry root biomass while, accession AAUFM-46, 215851, 238299, AAUFM-49, had the lowest root dry biomass. The analysis of variance indicated that there was no significance difference among accessions ($P > 0.05$) for root: shoot ratio. However, root shoot ration showed strong significant correlation ($r^2 = 0.277$) with dry root weight level; whereas root: shoot ratio showed negative correlation ($r^2 = -0.299$) with dry shoot weight. The root shoot weight showed positive correlation with CCI, relative water content, yield per head and yield per plant. The first top ten accessions in morphological measurements are summarized (Table 10), in descending order whereas dry biomass of root and shoot, yield related and physiological measurements are tabulated in Table 11.

Table 10. Top 20 selected finger millet accession for the following trait in descending order

| PH | TN | PT | GLN | GLA | TGLA | EN | EL |
|---|---|---|---|---|---|---|---|
| 230107 | AAUFM-1 | AAUFM-20 | 215851 | AAUFM-19 | AAUFM-36 | AAUFM-14 | AAUFM-23 |
| AAUFM-10 | AAUFM-20 | 230103 | 242132 | AAUFM-36 | AAUFM-19 | AAUFM-44 | AAUFM-12 |
| 230106 | 230105 | AAUFM-17 | AAUFM-15 | 238310 | 215851 | AAUFM-24 | AAUFM-1 |
| 230110 | 215989 | AAUFM-38 | AAUFM-47 | 241618 | 241618 | AAUFM-5 | 234194 |
| 230108 | 230103 | 230102 | 237475 | AAUFM-29 | AAUFM-15 | AAUFM-20 | 241617 |
| 230109 | AAUFM-38 | AAUFM-2 | 238300 | 230110 | 230110 | AAUFM-7 | 238310 |
| 230103 | 225892 | 230105 | AAUFM-44 | AAUFM-39 | AAUFM-44 | 242135 | 237475 |
| AAUFM-47 | 238300 | 242624 | 237465 | 215989 | 234159 | 225892 | AAUFM-29 |
| 208440 | AAUFM-11 | 238334 | 241618 | 238325 | AAUFM-47 | 235145 | 238300 |
| AAUFM-17 | AAUFM-29 | AAUFM-4 | 234159 | 234159 | 238300 | AAUFM-4 | 242616 |
| 234158 | AAUFM-2 | AAUFM-12 | 230110 | 215851 | 238310 | AAUFM-15 | AAUFM-31 |
| AAUFM-16 | 230102 | AAUFM-23 | 242133 | AAUFM-44 | 237465 | AAUFM-22 | 235782 |
| AAUFM-21 | AAUFM-19 | 242132 | AAUFM-2 | 242133 | 242133 | 235783 | AAUFM-32 |
| 238310 | 242620 | AAUFM-15 | 230107 | 241617 | 242132 | 238310 | AAUFM-28 |
| AAUFM-5 | AAUFM-17 | 242620 | 215990 | 237465 | 237475 | AAUFM-21 | AAUFM-10 |
| AAUFM-20 | 234199 | AAUFM-49 | AAUFM-26 | AAUFM-7 | AAUFM-2 | AAUFM-18 | AAUFM-33 |
| AAUFM-14 | AAUFM-21 | AAUFM-19 | AAUFM-48 | AAUFM-6 | AAUFM-39 | AAUFM-48 | AAUFM-14 |
| TADESSE | AAUFM-16 | AAUFM-11 | 100002 | AAUFM-23 | 215990 | 215851 | 238305 |
| AAUFM-22 | AAUFM-15 | AAUFM-9 | 238299 | 230105 | BONEYA | 208440 | AAUFM-35 |
| AAUFM-46 | 242132 | AAUFM-46 | BONEYA | BONEYA | 230107 | 242616 | AAUFM-47 |

PH- plant height, NT ï number of tillers, PT- productive tillers, NGL- number of green leaf, GLA- green leaf area, TGLA- Total green leaf area, EN- Ear number, NL Ear length

Table 11. Top 20 selected finger millet accessions for the following parameters in descending order

| **DSW** | **DRW** | **R:S** | **GYPH (g)** | **GYPP (g)** | **CCI** | **RWC** |
|---|---|---|---|---|---|---|
| 230109 | 215965 | AAUFM-12 | AAUFM-7 | 238399 | 230108 | 215985 |
| 242111 | 242616 | AAUFM-11 | TADESSE | 238325 | 230109 | AAUFM-6 |
| AAUFM-40 | AAUFM-42 | AAUFM-16 | 238325 | AAUFM-2 | 234194 | 215989 |
| AAUFM-2 | 242120 | AAUFM-15 | AAUFM-43 | AAUFM-30 | AAUFM-8 | 235782 |
| AAUFM-37 | 242624 | AAUFM-39 | AAUFM-2 | AAUFM-44 | 242132 | 242620 |
| 215965 | AAUFM-39 | 238299 | 230109 | AAUFM-38 | AAUFM-39 | AAUFM-8 |
| AAUFM-7 | AAUFM-12 | 235140 | AAUFM-50 | AAUFM-36 | 230106 | COLL-010 |
| AAUFM-21 | AAUFM-29 | AAUFM-9 | AAUFM-44 | AAUFM-18 | AAUFM-9 | 234194 |
| 235782 | AAUFM-31 | 242120 | BONEYA | TADESSE | 235140 | AAUFM-23 |
| AAUFM-28 | AAUFM-40 | 230109 | 238299 | AAUFM-42 | AAUFM-49 | 238327 |
| 234199 | 241618 | 234159 | 235145 | 235965 | 230110 | AAUFM-24 |
| TADESSE | 243639 | AAUFM-22 | AAUFM-21 | AAUFM-48 | AAUFM-46 | AAUFM-14 |
| AAUFM-16 | AAUFM-30 | AAUFM-38 | AAUFM-48 | AAUFM-50 | 215989 | AAUFM-33 |
| 242624 | AAUFM-37 | 241618 | 234158 | 242616 | 238325 | BONEYA |
| 230107 | AAUFM-14 | AAUFM-31 | AAUFM-38 | AAUFM-4 | AAUFM -18 | AAUFM-29 |
| AAUFM-35 | 230110 | 242132 | AAUFM-5 | 230109 | 234158 | 238334 |
| 237465 | BONEYA | AAUFM-5 | AAUFM-10 | AAUFM-5 | AAUFM-32 | 243639 |
| 242132 | 238310 | 242616 | AAUFM-24 | AAUFM-23 | 241618 | 235140 |
| 238300 | AAUFM-22 | 230108 | AAUFM-4 | AAUFM-31 | 230102 | 215982 |
| AAUFM-4 | TADESSE | AAUFM-22 | AAUFM-48 | 215990 | AAUFM-42 | TADESSE |

DRW- dry root weight, DSW- Dry shoot weight, R: S - root shoot ratio, GYPH- Grain yield per head, GYPP=Grain yield per plant, CCI-is for Chlorophyll content, RWC- relative water content

### 4.8. Cluster Analysis

Fifteen quantitative traits were used to carryout cluster analysis and all the 96 accessions were grouped into six clusters (Fig. 11). Overall, in the cluster analysis finger millet accession tended to form groups based on their geographic proximity and origin. The first cluster contained forty five accessions, three from Amhara Regional State (Gondar, Gojam and Wollo), thirty seven were collected from Tigray and three from Eritrea. The second cluster contained nineteen accessions, i.e., eighteen from Tigray and one from Amhara. Cluster 3 contained twenty three accessions (ten from Tigray and thirteen from Amhara). Cluster 4 contained five accessions, three from Tigray and one accession from Amhara and Eritrea. The fifth cluster contained only one accession from Tigray while the last cluster contained two accessions from Tigray. Some accessions from Eritrean tended to form groups with accessions from northern Tigray. This similarity and tendency of grouping could be due to the geographic proximity among the two localities and possibility of seed flow. There were also accessions forming distinct groups. For example, accessions grouped in clusters 5 and 6 were far from their respective groups (clusters 1 an d 2). Accession 215851 which was collected from Amhara region grouped in cluster 4, which was far from where the majority of the accessions were collected from the same place (cluster 1 and 2). Most accessions grouped together were from the same origin, however there were some accessions that originated from the same area but grouped far from the rest of their group.

Table 12. Number of clusters from 96 accessions categorized into six groups based on their measured parameters

| Clusters | Total accessions in each Clusters | No. of accessions from the origin | Origin | Accessions |
|---|---|---|---|---|
| C1 | 45 | 3 | Eritrea | 230102,230105,230108 |
| | | 39 | Tigray | AAUFM-4, AAUFM-17,AAUFM-21,AUFM-7, 230108, AUFM-20, AUFM-30, AUFM-10, AUFM-42, 238334, AUFM-1, AUFM-11, AUFM-23, 234158, AAUFM-25,235145, 234199, AUFM-46, 242616, AUFM-5, TADESSE,AAUFM-29, AAUFM-50, AUFM-6, AUFM-31, AAUFM-49, 230106, 234194, AUFM-22, 241617, 238305, AUFM-35, 238525, 206046, 238327, AAUFM-41, 230109, 237476, 238334 |
| | | 3 | Amhara | 215965, 2084402, 243639 |
| C2 | 19 | 18 | Tigray | 238299, AAUFM-45, AAUFM-26, AAUFM-29, AAUFM-40, 2230107, AAUFM-9, AAUFM-39, AAUFM-48, 230110, 238310, AAUFM-47, AAUFM-44, AAUFM-15, 234159, 237465, 237475, 238300, |
| | | 1 | Amhara | 242120, |
| C3 | 23 | 10 | Tigray | 242620, AAUFM-14, 242622, AAUFM-37, AAUFM-12, AAUFM-18, AAUFM-33, AAUFM-24, AAUFM-8, AAUFM-16 |
| | | 13 | Amhara | 242132, 242133, 100002, 215990, 215989, 242135, 235140, 235782, 235783, 225892, 215982, 215885, 242111 |
| C4 | 5 | 1 | Eritrea | 230103 |
| | | 3 | Tigray | AAUFM-43, AAUFM-43, AAUFM-2 |
| | | 1 | Amhara | 215851 |
| C5 | 1 | 1 | Tigray | 215651 |
| C6 | 2 | 2 | Tigray | AAUFM-35, AAUFM-19 |

