AGRO-MORPHOLOGICAL AND NUTRITIONAL CHARACTERIZATION OF TOMATO LANDRACES (*Lycopersicon* species) IN AFRICA

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DECLARATION

This thesis is my original work and it has not been presented for a degree in any other university.

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This thesis is dedicated to my wife Irene and my son Peter for their prayers, patience and true love during my study.

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABBREVIATIONS

AAS	Atomic absorption spectroscopy
AES	Atomic emission spectroscopy
ANOVA	Analysis of variance
AOAC	Association of analytical communities
AVDRC	Asian vegetable research and development center
CAN	Calcium ammonium nitrate
DARwin	Dissimilarity analysis representation for windows
DPPH	2, 2-Diphenyl-1-picryl hydrazyl
FAO	Food and Agriculture Organization
GAE	Gallic acid equivalent
GBK	Genebank of Kenya
HCDA	Horticultural Crops Development Authority
HCL	Hydrochloric acid
HPLC	High-performance liquid chromatography
IPPC	Intergovernmental Panel on Climate Change
IPGRI	International Plant Genetic Resources Institute
KALRO	Kenya Agricultural and Livestock Research Organisation
KARI	Kenya Agricultural Research Institute
KHCP	Kenya Horticulture Competitiveness Program
LRWC	Leaf relative water content
LSD	Least significant difference
N.P.K	Nitrogen, Phosphorus, Potassium
NGRI	National Genetic Resources Institute
OPV	Open pollinated varieties
SLA	Single leaf area
SPAD	Soil Plant Analysis Development
UPGMA	Unweighted pair-group method using arithmetic average

ABSTRACT

Tomato (*Solanum lycopersicum*), often associated with a wide range of health benefits due to its rich nutritional quality, is an important fruit vegetable crop in Kenya. However, varieties grown in Kenya are few and highly susceptible to biotic and abiotic stresses that adversely affect productivity. Wild relatives and unimproved accessions of crops are often better adapted to biotic and abiotic stresses and serve as a source of desirable genes for crop improvement in this respect. The main objective of this study was to characterize 69 tomato ecotypes from the World Vegetable Centre and the National Genebank of Kenya. The specific objectives were: (1) to evaluate the African tomato landraces for morphological and agronomic traits (2) to determine the effect of water stress on growth, yield and nutritional quality of selected African tomato landraces. Field and greenhouse experiments were laid out in a randomized complete block design with three replications at the University of Nairobi's Kabete Field Station, Kenya, in 2014 and 2015. Characters were evaluated based on the International Plant Genetic Resources Institute tomato descriptor list of 14 agronomic and 10 morphological traits at flowering and fruiting stages. Twenty (20) accessions were selected for their desirable agronomic traits from the initial list of 69 accessions and subjected to four watering levels: 100%, 80%, 60% and 40% of the field capacity (FC). During growth, accessions from all watering levels were evaluated for agronomic and physiological traits. Fully ripe fruits were harvested from the 20 accessions at 100% and 60% FC respectively and evaluated for β-carotene, vitamin C, minerals, simple sugars, total phenolics and total antioxidant activity. Analysis of variance from the first experiment indicated significant differences ($P<0.05$) in the accessions for all the agronomic traits evaluated. Accessions with the highest and the least number of fruits recorded means of 8.3 and 442.3 fruits per plant respectively. Similarly, fruit weight varied widely within the range of 565 g to 2759 g per plant. Yield showed positive and significant correlation with fruit length ($r=0.42$), fruit width ($r=0.51$), fruit weight ($r=0.50$) and stem girth ($r=0.41$). The first three components of principal component analysis explained 78.2% of total variations among the genotypes. The characters contributing most to variability were growth type, foliage density, fruit size and fruit cross sectional shape. Cluster analysis using unweighted pair group method with arithmetic mean grouped the genotypes into two clusters. Cluster I contained 63 accessions while cluster II had 6 accessions. Results from the second experiment showed significant ($P<0.05$) interactions among accessions and water levels for both agronomic and physiological traits evaluated. Water stress significantly reduced fruit yield

which ranged from 127.3 to 1487.7 g at 60% FC compared to 521.0 to 2404.3 g at 100% FC. Similarly, reductions in stem girth, plant height and leaf