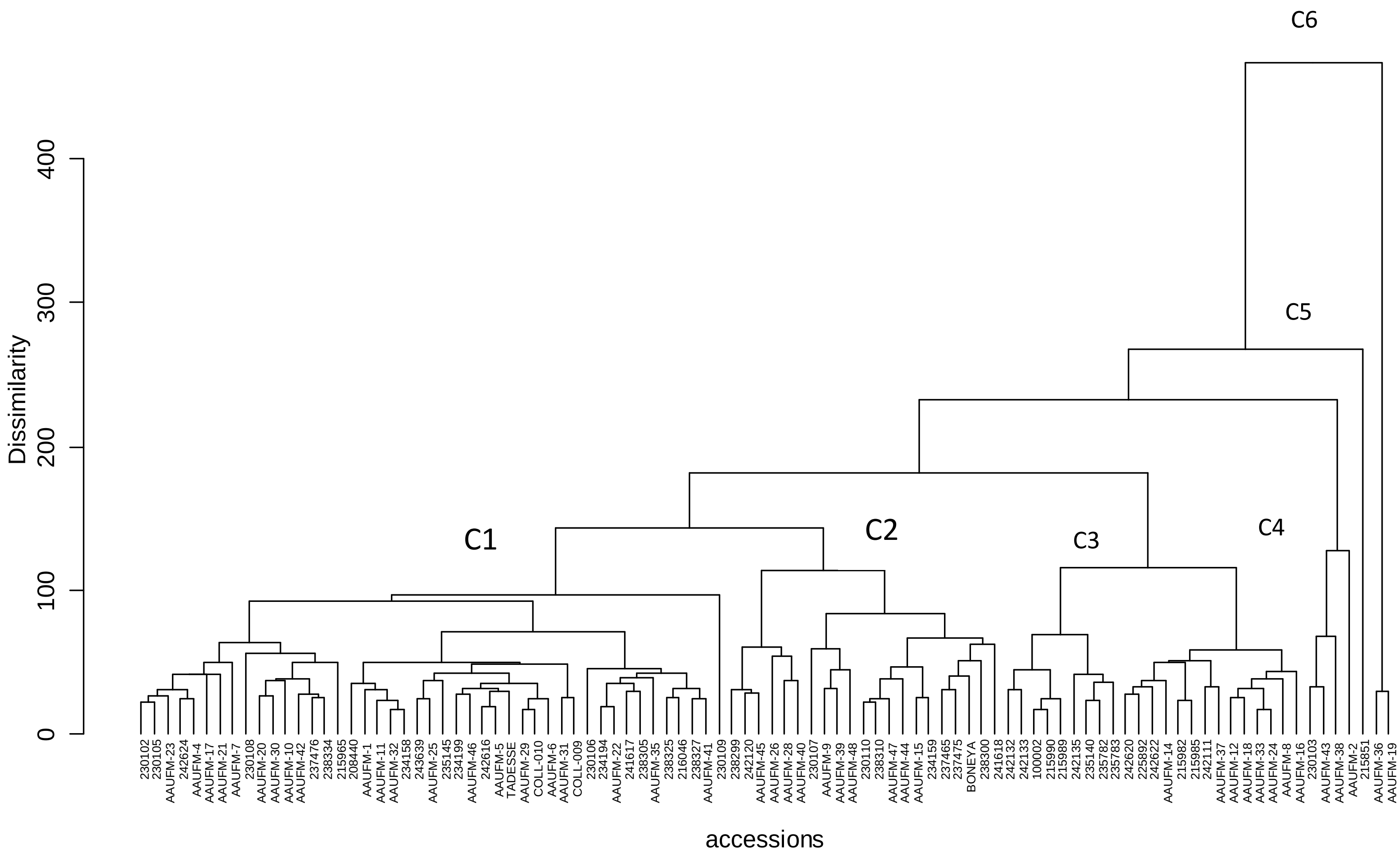


Figure 11. Dendrogram showing similarity among ninety six accessions based on the fifteen parameters measured

Table 13. Correlation coefficient among different morpho-physiological traits of ninety six genotypes of finger millet accessions

| | PH | NT | PT | GLN | GLA | TGLA | EN | EL | DRW | DSW | R:S | CCI | RWC | GYPH | GYPP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PH | 1 | | | | | | | | | | | | | | |
| NT | .091 | 1 | | | | | | | | | | | | | |
| PT | .430** | .581** | 1 | | | | | | | | | | | | |
| GLN | -.032 | .071 | .118 | 1 | | | | | | | | | | | |
| GLA | .001 | .135 | .062 | .053 | 1 | | | | | | | | | | |
| TGLA | .000 | .145 | .125 | .669** | .767** | 1 | | | | | | | | | |
| EN | .331** | .001 | .329** | .083 | -.049 | .029 | 1 | | | | | | | | |
| EL | .166 | .155 | .283** | .040 | -.104 | -.054 | .364** | 1 | | | | | | | |
| DRW | .012 | -.225* | -229* | .007 | -.181* | -.129 | -.025 | .191* | 1 | | | | | | |
| DSW | -.066 | .059 | -.062 | .105 | -.032 | .023 | -.074 | .043 | .115 | 1 | | | | | |
| R:S | -.015 | -.114 | .097 | -.008 | -.037 | -.028 | -.005 | .108 | .277** | -.229** | 1 | | | | |
| CCI | .196* | -.034 | .194* | -.060 | -.076 | -.084 | .511** | .201* | .201* | .040 | .054 | 1 | | | |
| RWC | -.153 | -.042 | -.143 | -.144 | .062 | -.053 | -.198* | .095 | .905 | -.013 | .122 | .004 | 1 | | |
| YPH | .191* | -.084 | .261** | -.152 | .037 | -.077 | .187* | .002 | .002 | .056 | .096 | .208* | -.211* | 1 | |
| YPP | .282** | .259** | .614** | -.054 | .009 | -.053 | .111 | -.069 | -.069 | .008 | .049 | .086 | -.143 | .733** | 1 |

**. Correlation is significant at the 0.01 level

*. Correlation is significant at the 0.05 level

Where ** and * = significant at p = 0.01 and p= 0.05 level respectively. PH= plant height, TN= Number of Tillers PT= Productive Tiller, GLN= green leaf number, GLA= green leaf area, TGLA= Total green leaf area, EN = Ear number, Ear length, DRW= dry root weight, DSW= dry shoot weight, R: S= root soot ration, RWC= Relative water content, GYPH= Grain yield per head (g), GYPP= Grain yield per plant (g) and CCI is designated for measurement of greenness of the leaf.

# CHAPTER FIVE

## 5. DISCUSSION

The objective of this research was to screen finger millet accessions collected from Ethiopia based on their response and potential to moisture stress condition. Different morphological and physiological parameters along with yield and yield relative parameters were taken to select and advance accessions which were tolerant to field moisture stress conditions.

### 5.1. Growth related parameters of finger millet genotype and implication on genotypic performance under moisture stress

The genotypes evaluated in the field were variable for most of the traits considered. Moreover specifically, accessions observed to show variation in day to heading and maturity. This was positively correlated with plant height, whereby early maturing accessions were observed to be taller (230107, 230108, 230106 105.6 cm, 103.6 cm and 99.4 cm, respectively) than the late maturing accessions (238325, AAUFM-41 and 216046 having plant height of 56.7 cm 52.1 cm and 67.2 cm respectively).

In contrast, the shortest plant such as accessions 215982 and 215985 with plant height of 36.4 cm and 36.8 cm, respectively were recorded for accessions collected from moisture rich area like Amhara Region (Northwestern part) which was very susceptible to water deficit. According to Vurayai *et al*. (2001), water deficit reduced plant height during the vegetative and flowering stages, which is attributed to reduction of stem and leaf expansion. In our study accession collected from moisture stress areas or degraded areas had some tendency of making use of the available moisture to mature within short time, as opposed to others from moisture rich area.

Plants have a capacity through morphological plasticity to adjust themselves to environmental conditions, which is usually unstable due to the various factors. Water stress is one of the environmental factors that affect negatively on the plant height of all cereals (Mirbahar *et al.,* 2009). In the present experiment, water deficit had an effect on various growth/morphological traits such as total green leaf area (TGLA), tiller number (TN), productive tillers (PT). Accession 216046, 242620 and 215982 collected from (Wellega, Adiaybo (Tigray) and Dembya (Gondar) regions, respectively, exhibited the lowest plant height with 36.4 cm, 67.2 cm and 73.2 cm respectively (Appendix 3). This is mainly due to limited available moisture content, which was not enough to support the growth and development of the crops. Similarly, Kramer (1983) reported that growth and development in morphological traits seriously hampered by water deficit are typical responses of crop plants when subjected to drought. Moreover, Inamullah *et al*. (1999) also observed that plant height in wheat varieties reduced significantly under water stress as compared to irrigated once.

As the soil water content decreased, the plant height, stem diameter, number and area of leaves, leaf area, herb yield and leaf chlorophyll contents decreased but the amount of anthocyanin and proline increased in balm (*Melissa officinalis*) (Aliabadi *et al*., 2009). Similar result was reported by Specht *et al*. (2001) in soybean, whereby the stem length was significantly decreased under water deficit conditions. Water stress greatly suppresses cell expansion and cell growth due to the low turgor pressure. It affects both elongation and expansion growth (Anjum *et al*., 2003a). According to Vaezi *et al*. (2010)

significant reduction in plant height was noticed due to water stress in barely with an average of 14.6% from the irrigated stand in chickpea the effects of drought during the vegetative phase and  anthesis stage was serious to significantly reduce the number of pods per plant (Mafakheri  *et al*., 2010).

Similarly, plant height was reduced up to 25% under water stressed citrus seedlings (Wu *et al*., 2008), while stem length was significantly affected under water stress condition in potato (Heuer and Nadler, 1995). The reduction in plant height could be associated with a decline in the cell enlargement and more leaf senescence under water stress condition (Bhatt and SrinivasaRao, 2005).

The effect of water deficit on plants ranges from cell to the organism level. However, different plants have different adaptation mechanism to drought stress. As mentioned by Blum (2005); and Mitchell *et al*. (1998), reduced plant size and leaf area are major mechanisms for moderating water use and reducing injury under drought stress. Moreover, crop cultivars breed for water-limited environments by selection for yield under water stress environment have a constitutively reduced leaf area, plant size, leaf area and tillering.

It affects both elongation and expansion growth (Anjum *et al*., 2003a). According to Vaezi, *et al*. (2010) significant reduction in plant height was noticed due to water stress in barely with an average of 14.6% from the irrigated stand in chickpea. In contrast, accessions AAUFM- 49, 242622 and AAUFM-32 collected from Tigray, Laelay Adiyabo and Htsay (Tigray) were observed to have the lowest record for green leaves number and green leaf area (Appendix 3). Accessions with the higher number of green leaf retention is another characteristic features of drought stress resistant mechanisms in plants (Blum *et al*., 2007). However when the soil moisture content declines, traits related to leaf mainly green leaf number and total green leaf area could be affected seriously for drought susceptible plants. This is in agreement with the report of Metcalfe *et al*. (1990); expansion of leaves of the drought-treated plants was slower than that of well watered plants and eventually attained the same final area. The production of new leaves was also extremely sensitive to soil water availability and well watered plants produced new leaves at a steady rate, one new leaf pair emerging approximately every 8 days.

Mean TGLA (Total Green Leaf Area) per plant drastically decreased for accessions under soil moisture stress condition. For instance, Accession AAUFM- 49, 242622 and AAUFM - 32 collected from Tigray, Laelay adiyabo and Htsay (Tigray) respectively, showed the lowest TGLA, which resulted in lower yield and agronomic performance. In agreement with the result of this study, reduction in TGLA has been reported for many plant species (Zhang *et al*., 2004; Farooq *et al*., 2009). However, the response varies depending on genotypes and intensity and duration of water stress (Li *et al*., 2008). Drought stress mostly reduced leaf growth and in turn the leaf areas in many species of plants such as Populus (Wullschleger *et al*., 2005), and rice (Farooq *et al*., 2009). In this study, the impact of drought stress on finger millet development was observed to vary from genotype to genotype. Similar report is also revealed by Sacks *et al*. (1997), the effect of water deficit on the development and growth of the leaves varies from species to species. Leaf growth was more sensitive to water stress in wheat than in maize (Sacks *et al*., 1997).

According to Sah and Zamora (2005), water stress influences the height and leaf area per plant, which ultimately influences the shoot dry matter of the plants. When drought is induced, there is a drastic decreasing of relative water content, leaf area, and the percentage of rolling of the leaf, in contrast increasing root: shoot ration tends to increase (Terzi and Kadioglu, 2006). Inhibition of leaf production and decline in leaf area, leads to retarded leaf growth and light interception, which resulted in reduced canopy photosynthesis. Drought stress affects both cell division and enlargement, though cell division appears to be less sensitive to water deficit than cell enlargement (Bouman and Tuong, 2000).

### 5.2. Physiological measurements of finger millet genotype in response to moisture stress

One of the effects of drought stress has been attributed to the destruction of chlorophyll pigments and the instability of the pigment followed by leaf abscission (Levit, 1980). The same observation was made in this study on susceptible genotypes of finger millet, however there were some accessions maintaining the green leaves longer than their counterparts (Appendix 11). Those accession with the highest CCI records (AAUFM-14, AAUFM-44 and AAUFM-24) exhibited the highest relative water content, highest number of green leaf area, the highest yield per head and the highest root shoot ratio. This could happen because of complementary function among the above listed traits. For example the highest root shoot ratio will contribute to the absorption of more water from the deepest part of the soil to the above ground part of the plant, in addition to the highest value of relative water content, the highest records of green leaf number may contribute to the production of the highest yield per head in these accessions. On the other hand accession with the lowest CCI records such as accessions 215982, 216046 and AAUFM-26 (Appendix 4) had the lowest ear numbers, plant height, yield per head, green leaf area, relative water content, the lowest root shoot ratio and yield per head. The lowest chlorophyll content (CCI reading value was recorded in accessions which were susceptible to drought (Appendix 7). Similar result were reported for eggplant by Kirnak *et al*. (2001), that water stress resulted in significant decreases in chlorophyll content and the leaf relative water content of eggplant and .the total chlorophyll content in highly water stress condition was reduced by 55% compared to the control.

Chlorophyll loss was associated to environmental stress and the variation in total chlorophyll carotenoids ratio may be a good indicator of stress in plants (Hendry and Price, 1993). Accessions which are affected by water deficit at the vegetative stage (Fig. 8A) had the lowest CCI reading than their counter parts. This was evidenced in finger millet accession 242111, 242120 and 242132 collected from Bure (Gondar), Laelay Adiyabo (Tigray) and Kemkem (Gonder), respectively. According to Mafakheri *et al*. (2010); drought stress imposed at the vegetative stage, significantly decreased chlorophyll *a* content, chlorophyll *b* content and total chlorophyll content at the vegetative and flowering stages, whereas drought stress imposed at anthesis also influenced these contents at flowering stage.

Accessions such as 235782, AAUFM-44, AAUFM-19 and AAUFM-6 obtained from north Gondar and east Tigray had the highest relative water content; this could be due to the highest root: shoot ratio so that the plants were able to absorb more water from the deepest part of the soil and replace the water lost from the leaf by transpiration. Leaf water content is a useful indicator of plant water balance, since it expresses the relative amount of water present on the plant tissues (Pirdashti *et al*., 2009). According to Kyparissis *et al*. (1995); relative water content could decrease as the extent of water stress becomes more severe.

Leaf relative water contents in plant genotype which are resistant to drought is higher than their counterparts. Increasing in relative water contents in plant under drought stress may depend on plant vigorous nature to drought which could be related to higher ratio of root to shoot (Hassanzadh *et al*., 2009).

According to Pastori and Trippi (1992), higher relative water content (RWC) has been reported to play a role in the stress tolerance of maize. In our study, accessions 242135, 215990 and 225892 which were collected from Amhara region were susceptible to drought with the lowest value in RWC. Similarly, Siddique *et al*. (2001) reported that wheat leaves subjected to drought condition were exhibited large reductions in RWC. Also exposure of plants to drought stress substantially decreased the leaf water potential, and transpiration rate, with a concomitant increase in leaf temperature (Siddique *et al*., 2001).

A decrease in the relative water content (RWC) in response to drought stress has also been noted in wheat as reported by (Moaveni, 2011), that when leaves were subjected to drought, leaves exhibited large reductions in RWC and water potential.

According to Anjum *et al.* (2011), Plant water relations are affected by reduced availability of water, stomatal opening and closing is more strongly affected. Moreover, change in leaf temperature may be an important factor in controlling leaf water status under drought stress condition.

### 5.3. Biomass and root related traits of finger millet in response to drought

The present study has shown the effect of water stress on the tillering capacity of finger millet accessions under relatively the same soil moisture level. Accessions AAUFM-1, AAUFM-20 and 210103 were observed to show the highest number of tillers 23.3, 22.3 and 21.2, respectively as shown on Table. 7. The highest numbers of productive tiller were recorded for AAUFM-20, 230103, AAUFM-17 and AAUFM-18. However, the number of productive tillers was highly affected by soil moisture content. Accessions susceptible to water deficit (Fig. 8A) had the lowest records of productive tillers, while other perform well at more or less similar soil moisture content. In the study conducted by Davidson & Chevalier (1987), tiller development was quickly reduced when soil water potential decreased and resulted in lower biomass and yield. An extensive tiller production is an important component for the production of high yield (Blum, 2005).

This study showed that, drought stress reduced the number of productive tillers and lowered the amount of grain yield per plant. During leaf development, drought reduced the number of fertile tillers, and the number of spiklets on each spikes. This could happened as a result of lower anthesis at heading stage as a cumulative effect the total seed yield is reduced dramatically (Dubetz and Bole, 1972). Bouman and Tuong, (2000) also reported similar result on rice in Philippines, whereby a reduction in tiller numbers, spikelets, and number of grains per panicle was observed under moisture stress condition (Bouman, and Tuong, 2000). Drought stress was reported to reduce dry matters production of balm, area of the leaf, plant height and tiller number (Aliabadi *et al*., 2009).

The results of the present study showed; accession 238325, AAUFM-41, AAUFM-53 and 216046 maintained the green leaves for long period while the soil moisture content declined and accessions like AAUFM-38 senesced. On the other hand this accession had the highest root biomass production (Fig. 5), as compared to other accessions. This is one of the adaptation mechanisms exhibited by tolerant crop varieties in the case of drought stress and the higher root biomass production could also help to absorb water from the deepest part of the soil and replace the water lost in the form of transpiration. However, according to Blum (2005), shoot/root dry matter ratio increases under drought stress, not because of an increase in root mass but due to a relatively greater decrease in shoot mass.

A prolific root system can confer the advantage to support accelerated plant growth during the early crop growth stage and extract water from shallow soil layers that is otherwise easily lost by evaporation in legumes. Increased root growth due to water stress was reported in sunflower. Whereas, diminished biomass due to water stress was observed in almost all genotypes of sunflower (Tahir and Mehid, 2001). Plant productivity under drought stress is strongly related to the processes of dry matter partitioning and temporal biomass distribution (Kage *et al*., 2004), which resulted in reduction in fresh and dry biomass production (Farooq *et al*., 2009).

Developing deep roots for high yield potential can be considered as important trait to select cultivars for higher yield (Blum, 2005). Similar observation also made by Bouman and Toung (2000), on rice whereby drought stress affects plant height and production of the above ground biomass. Roots are the only sources to acquire water from soil, the root growth, its density, biomass production, proliferation and length are the major response of plant to lower moisture content in the soil (Salem, 2003). Production of ramified root system under drought is an important trait for improved above ground dry mass plant species or varieties.

The development of root system increases the water uptake and maintains requisite osmotic pressure through higher proline levels in *Phoenix dactylifera* (Djibril *et al*., 2005). However, the growth response of root to drought is not similar in all plant species. For example, the root growth in maize and wheat under water deficit condition was not significant (Sacks *et al*., 1997). Mild water stress affected the shoot dry weight, while shoot dry weight was greater than root dry weight loss under severe stress in sugar beet genotypes (Mohammadian *et al*., 2005).

According to Jaleel *et al*. (2009), a branched root system has been implicated in the drought tolerance and high biomass production primarily due to its ability to extract more water from soil. Huang and Fry (1998), also showed the importance of root: shoot dry weight ratio as physiological response of plant to drought. The root: shoot ratio increased during drought, reaching 0.83 in the control plants and 2.67 in drought exposed plants in *Ctenanthe setosa* (Terzi and Kadioglu, 2006). Moreover, water stressed sorghum showed larger root/shoot ratio and root length as opposed to the control (Xu and Bland, 1993).

The data in this study also showed an increasing trend of root: shoot ration for drought tolerant accessions. Similar results were also reported by Huang and Fry (1998) and Wu and Cosgrove (2000) on Maize and fescue cultivar, which indicate that, the root: shoot dry matter increase when drought stress develops. There was a report also from Mathews *et al*. (1990) that drought resistant sorghum varieties were able to maintain higher water status by increasing their root: shoot ration as the drought stress got severe.

**5.4. Yield and yield components of finger millet genotypes under drought condition**

Yield is the sum total of the grain from the main plant and the tillers as well and hence, the number of productive tillers directly correlates with seed yield. Accessions 238299, 238325, AAUFM-2, AAUFM-30 had the highest yield per head and per plant in the present study. Moreover, these accessions had moderate to high number of productive tillers, seed weight per head, relative water content, CCI reading, the size of ears and the number of the aggregated nature of the spikelet in the panicle.

Accessions 242120, 242432 and 242111, collected from north western, Amhara Region were observed to be more susceptible to drought. These accessions performed very well and were able to produce several tillers like their counter parts when the soil moisture content was 32%. When the soil moisture content declined to 18% and the crop started to wilt, and the number of productive tillers counted from this accessions was the lowest from the others. When the soil water status drops to 7% the plants started to dry.
The later performed better mainly due to high root: shoot ration, high record of relative water content, total green leaf area and the highest number of fingers which might contribute for the production high yield. Similar results were obtained in sorghum and sunflower by Stone *et al*. (2001). When sunflowers faced water deficit during the early vegetative phase, it caused stimulation of deeper root system and this helped the crop to produce considerable yields in arid areas. On the other hand, some evidence has indicated

that water stress causes considerable decrease in yield and soil content of sun flower (Mostajeran and Rahimi, 2009).

Among the different abiotic factors affecting the productivity of crops, drought and high temperature are considered as key stress factors on crop yield (Fabian *et al*., 2008; Mafakheri *et al*., 2010; Jalee *et al*., 2009). According to Blum (2005), yield under water limited conditions can be determined by the genetic factors controlling yield potential, and/or drought resistance, and/or water use efficiency (WUE) efficiency of the plant. Keyvan (2010), also observed similar trend on wheat in Iran and drought is considered as the most important limiting factor that reduces of the yield of wheat. It is known that drought can affects chlorophyll content, inhibits root growth, dry matter production and severely reduces the yield and yield components of crops (Jalee *et al*., 2009; Pirdashti *et al*., 2009).

Crop plants are frequently subjected to water stress during the course of their lifetimes. However, certain stages, such as germination, seedling growth, crown root development and flowering are the most critical and sensitive stage for water stress damages (Bibi *et al*., 2010; Nouri *et al*., 2011). Water stress during the flowering and grain filling periods reduced seed yield and seed weight and accelerated maturity of dry bean (Singh, 1995).
According to Bouman and Tuong (2000), it was indicated that lowland rice field experiments showed that yields are consistently reduced with increased duration of drought. Moreover, drought stress decreased yield and root length of barley (Khalvati *et al*., 2005) and similar result was observed on rice in Iran by (Pirdashti *et al*., 2009).

Insufficient rainfall can reduce the corn reproductive stage which resulted in significant reduction in grain yields (Liu and Wiatrak, 2011) and 28.05% yield reduction was also recorded in barley (Vaezi *et al*., 2010).

Generally, drought stress reduces the yield to such an extent that it is likely to depend on stress duration and phenological stage with more susceptible at reproductive stage than vegetative stage. This is also observed in this experiment whereby accessions without yield (wilted accessions) were seriously affected during anthesis.

**5.5. Patterns of Finger millet diversity in response to drought**

The 96 accessions evaluated in this experiment showed different pattern under drought condition. Accession collected from the same area showed different response to drought stress. The two accessions, 230103 and 230109 originally collected from Eritrea at an altitude of 1700 and 1800 m a.s.l respectively interestingly tolerated drought with the measured traits like dry root weight (DRW), root to shoot ratio, grain yield per plant (GYPP) and CCI readings. However, these accessions had the lowest recording of morphological measurements like green leaf number (4.3 and 2.5) and green leaf area (12.3 $cm^2$ and 18.9 $cm^2$) compared with accessions AAUFM-36 and AAUFM-19 obtained from Tigray that had green leaf area of 542.1 $cm^2$ and 528.6 $cm^2$, respectively. High dry root biomass production collected from Eritrea may contribute for the plant to absorb more water from the deepest part of the soil and replace the water lost from the plant body in the form of transpiration. Similarly, Polania *et al*. (2010) reported that drought resistance on *Canavalia* plant under low soil moisture condition was associated with deep rooting system and explores greater volume of soil to absorb more water. According to Werner *et al*. (2010), the size and the architecture of the root system determine the plantõs ability to access water and nutrients in Tobacco Plants. The lowest recording of RWC was observed for AAUFM-23 and 230109 with 72% and 57%, respectively. However accessions namely 215985 collected from *Alefa* (Gondar) and AAUFM-6 taken from Tigray having the highest recording RWC with 100% and 96%, respectively. This report is in agreement with Ashinie Bogale *et al*. (2011) whereby RWC of the leaves in durum wheat was decreased by 36.7% in moisture stress condition relative to the well-watered treatment. Generally, accessions collected from northern part of Ethiopia and Eritrea tend to show some tendency of moisture stress tolerance, while accessions from western and north western part wilted in response to severe drought.

## 6. CONCLUSION AND RECOMMENDATION

The present study indicated the existence of variability among accessions collected from different localities in terms of their reaction to moisture stress. Several accessions were observed to show moderate to high levels of tolerance against limited moisture. There were also accessions observed to be very susceptible to drought stress that wilted before heading. The following finger millet accessions are selected due to their drought stress re sistance potential. AAUFM-7, AAUFM-2, AAUFM-44, AAUFM-30, AAUFM-43, TADESSE, AAUFM-10, AAUFM-42, AAUFM-50, AAUFM-19,AAUFM-30, 230103, AAUFM-21, AAUFM-24, AAUFM-23, AAUFM-39, 215965, 238325, 238299, 230109, 241618, AAUFM-20, AAUFM-36. The above accessions were selected for the drought tolerance based on the combined morphological (number of productive tillers, total green leaf area, number and size of fingers, physiological (Relative water content and CCI reading) and yield related measurements (yield per head and yield per plant in gram).

Cluster analysis of all the 96 accessions resulted in six distinct groups. Out of the total, 23 accessions selected and promoted for their good performance against drought, 11 of belongs to cluster 1 whereby nine accessions were obtained from Tigray, one from Eritrea (230109) and the released variety Tadesse. Three more selected accessions from Tigray (AAUFM-44, 238299, AAUFM-29) belong to cluster 2, while three accessions from Tigray are grouped in cluster 3. The rest of the selected accessions are grouped in cluster 4 and 6, and most of them are from Tigray and Eritrea. Overall, this study showed the presence of higher variability among genotypes in response to drought, and also indicates the higher drought performance of germplasm collected from northern Ethiopia.

Hence, to improve finger millet productivity in drought areas, breeders should target germplasm collected from northern part of Ethiopia and Eritrea for initial screening.

For the next field evaluation on finger millet related to drought stress tolerant performance, the following recommendations are forwarded.

i. Measuring intensive physiological measurements like water use efficiency,

ii. Photosynthetic performance and biochemical analysis for example the concentration of proline would give a clue.

iii. Weekly measurement of green leaf number and green leaf area would also provide idea to estimate rate of senescence.

iv. Another important parameter for drought stress tolerant is identifying accessions having staygreen property. In this study, two accessions (215965, AAUFM-37) showed some tendency of staygreen property but this should be confirmed in the future study.

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## APPENDICES

Appendix 1. Finger millet accession and their passport data

| Accession No. | Genus name | Region province | Zone | Woreda District | Latitude | Longitude | Altitude | Locality | Remark |
|---|---|---|---|---|---|---|---|---|---|
| 230102 | *E. coracana* | | | | 14-33-00-N | 37-46-00-E | 1850 | *Gundet* | *Eritrea collection* |
| 230103 | *E. coracana* | | | | 14-33-00-N | 37-46-00-E | 1700 | *AilaGundet* | *Eritrea collection* |
| 238299 | *E. coracana* | Tigray | MEHAKE LEGNA W | WERIEL EHE | 13-04-00-N | 38-04-00-E | 1940 | Adi-Ha-Tsiro-EdagaArbi 24km from Adwa | |
| 208440 | *E. coracana* | Amhara | DEBUB GONDAR | FOGERA | 11-55-00-N | 37-22-00-E | 1850 | Zekana 3km away from Werota - Weldya junction to Debre Tabor | |
| 230106 | *E. coracana* | | | | 14-33-00-N | 37-46-00-E | 1800 | AilaGundet | Eritrea collection |
| 230107 | *E. coracana* | | | | 14-33-00-N | 37-46-00-E | 1800 | Adiquala | Eritrea collection |
| 230108 | *E. coracana* | | | | 14-32-00-N | 37-46-00-E | 1780 | Gundet | Eritrea collection |
| 230109 | *E. coracana* | | | | 14-32-00-N | 37-46-00-E | 1800 | AilaGundet | Eritrea collection |
| 230110 | *E. coracana* | | | | 14-33-00-N | 37-46-00-E | 1700 | AilaGundet | Eritrea collection |
| 242120 | *E. coracana* | Amhara | DEBUB GONDAR | DERA | 11-49-00-N | 37-36-00-E | 1805 | 16 Km N of Hamuset town the road to Gonder town | |
| 242132 | *E. coracana* | Amhara | DEBUB GONDAR | KEMEKE M | 12-03-00-N | 38-00-00-E | 1910 | 16 Km S of ebinat town the way to AdisZemen town | |
| 242133 | *E. coracana* | Amhara | DEBUB GONDAR | FOGERA | 12-01-00-N | 37-43-00-E | 1825 | 25 Km S.E of AdisZemen town the way Debre tabor town | |
| 242135 | *E. coracana* | Amhara | SEMEN WELLO | GUBA LAFTO | 11-50-00-N | 39-35-00-E | 1910 | Mechare about 6 Km S.E of Woldiya town of the main road | |
| 100002 | *E. coracana* | Amhara | SEMEN GONDAR | GONDAR ZURIA | 12-33-00-N | 37-24-00-E | 2004 | Kebezi 3km. from Azezo on the way to shiloa | |
| 242620 | *E. coracana* | MIRABA WI | LAELAY ADIYABO | | 14-38-48N | E | 1770 | AdiDairo | |

| Accession No. | Genus name | Region province | Zone | Woreda District | Latitude | Longitude | Altitude | Locality | Remark |
|---|---|---|---|---|---|---|---|---|---|
| 215982 | *E. coracana* | Amhara | SEMEN GONDAR | DEMBIA | 12-17-00-N | 37-7 -00-E | 1850 | BichigneCa 12Km from Chuahit on the way to Delgila | |
| 242111 | *E. coracana* | Amhara | MIRAB GOJAM | BURE WEMBER MA | 10-39-00-N | 36-56-00-E | 2100 | 1 Km S.W of Shindi 17 Km S.Wof Bure town | |
| 215985 | *E. coracana* | Amhara | SEMEN GONDAR | ALEFA | 12-17-00-N | 37-4 -00-E | 1940 | SerataCa 16Km away from Delgi on the way to Aykel | |
| 215989 | *E. coracana* | Amhara | SEMEN GONDAR | GONDAR ZURIA | 11-55-00-N | 37-35-00-E | 2000 | SihordebreKidusCa 55 Km on GonderWoreta Rd. | |
| 215990 | *E. coracana* | Amhara | SEMEN GONDAR | GONDAR ZURIA | 11-50-00-N | 37-32-00-E | 1910 | InchayGebrilCa 68 km away from Gonder to Woreta Rd. | |
| 225892 | *E. coracana* | Amhara | SEMEN GONDAR | DEMBIA | 12-31-00-N | 37-19-00-E | 1710 | AmanuellWuduno 40km, GonderAykel road | |
| 235140 | *E. coracana* | Amhara | SEMEN GONDAR | GONDAR ZURIA | 36-30-00-N | 37-05-00-E | 1950 | 2km From Gonder-Addis-Abeba | |
| 235782 | *E. coracana* | Amhara | SEMEN GONDAR | ALEFA | 12-02-00-N | 45-11-00-E | 1860 | Dengelber 25km.from AlefaShawera on the way to Alefa | |
| 235783 | *E. coracana* | Amhara | SEMEN GONDAR | ALEFA | 12-01-0 -N | 45-12-00-E | 2000 | Ambarrgge 15km. Alefa - Delgge on the way to AlefaTakussa | |
| 215851 | *E. coracana* | Amhara | BAHIR DAR SPECIAL | BAHIR DAR | 11-32-00-N | 34-26-00-E | 1800 | NegdaCa 8 Km away from Bahir Dar on the way to Tissabay | |
| 243639 | *E. coracana* | Amhara | AGEW AWI | DANGEL A | | | 2070 | 9.6 Km from Dangla to Jisakebele | |
| 235145 | *E. coracana* | Tigray | MEHAKE LEGNAW | KOLA TEMBEN | 13-53-00-N | 39-58-00-E | 1730 | KeyeheTekleGeskegmdasley | |
| 234199 | *E. coracana* | Tigray | MIRABA WI | TAHTAY KORARO | 14-04-00-N | 38-17-00-E | 1920 | 8km. from Indaslase to Axum | |
| 237465 | *E. coracana* | Tigray | MIRABA WI | MEDEBA Y ZANA | 14-00-00-N | 38-00-00-E | 1960 | Seleleka, 5km. shire - asfidale | |
| AAUFM-44 | *E. coracana* | Tigray | MISRAK | AFESHK UM | | | | DEBRE MIHRET | |
| AAUFM-14 | *E. coracana* | Tigray | ADWA | MEREB | | | | DARO TEKSI | |
| 237475 | *E. coracana* | Tigray | MIRABA WI | LAELAY ADIYABO | 14-00-00-N | 38-00-00-E | 1750 | Adinebried 55km. Indaslase to sheraro | |
| 234194 | *E. coracana* | Tigray | MIRABA WI | TAHTAY ADIYAB | 14-21-00-N | 38-07-00-E | 1840 | Adiabo 7km. from Adidaro | |
| AAUFM-14 | *E. coracana* | | ADWA | MEREB | | | | DARO TEKSI | |

| Accession No. | Genus name | Region province | Zone | Woreda District | Latitude | Longitude | Altitude | Locality | Remark |
|---|---|---|---|---|---|---|---|---|---|
| 242616 | *E. coracana* | Tigray | MEHAKE LEGNAW | ADWA | 14-37-96-N | 38-79-81-E | 1400 | 35 Km from Adwa to Rama | |
| 242617 | *E. coracana* | Tigray | MEHAKE LEGNAW | WERIE LEHE | 14-38-03-N | 38-79-09-E | 1700 | 9 Km Adwa to My Kinetal old RD. E. qadua | |
| 242618 | *E. coracana* | Tigray | MEHAKE LEGNAW | FERESMA Y | 14-36-07-N | 38-79-93-E | 1950 | 30 Km from S.W Adwa to Feresmay | |
| AAUFM-29 | *E. coracana* | | | | | | | | |
| 242622 | *E. coracana* | Tigray | MIRABA WI | LAELAY ADIYABO | 14-38-26-N | 38-17-50-E | 1720 | 27 Km from S.E Shere on the way to Adarro | |
| AAUFM-7 | *E. coracana* | | | | | | | | |
| 242624 | *E. coracana* | Tigray | MIRABA WI | ASEGEDE TSIMBEL A | 13-77-07-N | 38-20-07-E | 1400 | 20 Km Endabaguna to Tekeze River | |
| 230105 | *E. coracana* | | | | 14-32-00-N | 37-47-00-E | 1600 | New Endagiorgis | Eritrea collection |
| 238300 | *E. coracana* | Tigray | MEHAKE LEGNAW | WERIELE HE | 14-04-00-N | 38-04-00-E | 1980 | LakenalAdihtsero 30km away from Adwa to Edagaarbi road | |
| AAUFM-26 | *E. coracana* | Tigray | MEDABY IZA | ADEMAE L | 14-05-47.24N | 38-26-17.94E | 2012 | 20 KM TO SHIRE FROM AXUM | |
| 238305 | *E. coracana* | Tigray | MEHAKE LEGNAW | ENTICHO | 14-02-00-N | 38-04-00-E | 1990 | Feres May 16km from Gendepta to Feres May | |
| AAUFM-28 | *E. coracana* | | | | | | | | |
| 238310 | *E. coracana* | Tigray | MEHAKE LEGNAW | MEREB LEHE | 14-02-00-N | 38-04-00-E | 1950 | 25km from Ahsa'ae | |
| 238325 | *E. coracana* | Tigray | MIRABA WI | MEDEBA Y ZANA | 14-05-00-N | 39-06-00-E | 1990 | Akatsine 30km Axum to Shire | |
| 238327 | *E. coracana* | Tigray | MIRABA WI | MEDEBA Y ZANA | 14-05-00-N | 38-04-00-E | 1900 | Debrekerbe 27km from Selekleka | |
| AAUFM-20 | *E. coracana* | Tigray | SOLODA | | | | | MASHINA ABOUT 12 KM | collection |
| BONEYA | *E. coracana* | | | | | | | | |
| AAUFM-36 | *E. coracana* | Tigray | | | 14-06-42.6E | 38-08-13.1E | 1568 | | |
| AAUFM-19 | *E. coracana* | C/Tigray | | Adwa | | | | | |
| AAUFM-23 | *E. coracana* | Tigray | | | | | | | |
| AAUFM-33 | *E. coracana* | Tigray | | | | | | 34 km from shire to shiraro | |
| AAUFM-11 | *E. coracana* | C/Tigray | GOBEZAY E | MEREB | 14-20-06.2N | 38-48-26.5E | 1502 | 25KM TO GOBEZAYE | |

| Accession No. | Genus name | Region province | Zone | Woreda District | Latitude | Longitude | Altitude | Locality | Remark |
|---|---|---|---|---|---|---|---|---|---|
| AAUFM-10 | *E. coracana* | Tigray | LAHENAYE | ROBA GEREDE | | | | B/N TEMBIEN ANDADWA 59 KM TO ADWA | |
| AAUFM-41 | *E. coracana* | Tigray | NEGUADIT | | 13-59-00.5N | 38-11-30.6E | 1793 | | |
| AAUFM-6 | *E. coracana* | Tigray | | | | | | | |
| AAUFM-21 | *E. coracana* | Tigray | | | 14-07-12.7N | 38-37-20.0E | 2142 | | |
| AAUFM-42 | *E. coracana* | Tigray | | ANANAMBA | | | | ADIBARAY | |
| AAUFM-8 | *E. coracana* | Tigray | | MAYQEN TELAY | 13-59-6.7E | 38-58-39.5E | 1812 | B/TEMBIEN & ADWA 55 KM TO ADWA | |
| AAUFM-32 | *E. coracana* | Tigray | | HTSAYA | | | | | |
| AAUFM-15 | *E. coracana* | Tigray | | | | | 1666 | | |
| AAUFM-35 | *E. coracana* | Tigray | | | 14-06-42.6N | 38-08-13.1E | 1568 | | |
| AAUFM-25 | *E. coracana* | Tigray | | | 14-06-55.8N | 38-29-14.1E | 2021 | B/N Axum and Shire 30km to shire | |
| AAUFM-22 | *E. coracana* | Tigray | | | | | | | |
| AAUFM-24 | *E. coracana* | Tigray | | | | | | Axum | |
| AAUFM-43 | *E. coracana* | Tigray | ADIABO | | 14-19-12.8N | 39-13-28.2E | 2058 | 50KM from Sero Town | Collection |
| AAUFM-46 | *E. coracana* | Tigray | | | | | | | |
| AAUFM-17 | *E. coracana* | C/Tigray | | WODI HAZA | | | 1811 | 15 KM form Adwa to Rama | |
| AAUFM-2 | *E. coracana* | Tigray | KOLLA TEMBIEN | | 13-41-25.6N | 39-01-09.7E | 1896 | | |
| AAUFM-4 | *E. coracana* | Tigray | KOLLA TEMBIEN | | 13-41-25.6N | 39-01-09.7E | 1896 | | |
| 234159 | *E. coracana* | Tigray | ADWA | 14-17-00-N | 38-51-00-E | 2100 | Adi-Berak | | |
| AAUFM-30 | *E. coracana* | Tigray | | | 14-06-29.1N | 37-59-32.3E | 1090 | | |
| AAUFM-31 | *E. coracana* | Tigray | West Aagedom | Tsmblal | | | | htsatsya | |
| AAUFM-37 | *E. coracana* | Tigray | | Mererb Distance | | | | WodiHazo | |
| AAUFM-18 | *E. coracana* | Tigray | | | 14-17-33.4N | 38-49-33.8E | 1811 | | |

| Accession No. | Genus name | Region province | Zone | Woreda District | Latitude | Longitude | Altitude | Locality | Remark |
|---|---|---|---|---|---|---|---|---|---|
| AAUFM-45 | *E. coracana* | Tigray | | | | | | | |
| AAUFM-47 | *E. coracana* | Tigray | | | | | | | |
| AAUFM-9 | *E. coracana* | Tigray | Central Tigray | WorAyleh e | | | | RobaGerede | |
| AAUFM-48 | *E. coracana* | Tigray | | | 12-31-07.2N | 39-04-37.4E | 2128 | 70 km form SekitaKebele 02 Tina | |
| 237476 | *E. coracana* | Tigray | MIRABA WI | Tahtaykora ro | 14-00-00-N | 38-00-00-E | 1870 | 13k. from shire to Gonder | |
| 238334 | *E. coracana* | MIRABA WI | TAHTAY ADIYABO | 14-06-00-N | 38-09-00-E | 1100 | Shera ro | | |
| 215965 | *E. coracana* | Amhara | DEBUB GONDAR | FOGERA | 11-46-00-N | 37-33-00-E | 1880 | Jigina 39Km on Bahi Dar Werota Road. | |
| AAUFM-38 | *E. coracana* | Tigray | MIRABA WI | AsgedeTs mblal | 13-52-00.2N | 38-10-46.4E | 1600 | 34 km form Shire to Gonder side | |
| 234158 | *E. coracana* | Tigray | MEHAKE LEGNAW | MEREB LEHE | 14-25-00-N | 38-47-00-E | 1360 | Mereb 5km. from Mereb to Asmara | |
| AAUFM-16 | *E. coracana* | | ADWA | MEREB | 14-18-09N | 38-49-03.4E | 1666 | | |
| AAUFM-49 | *E. coracana* | | | | | | | | |
| AAUFM-5 | *E. coracana* | Tigray | KOLLA TEMBIEN | | 13-41-25.6N | 39-01-09.7E | 1896 | | |
| TADSEESE | *E. coracana* | | | | | | | | |
| AAUFM-50 | *E. coracana* | | | | | | | | |
| AAUFM-40 | *E. coracana* | Tigray | LEMLEM | ASGEDE TSMBLAL | 13-59-00.5N | 38-11-30.6E | 1793 | NEGODIT | |
| 216046 | *E. coracana* | Oromiya | MIRAB WELLEG A | NEJO | 09-40-00-N | 35-17-00-E | 1680 | Kiltncommittica 34km on NejoMendi Rd past Goro town | |
| AAUFM-39 | *E. coracana* | Tigray | | | 13-52-00.2N | 38-10-46.4E | 1660 | 34 km form Shire to Gonder Side | |

Appendix 2. Shows date of sowing, date of germination and maturation of finger millet at Dera Sub site of Kulumsa Agricultural research center

| Accession No. | Date of sowing | Date Germination | Date of Flowering | Date of Maturation |
|---|---|---|---|---|
| 230102 | 10-7-2011 | 20-07-2011 | 23-10-2011 | 24-11-2011 |
| 230103 | 10-7-2011 | 28-07-2011 | 23-10-2011 | 24-11-2011 |
| 238299 | 10-7-2011 | 19-07-2011 | 23-10-2011 | 24-11-2011 |
| 208440 | 10-7-2011 | 22-07-2011 | 23-10-2011 | 25-12-2011 |
| 230106 | 10-7-2011 | 20-07-2011 | 24-10-2011 | 24-11-2011 |
| 230107 | 10-7-2011 | 20-07-2011 | 23-10-2011 | 30-11-2011 |
| 230108 | 10-7-2011 | 21-07-2011 | 23-10-2011 | 24-11-2011 |
| 230109 | 10-7-2011 | 20-07-2011 | 23-10-2011 | 24-11-2012 |
| 230110 | 10-7-2011 | 21-07-2011 | 24-10-2011 | 24-11-2011 |
| 242120 | 10-7-2011 | 23-07-2011 | 24-10-2011 | 1-01-2011 |
| 242132 | 10-7-2011 | 22-07-2011 | 27-10-2011 | 30-11-2011 |
| 242133 | 10-7-2011 | 23-07-2011 | 2910-2011 | 30-11-2011 |
| 242135 | 10-7-2011 | 23-07-2011 | 23-10-2011 | 5-12-211 |
| 100002 | 10-7-2011 | 24-07-2011 | 30-10-2011 | 1-1-2012 |
| 242620 | 10-7-2011 | 25-07-2011 | 23-10-2011 | 24-11-2011 |
| 215982 | 10-7-2011 | 24-07-2011 | Dead | Dead |
| 242111 | 10-7-2011 | 23-07-2011 | Dead | Dead |
| 215985 | 10-7-2011 | 25-07-201 | Dead | Dead |
| 215989 | 10-7-2011 | 25-07-2011 | Dead | Dead |
| 215990 | 10-7-2011 | 26-07-2011 | Dead | Dead |
| 225892 | 10-7-2011 | 24-07-2011 | Dead | Dead |
| 235140 | 10-7-2011 | 26-07-2011 | Dead | Dead |
| 235782 | 10-7-2011 | 26-07-2011 | Dead | Dead |
| 235783 | 10-7-2011 | 22-07-2011 | | 30-11-2011 |
| 215851 | 10-7-2011 | 25-07-2011 | | 30-11-2011 |
| 243639 | 10-7-2011 | 24-07-2011 | Dead | Dead |
| 235145 | 10-7-2011 | 25-07-2011 | 27-10-2011 | 24-11-2011 |
| 234199 | 10-7-2011 | 22-07-2011 | 2910-2011 | 24-11-2011 |
| 237465 | 10-7-2011 | 23-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-44 | 10-7-2011 | 28-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-14 | 10-7-2011 | 28-07-2011 | 23-10-2011 | 24-11-2011 |
| 237475 | 10-7-2011 | 25-07-2011 | 23-10-2011 | 24-11-2011 |
| 234194 | 10-7-2011 | 24-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-14 | 10-7-2011 | 25-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUUFM-14 | 10-7-2011 | 25-07-2011 | 23-10-2011 | 24-11-2011 |
| 242616 | 10-7-2011 | 24-07-1011 | 23-10-2011 | 24-11-2011 |
| 242617 | 10-7-2011 | 25-07-1011 | 23-10-2011 | 24-11-2011 |
| 242618 | 10-7-2011 | 24-07-1011 | 23-10-2011 | 24-11-2011 |
| AAUFM-29 | 10-7-2011 | 27-07-1011 | 23-10-2011 | 30-11-2011 |

| Accession No. | Date of sowing | Date Germination | Date of Flowering | Date of Maturation |
|---|---|---|---|---|
| 242622 | 10-7-2011 | 27-07-2011 | 23-10-2011 | 30-11-2011 |
| AAUFM-7 | 10-7-2011 | 23-07-2011 | 23-10-2011 | 30-11-2011 |
| 242624 | 10-7-2011 | 26-07-2011 | 23-10-2011 | 30-11-2011 |
| 230105 | 10-7-2011 | 18-07-2011 | 23-10-2011 | 24-11-2011 |
| 238300 | 10-7-2011 | 23-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-26 | 10-7-2011 | 24-07-2011 | 23-10-2011 | 30-11-2011 |
| 238305 | 10-7-2011 | 26-07-2011 | 30-10-2011 | 1/1/2012 |
| AAUFM-28 | 10-7-2011 | 23-07-2011 | 24-10-2011 | 24-11-2011 |
| 238310 | 10-7-2011 | 28-07-2011 | | Not known |
| 238325 | 10-7-2011 | 26-07-2011 | 23-10-2011 | 24-11-2011 |
| 238327 | 10-7-2011 | 27-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-20 | 10-7-2011 | 28-07-2011 | 23-10-2011 | 24-11-2011 |
| BONEYA | 10-7-2011 | 25-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-36 | 10-7-2011 | 29-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-19 | 10-7-2011 | 27-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-23 | 10-7-2011 | 25-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-33 | 10-7-2011 | 24-07-2011 | | Not known |
| AAUFM-11 | 10-7-2011 | 24-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-10 | 10-7-2011 | 25-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-41 | 10-7-2011 | 25-07-2011 | ------------- | -------- |
| AAUFM-6 | 10-7-2011 | 24-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-21 | 10-7-2011 | 25-07-2011 | 23-10-2011 | 24-11-2012 |
| AAUFM-42 | 10-7-2011 | 27-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-8 | 10-7-2011 | 24-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-32 | 10-7-2011 | 25-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-15 | 10-7-2011 | 27-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-35 | 10-7-2011 | 24-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-25 | 10-7-2011 | 27-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-22 | 10-7-2011 | 28-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-24 | 10-7-2011 | 27-07-2011 | 23-10-2011 | 30-11-2011 |
| AAUFM-43 | 10-7-2011 | 24-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-46 | 10-7-2011 | 28-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-17 | 10-7-2011 | 29-07-2011 | 23-10-2011 | 24-11-2011 |
| AAUFM-2 | 10-7-2011 | 26-07-2011 | 26-10-2011 | 30-11-2011 |
| AAUFM-4 | 10-7-2011 | 29-07-2011 | 26-10-2011 | 30-11-2011 |
| 234159 | 10-7-2011 | 28-07-2011 | 26-10-2011 | 30-11-2011 |
| AAUFM-30 | 10-7-2011 | 28-07-2011 | 26-10-2011 | ---------- |
| AAUFM-31 | 10-7-2011 | 29-07-2011 | ------- | 24-11-2011 |
| AAUFM-37 | 10-7-2011 | 28-07-2011 | 24-10-2011 | 24-11-2011 |
| AAUFM-18 | 10-7-2011 | 28-07-2011 | 26-10-2011 | 24-11-2011 |

| Accession No. | Date of sowing | Date Germination | Date of Flowering | Date of Maturation |
|---|---|---|---|---|
| AAUFM-45 | 10-7-2011 | 27-07-2011 | 25-10-2011 | 30-11-2011 |
| AAUFM-47 | 10-7-2011 | 27-07-2011 | 26-10-2011 | 30-11-2011 |
| AAUFM-9 | 10-7-2011 | 28-07-2011 | 25-10-2011 | 30-11-2011 |
| AAUFM-48 | 10-7-2011 | 27-07-2011 | 26-10-2011 | 24-11-2011 |
| 237476 | 10-7-2011 | 25-07-2011 | 30-10-2011 | 10/1/2012 |
| 238334 | 10-7-2011 | 26-07-2011 | 26-10-2011 | 30-11-201 |
| 215965 | 10-7-2011 | 25-07-2011 | ---------------- | -------------- |
| AAUFM-38 | 10-7-2011 | 29-07-2011 | 22-10-2011 | 24-11-2011 |
| 234158 | 10-7-2011 | 24-07-2011 | 22-10-2011 | 24-11-2011 |
| AAUFM-16 | 10-7-2011 | 26-07-2011 | 26-10-2011 | 30-11-2011 |
| COLL-009 | 10-7-2011 | 25-07-2011 | 26-10-2011 | 30-11-2011 |
| AAUFM-5 | 10-7-2011 | 26-07-2011 | 26-10-2011 | 10/1/2012 |
| TADSEESE | 10-7-2011 | 22-07-2011 | 26-10-2011 | 30-11-2011 |
| COLL-010 | 10-7-2011 | 28-07-2011 | 26-10-2011 | 30-11-2011 |
| AAUFM-40 | 10-7-2011 | 24-07-2011 | ------------- | ----------- |
| 216046 | 10-7-2011 | 23-07-2011 | 26-10-2011 | 30-11-2011 |
| AAUFM-39 | 10-7-2011 | 24-07-2011 | 26-10-2011 | 30-11-2011 |

Appendix 3. Mean agronomic character of Finger millet accessions

| Accession No. | PH | TN | PT | GLN | GLA | TGLA | EN | EL |
|---|---|---|---|---|---|---|---|---|
| 230102 | 81.5 | 18.3 | 16.9 | 4.0 | 13.6 | 54.4 | 8.4 | 8.4 |
| 230103 | 93.2 | 19.7 | 18.7 | 4.3 | 12.3 | 52.4 | 9.9 | 8.9 |
| 238299 | 82.3 | 13.7 | 11.0 | 6.5 | 21.4 | 139.3 | 10.1 | 8.1 |
| 208440 | 90.3 | 11.6 | 10.6 | 1.5 | 16.6 | 24.9 | 10.7 | 9.5 |
| 230106 | 99.4 | 13.1 | 11.6 | 4.0 | 17.3 | 69.1 | 9.9 | 9.0 |
| 230107 | 105.5 | 11.7 | 11.6 | 7.0 | 23.5 | 164.2 | 9.5 | 8.3 |
| 230108 | 95.7 | 12.8 | 12.8 | 4.8 | 22.0 | 105.4 | 10.3 | 8.8 |
| 230109 | 93.4 | 10.6 | 9.3 | 2.5 | 18.9 | 47.2 | 10.1 | 7.9 |
| 230110 | 97.3 | 11.7 | 11.1 | 7.3 | 30.0 | 219.7 | 9.6 | 8.7 |
| 242120 | 58.9 | 12.5 | 7.5 | 6.0 | 21.8 | 130.8 | 6.8 | 9.7 |
| 242132 | 81.0 | 17.3 | 13.8 | 10.2 | 18.7 | 190.3 | 10.4 | 8.3 |
| 242133 | 82.2 | 13.1 | 11.4 | 7.2 | 26.9 | 193.4 | 10.1 | 8.5 |
| 242135 | 67.9 | 8.8 | 5.6 | 5.0 | 22.2 | 110.8 | 11.4 | 9.8 |
| 100002 | 59.2 | 11.3 | 3.4 | 6.8 | 23.1 | 155.8 | 6.6 | 6.9 |
| 242620 | 73.2 | 18.3 | 13.6 | 1.3 | 23.8 | 31.7 | 9.8 | 8.7 |
| 215982 | 36.4 | 11.9 | 0.3 | 1.7 | 23.7 | 39.5 | 2.2 | 5.3 |

| Accession No. | PH | TN | PT | GLN | GLA | TGLA | EN | EL |
|---|---|---|---|---|---|---|---|---|
| 242111 | 57.9 | 14.8 | 4.9 | 1.5 | 22.4 | 33.7 | 5.7 | 6.1 |
| 215985 | 34.8 | 14.1 | 3.6 | 2.0 | 24.4 | 48.7 | 3.2 | 4.7 |
| 215989 | 61.0 | 20.1 | 6.5 | 5.5 | 28.8 | 158.5 | 10.0 | 9.5 |
| 215990 | 62.7 | 15.8 | 7.9 | 7.0 | 23.8 | 166.7 | 9.0 | 9.1 |
| 225892 | 68.4 | 19.2 | 12.3 | 1.5 | 22.0 | 33.0 | 11.3 | 9.8 |
| 235140 | 52.3 | 15.6 | 5.0 | 4.8 | 22.8 | 108.1 | 6.8 | 6.4 |
| 235782 | 67.3 | 11.6 | 6.3 | 4.5 | 25.5 | 114.5 | 9.2 | 11.8 |
| 235783 | 74.6 | 14.0 | 11.8 | 5.0 | 21.6 | 107.9 | 10.9 | 9.7 |
| 215851 | 73.8 | 16.2 | 13.0 | 10.8 | 27.9 | 300.3 | 10.7 | 9.5 |
| 243639 | 64.6 | 17.2 | 8.3 | 4.8 | 18.2 | 86.3 | 6.7 | 10.3 |
| 235145 | 70.9 | 13.8 | 11.5 | 3.5 | 18.1 | 63.3 | 11.1 | 9.0 |
| 234199 | 65.4 | 17.7 | 11.9 | 1.7 | 24.3 | 40.6 | 8.3 | 10.7 |
| 237465 | 71.9 | 15.9 | 11.2 | 7.6 | 26.7 | 202.8 | 10.6 | 8.9 |
| AAUFM-44 | 62.4 | 13.6 | 8.7 | 8.0 | 27.2 | 217.3 | 20.6 | 8.8 |
| AAUFM-14 | 65.1 | 13.5 | 14.2 | 2.0 | 24.1 | 48.3 | 10.5 | 14.3 |
| 237475 | 81.4 | 15.8 | 10.7 | 8.4 | 21.8 | 183.0 | 9.8 | 12.9 |
| 234194 | 78.1 | 12.1 | 9.7 | 1.8 | 20.8 | 36.4 | 9.9 | 13.6 |
| AAUFM-14 | 82.5 | 23.3 | 11.8 | 1.3 | 21.3 | 26.7 | 10.0 | 13.7 |
| AAUUFM-14 | 84.5 | 14.7 | 9.5 | 1.5 | 22.0 | 33.0 | 22.7 | 11.0 |
| 242616 | 80.6 | 12.8 | 10.0 | 2.3 | 20.9 | 47.0 | 10.7 | 12.2 |
| 242617 | 80.4 | 12.5 | 8.3 | 2.5 | 26.9 | 67.2 | 10.0 | 13.4 |
| 242618 | 78.5 | 16.3 | 10.6 | 7.6 | 32.3 | 245.2 | 10.0 | 9.5 |
| AAUFM-29 | 64.3 | 18.8 | 12.5 | 1.8 | 30.2 | 52.8 | 9.3 | 12.7 |
| 242622 | 55.6 | 12.5 | 7.9 | 1.0 | 22.0 | 22.0 | 9.4 | 8.3 |
| AAUFM-7 | 77.9 | 10.2 | 6.4 | 2.0 | 26.2 | 52.5 | 11.5 | 10.5 |
| 242624 | 76.6 | 16.5 | 15.3 | 3.5 | 19.2 | 67.2 | 10.4 | 8.3 |
| 230105 | 75.4 | 21.2 | 16.6 | 2.0 | 25.7 | 51.4 | 10.3 | 10.0 |
| 238300 | 76.0 | 19.1 | 10.6 | 8.2 | 25.0 | 204.7 | 10.6 | 12.6 |
| AAUFM-26 | 61.7 | 12.7 | 5.6 | 7.0 | 18.1 | 127.0 | 5.8 | 8.4 |
| 238305 | 68.0 | 14.3 | 9.2 | 3.7 | 20.8 | 76.4 | 10.2 | 11.0 |
| AAUFM-28 | 56.4 | 15.4 | 5.5 | 4.8 | 20.7 | 99.5 | 7.2 | 11.4 |
| 238310 | 85.9 | 16.7 | 12.9 | 5.6 | 36.5 | 204.2 | 10.9 | 13.1 |
| 238325 | 56.7 | 7.6 | 5.6 | 2.0 | 28.8 | 57.6 | 8.6 | 6.9 |
| 238327 | 66.3 | 13.6 | 10.9 | 2.5 | 25.5 | 63.8 | 9.1 | 9.6 |
| AAUFM-20 | 85.1 | 22.3 | 18.9 | 4.0 | 24.0 | 96.2 | 11.9 | 9.7 |
| BONEYA | 75.5 | 10.4 | 8.2 | 6.5 | 25.6 | 166.6 | 8.7 | 10.6 |
| AAUFM-36 | 71.1 | 16.3 | 12.6 | 4.3 | 125.1 | 542.1 | 7.9 | 7.7 |

| Accession No. | PH | TN | PT | GLN | GLA | TGLA | EN | EL |
|---|---|---|---|---|---|---|---|---|
| AAUFM-19 | 80.7 | 18.3 | 13.4 | 3.7 | 144.2 | 528.6 | 9.2 | 7.8 |
| AAUFM-23 | 67.5 | 16.5 | 14.0 | 2.7 | 25.8 | 68.8 | 8.9 | 14.6 |
| AAUFM-33 | 55.2 | 11.7 | 4.7 | 2.3 | 20.4 | 47.6 | 7.2 | 11.0 |
| AAUFM-11 | 72.6 | 19.0 | 13.4 | 1.7 | 17.7 | 29.4 | 9.6 | 10.1 |
| AAUFM-10 | 103.6 | 15.2 | 13.0 | 6.0 | 18.0 | 107.9 | 10.3 | 11.4 |
| AAUFM-41 | 52.2 | 16.3 | 4.8 | 2.0 | 24.4 | 48.7 | 6.8 | 7.6 |
| AAUFM-6 | 81.1 | 13.4 | 11.7 | 1.3 | 25.8 | 34.4 | 10.5 | 10.2 |
| AAUFM-21 | 86.5 | 17.7 | 13.1 | 1.7 | 22.2 | 37.0 | 10.8 | 8.7 |
| AAUFM-42 | 77.4 | 11.8 | 10.9 | 5.0 | 22.8 | 113.9 | 9.2 | 10.7 |
| AAUFM-8 | 78.5 | 9.4 | 8.4 | 3.0 | 18.8 | 56.3 | 9.4 | 7.8 |
| AAUFM-32 | 81.5 | 15.2 | 12.6 | 1.0 | 20.6 | 20.6 | 10.1 | 11.7 |
| AAUFM-15 | 71.0 | 17.4 | 13.7 | 10.0 | 22.9 | 228.9 | 11.0 | 10.7 |
| AAUFM-35 | 82.0 | 15.6 | 8.6 | 2.0 | 21.3 | 42.5 | 9.8 | 11.0 |
| AAUFM-25 | 75.4 | 13.3 | 11.2 | 3.0 | 23.7 | 71.0 | 9.0 | 8.8 |
| AAUFM-22 | 82.9 | 12.6 | 11.0 | 2.6 | 18.8 | 48.8 | 11.0 | 8.6 |
| AAUFM-24 | 66.8 | 5.9 | 3.5 | 2.3 | 19.7 | 46.0 | 16.9 | 9.6 |
| AAUFM-43 | 79.4 | 16.6 | 12.7 | 1.4 | 17.9 | 25.0 | 10.3 | 8.7 |
| AAUFM-46 | 82.6 | 14.5 | 13.1 | 3.0 | 16.3 | 48.8 | 9.1 | 8.3 |
| AAUFM-17 | 88.0 | 17.9 | 17.3 | 2.6 | 12.3 | 32.0 | 9.5 | 8.7 |
| AAUFM-2 | 79.0 | 18.5 | 16.9 | 7.2 | 23.5 | 169.5 | 10.5 | 10.5 |
| AAUFM-4 | 82.1 | 15.8 | 14.3 | 4.5 | 15.2 | 68.5 | 11.1 | 9.5 |
| 234159 | 71.5 | 16.5 | 12.6 | 7.6 | 28.6 | 217.1 | 8.9 | 8.2 |
| AAUFM-30 | 64.5 | 13.2 | 12.1 | 4.3 | 25.0 | 106.2 | 8.9 | 7.8 |
| AAUFM-31 | 76.1 | 12.7 | 11.8 | 2.0 | 14.9 | 29.9 | 9.7 | 12.1 |
| AAUFM-37 | 50.0 | 12.2 | 3.9 | 3.2 | 18.3 | 58.5 | 5.1 | 7.9 |
| AAUFM-18 | 74.9 | 11.7 | 8.5 | 2.5 | 16.8 | 42.0 | 10.7 | 9.7 |
| AAUFM-45 | 79.4 | 11.3 | 9.6 | 6.4 | 17.9 | 114.7 | 10.1 | 10.9 |
| AAUFM-47 | 91.5 | 11.2 | 10.2 | 9.4 | 22.1 | 207.9 | 10.6 | 11.0 |
| AAUFM-9 | 75.9 | 14.1 | 13.3 | 5.8 | 25.4 | 146.0 | 10.4 | 8.8 |
| AAUFM-48 | 80.7 | 14.0 | 12.0 | 6.8 | 21.4 | 145.4 | 10.7 | 9.8 |
| 237476 | 76.2 | 13.7 | 12.5 | 3.7 | 24.0 | 88.0 | 9.4 | 8.1 |
| 238334 | 72.9 | 17.3 | 15.3 | 4.2 | 23.5 | 98.7 | 10.0 | 8.4 |
| 215965 | 75.8 | 16.1 | 12.9 | 4.2 | 22.0 | 92.2 | 9.6 | 10.4 |
| AAUFM-38 | 75.7 | 19.3 | 17.1 | 5.0 | 20.7 | 103.3 | 9.2 | 8.3 |
| 234158 | 87.6 | 9.1 | 8.5 | 1.2 | 22.2 | 26.6 | 9.3 | 8.0 |
| AAUFM-16 | 86.7 | 17.5 | 13.1 | 1.7 | 20.0 | 33.3 | 9.7 | 9.0 |
| COLL-009 | 81.6 | 15.8 | 13.5 | 1.2 | 18.9 | 22.6 | 10.0 | 7.5 |
| AAUFM-5 | 85.2 | 11.1 | 10.1 | 2.0 | 21.2 | 42.5 | 12.4 | 8.8 |

| Accession No. | PH | TN | PT | GLN | GLA | TGLA | EN | EL |
|---|---|---|---|---|---|---|---|---|
| TADSEESE | 83.4 | 9.7 | 6.4 | 2.7 | 23.8 | 63.5 | 6.8 | 7.3 |
| COLL-010 | 69.2 | 11.2 | 10.0 | 1.7 | 25.1 | 41.8 | 9.3 | 9.2 |
| AAUFM-40 | 78.9 | 13.0 | 9.4 | 3.5 | 22.6 | 79.2 | 9.9 | 8.8 |
| 216046 | 67.2 | 14.3 | 2.4 | 2.0 | 20.1 | 40.1 | 3.5 | 1.6 |
| AAUFM-39 | 65.5 | 15.4 | 12.3 | 5.8 | 29.2 | 169.2 | 9.1 | 10.0 |

Appendix 4. Mean physiological, dry biomass and grain yield related measurements

| Accession No. | DRW | DSW | R:S | CCI | RWC | GYPH | GYPP |
|---|---|---|---|---|---|---|---|
| 230102 | 2.8 | 58.5 | 0.05 | 10.4 | 71.3 | 2.68 | 230.8 |
| 230103 | 3.6 | 60.3 | 0.06 | 12.4 | 78.7 | 4.00 | 355.3 |
| 238299 | 2.3 | 61.5 | 0.04 | 12.7 | 60.5 | 4.00 | 125.8 |
| 208440 | 3.1 | 71.3 | 0.04 | 11.9 | 59.0 | 2.30 | 145.8 |
| 230106 | 4.3 | 50.9 | 0.08 | 11.1 | 77.9 | 3.13 | 131.1 |
| 230107 | 2.7 | 79.5 | 0.03 | 10.8 | 69.6 | 3.22 | 167.0 |
| 230108 | 3.2 | 60.1 | 0.05 | 12.0 | 72.6 | 2.20 | 181.2 |
| 230109 | 4.3 | 138.5 | 0.03 | 11.9 | 57.6 | 4.10 | 185.4 |
| 230110 | 5.1 | 58.6 | 0.09 | 11.7 | 66.8 | 4.55 | 155.4 |
| 242120 | 5.5 | 70.2 | 0.08 | 11.8 | 70.7 | 3.00 | 121.0 |
| 242132 | 3.1 | 78.3 | 0.04 | 10.5 | 63.3 | 0.00 | 0.0 |
| 242133 | 4.5 | 51.2 | 0.09 | 13.3 | 71.2 | 0.00 | 0.0 |
| 242135 | 4.2 | 63.2 | 0.07 | 14.5 | 49.2 | 0.00 | 0.0 |
| 100002 | 3.5 | 64.8 | 0.05 | 9.0 | 78.4 | 0.00 | 0.0 |
| 242620 | 4.8 | 67.3 | 0.07 | 13.2 | 91.5 | 0.00 | 0.0 |
| 215982 | 4.5 | 63.9 | 0.07 | 6.2 | 82.5 | 0.00 | 0.0 |
| 242111 | 4.5 | 105.2 | 0.04 | 9.1 | 77.8 | 0.00 | 0.0 |
| 215985 | 4.4 | 55.0 | 0.08 | 14.8 | 100.0 | 0.00 | 0.0 |
| 215989 | 3.2 | 70.2 | 0.05 | 12.0 | 93.7 | 0.00 | 0.0 |
| 215990 | 4.6 | 63.4 | 0.07 | 10.1 | 69.0 | 0.00 | 0.0 |
| 225892 | 3.7 | 68.9 | 0.05 | 12.8 | 65.0 | 0.00 | 0.0 |
| 235140 | 4.1 | 71.2 | 0.06 | 10.0 | 82.6 | 0.00 | 0.0 |
| 235782 | 4.6 | 81.9 | 0.06 | 15.2 | 92.3 | 0.00 | 0.0 |
| 235783 | 2.9 | 47.1 | 0.06 | 13.9 | 81.4 | 0.00 | 0.0 |
| 215851 | 2.2 | 48.3 | 0.05 | 12.4 | 76.8 | 0.00 | 0.0 |
| 243639 | 5.2 | 69.8 | 0.07 | 11.2 | 82.8 | 2.40 | 175.4 |
| 235145 | 2.6 | 50.7 | 0.05 | 13.0 | 57.9 | 3.33 | 175.8 |
| 234199 | 4.8 | 81.7 | 0.06 | 11.5 | 64.6 | 3.28 | 182.8 |
| 237465 | 4.0 | 78.7 | 0.05 | 13.6 | 73.2 | 2.50 | 130.2 |

| Accession No. | DRW | DSW | R:S | CCI | RWC | GYPH | GYPP |
|---|---|---|---|---|---|---|---|
| AAUFM-44 | 3.7 | 54.5 | 0.07 | 18.2 | 56.3 | 3.50 | 161.8 |
| AAUFM-12 | 5.5 | 52.3 | 0.10 | 15.4 | 72.9 | 3.20 | 42.0 |
| 237475 | 4.3 | 62.9 | 0.07 | 13.2 | 69.2 | 2.12 | 117.9 |
| 234194 | 3.9 | 56.8 | 0.07 | 12.4 | 87.0 | 2.00 | 104.2 |
| AAUFM-1 | 4.7 | 50.5 | 0.09 | 14.1 | 48.7 | 4.00 | 162.7 |
| AAUFM-14 | 5.1 | 55.1 | 0.09 | 20.2 | 85.1 | 2.00 | 23.0 |
| 242616 | 6.2 | 67.1 | 0.09 | 12.7 | 75.0 | 3.00 | 200.8 |
| 241617 | 3.3 | 62.5 | 0.05 | 14.0 | 73.2 | 3.00 | 99.9 |
| 241618 | 5.2 | 61.1 | 0.09 | 11.2 | 74.7 | 2.30 | 114.6 |
| AAUFM-29 | 5.3 | 56.2 | 0.09 | 12.5 | 83.4 | 2.50 | 185.8 |
| 242622 | 4.5 | 63.1 | 0.07 | 12.1 | 73.5 | 3.00 | 20.5 |
| AAUFM-7 | 4.6 | 86.6 | 0.05 | 14.6 | 70.8 | 8.00 | 273.8 |
| 242624 | 5.5 | 80.3 | 0.07 | 13.0 | 81.0 | 2.50 | 231.3 |
| 230105 | 3.9 | 73.3 | 0.05 | 13.7 | 71.4 | 3.70 | 223.8 |
| 238300 | 4.9 | 76.9 | 0.06 | 13.4 | 73.7 | 2.30 | 88.1 |
| AAUFM-26 | 3.4 | 70.0 | 0.05 | 6.7 | 72.0 | 3.13 | 61.7 |
| 238305 | 4.1 | 62.6 | 0.07 | 12.3 | 78.7 | 3.50 | 123.0 |
| AAUFM-28 | 2.7 | 81.8 | 0.03 | 12.7 | 72.8 | 4.50 | 94.3 |
| 238310 | 4.9 | 57.3 | 0.09 | 14.5 | 65.8 | 2.60 | 158.0 |
| 238325 | 3.0 | 68.9 | 0.04 | 12.6 | 79.5 | 3.90 | 122.5 |
| 238327 | 3.6 | 62.0 | 0.06 | 11.9 | 86.5 | 2.88 | 143.0 |
| AAUFM-20 | 2.7 | 46.4 | 0.06 | 14.8 | 77.9 | 3.10 | 249.9 |
| BONEYA | 5.0 | 60.8 | 0.08 | 13.4 | 83.8 | 3.10 | 144.0 |
| AAUFM-36 | 2.7 | 53.3 | 0.05 | 10.0 | 76.0 | 3.20 | 163.4 |
| AAUFM-19 | 2.9 | 64.0 | 0.04 | 11.6 | 77.4 | 3.40 | 172.7 |
| AAUFM-23 | 3.4 | 55.9 | 0.06 | 15.8 | 72.9 | 4.30 | 230.8 |
| AAUFM-33 | 4.0 | 70.1 | 0.06 | 15.3 | 84.8 | 3.00 | 44.9 |
| AAUFM-11 | 3.5 | 59.2 | 0.06 | 13.3 | 81.3 | 2.80 | 162.5 |
| AAUFM-10 | 3.4 | 52.7 | 0.06 | 12.2 | 67.5 | 4.10 | 236.3 |
| AAUFM-41 | 4.5 | 56.2 | 0.08 | 10.9 | 76.8 | 2.30 | 145.0 |
| AAUFM-6 | 3.7 | 59.8 | 0.06 | 14.6 | 95.9 | 3.26 | 183.4 |
| AAUFM-21 | 3.7 | 86.4 | 0.04 | 13.5 | 86.8 | 3.30 | 218.2 |
| AAUFM-42 | 5.8 | 61.8 | 0.09 | 14.5 | 76.0 | 4.10 | 217.6 |
| AAUFM-8 | 4.3 | 35.7 | 0.12 | 12.5 | 88.8 | 1.76 | 37.8 |
| AAUFM-32 | 3.7 | 48.4 | 0.08 | 14.5 | 70.4 | 3.50 | 171.7 |
| AAUFM-15 | 4.2 | 56.3 | 0.07 | 14.5 | 79.0 | 3.50 | 192.3 |
| AAUFM-35 | 3.8 | 79.4 | 0.05 | 13.3 | 58.9 | 2.00 | 95.5 |
| AAUFM-25 | 4.5 | 76.2 | 0.06 | 12.4 | 75.8 | 2.50 | 166.3 |
| AAUFM-22 | 4.9 | 59.4 | 0.08 | 14.6 | 77.3 | 1.80 | 111.9 |

| Accession no | DRW | DSW | R:S | CCI | RWC | GYPH | GYPP |
|---|---|---|---|---|---|---|---|
| AAUFM-24 | 4.2 | 69.4 | 0.06 | 18.1 | 85.2 | 4.25 | 40.5 |
| AAUFM-43 | 3.7 | 62.4 | 0.06 | 14.3 | 70.6 | 4.50 | 353.8 |
| AAUFM-46 | 2.0 | 74.0 | 0.03 | 12.2 | 71.7 | 3.20 | 168.1 |
| AAUFM-17 | 3.2 | 71.4 | 0.04 | 11.6 | 67.2 | 3.20 | 249.5 |
| AAUFM-2 | 4.0 | 98.2 | 0.04 | 12.1 | 74.7 | 3.76 | 309.6 |
| AAUFM-4 | 3.1 | 76.9 | 0.04 | 12.5 | 72.8 | 3.14 | 252.6 |
| 234159 | 4.5 | 76.1 | 0.06 | 13.4 | 72.2 | 2.90 | 194.2 |
| AAUFM-30 | 5.2 | 46.2 | 0.11 | 11.9 | 76.3 | 4.20 | 247.5 |
| AAUFM-31 | 5.3 | 49.1 | 0.11 | 14.5 | 79.0 | 3.80 | 197.0 |
| AAUFM-37 | 5.2 | 91.3 | 0.06 | 9.9 | 72.0 | 2.30 | 10.4 |
| AAUFM-18 | 3.8 | 53.4 | 0.07 | 11.1 | 64.7 | 3.16 | 60.2 |
| AAUFM-45 | 4.4 | 64.4 | 0.07 | 12.5 | 74.2 | 2.40 | 111.6 |
| AAUFM-47 | 4.0 | 70.9 | 0.06 | 14.5 | 78.2 | 3.50 | 157.2 |
| AAUFM-9 | 4.1 | 67.2 | 0.06 | 13.0 | 77.3 | 2.64 | 197.9 |
| AAUFM-48 | 4.6 | 44.7 | 0.10 | 11.4 | 80.0 | 3.60 | 226.5 |
| 237476 | 3.5 | 52.6 | 0.07 | 12.4 | 67.1 | 3.20 | 211.7 |
| 238334 | 2.8 | 46.0 | 0.06 | 11.9 | 83.1 | 3.20 | 225.1 |
| 215965 | 6.3 | 89.4 | 0.07 | 16.2 | 61.8 | 3.10 | 213.9 |
| AAUFM-38 | 3.4 | 52.3 | 0.07 | 11.5 | 75.0 | 3.80 | 358.6 |
| 234158 | 4.1 | 47.2 | 0.09 | 10.6 | 73.1 | 3.24 | 160.6 |
| AAUFM-16 | 3.0 | 81.0 | 0.04 | 11.6 | 75.3 | 2.60 | 59.3 |
| COLL-009 | 2.6 | 44.7 | 0.06 | 9.7 | 77.3 | 3.36 | 218.2 |
| AAUFM-5 | 4.2 | 64.7 | 0.06 | 15.1 | 66.5 | 3.50 | 186.7 |
| TADESSE | 4.9 | 81.5 | 0.06 | 11.0 | 81.9 | 3.00 | 196.3 |
| COL-010 | 4.8 | 52.0 | 0.09 | 12.9 | 87.4 | 4.10 | 182.7 |
| AAUFM-40 | 5.3 | 99.7 | 0.05 | 13.9 | 74.6 | 2.80 | 83.4 |
| 216046 | 3.9 | 69.4 | 0.06 | 7.4 | 77.4 | 3.00 | 123.0 |
| AAUFM-39 | 5.5 | 52.4 | 0.11 | 13.0 | 78.1 | 2.80 | 185.4 |

Where, DRW= Dry root weight, DSW= Dry shoot weight, R: S= root shoot ratio, RWC= relative water content, GYPH= Grain yield per head and GYPP= grain yield per plant

Appendix 5. Analysis of variance for all measured parameters

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| PH | Between Groups | 32335.653 | 95 | 340.375 | 2.410 | .000 |
| | Within Groups | 27119.333 | 192 | 141.247 | | |
| | Total | 59454.986 | 287 | | | |
| TN | Between Groups | 3347.052 | 95 | 35.232 | 1.270 | .084 |
| | Within Groups | 5326.667 | 192 | 27.743 | | |
| | Total | 8673.719 | 287 | | | |
| PT | Between Groups | 2281.330 | 95 | 24.014 | 1.614 | .003 |
| | Within Groups | 2857.333 | 192 | 14.882 | | |
| | Total | 5138.663 | 287 | | | |
| GLN | Between Groups | 501.463 | 95 | 5.279 | 1.630 | .002 |
| | Within Groups | 621.673 | 192 | 3.238 | | |
| | Total | 1123.137 | 287 | | | |
| GLA | Between Groups | 4952.305 | 95 | 52.130 | 1.345 | .043 |
| | Within Groups | 7441.260 | 192 | 38.757 | | |
| | Total | 12393.565 | 287 | | | |
| TGLA | Between Groups | 326565.213 | 95 | 3437.529 | 1.328 | .050 |
| | Within Groups | 496835.873 | 192 | 2587.687 | | |
| | Total | 823401.087 | 287 | | | |
| EN | Between Groups | 391.163 | 95 | 4.118 | 1.254 | .096 |
| | Within Groups | 630.667 | 192 | 3.285 | | |
| | Total | 1021.830 | 287 | | | |
| EL | Between Groups | 1357.247 | 95 | 14.287 | 1.417 | .022 |
| | Within Groups | 1935.333 | 192 | 10.080 | | |
| | Total | 3292.580 | 287 | | | |
| DRW | Between Groups | 169.031 | 95 | 1.779 | 1.329 | .050 |
| | Within Groups | 256.973 | 192 | 1.338 | | |
| | Total | 426.004 | 287 | | | |
| DSW | Between Groups | 36847.635 | 95 | 387.870 | .943 | .622 |
| | Within Groups | 79005.333 | 192 | 411.486 | | |
| | Total | 115852.969 | 287 | | | |
| RS | Between Groups | .124 | 95 | .001 | 1.143 | .218 |
| | Within Groups | .220 | 192 | .001 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Total | | | | | |
| RS | | .344 | 287 | | | |
| CCI | Between Groups | 1811.113 | 95 | 19.064 | 8.952 | .000 |
| | Within Groups | 408.887 | 192 | 2.130 | | |
| | Total | 2219.999 | 287 | | | |
| RWC | Between Groups | 6486.163 | 95 | 68.275 | .843 | .825 |
| | Within Groups | 15557.333 | 192 | 81.028 | | |
| | Total | 22043.497 | 287 | | | |
| GYPH | Between Groups | 237.770 | 95 | 2.503 | 3.929 | .000 |
| | Within Groups | 122.293 | 192 | .637 | | |
| | Total | 360.063 | 287 | | | |
| GYPP | Between Groups | 111866.626 | 95 | 1177.543 | 2.214 | .000 |
| | Within Groups | 102107.453 | 192 | 531.810 | | |
| | Total | 213974.079 | 287 | | | |

Appendix 6. Partial view of the study plot at Dhera

Photo by Dagnachew Lule

Appendix 7. Finger millet accession which are susceptible to drought stress

Photo by Awol Assefa

Appendix 8. Finger millet accession with different panicle shape

Photo by Awol Assefa

Appendix 9. Partial view of the study plot during harvesting time at Dhera

Photo by Geremew Tessema

Appendix 10. Accession AAUFM-37 retains the green leaves

Photo by Awol Assefa

Appendix 11. Accession 215965 is late mature than their counter part

Photo by Awol Assefa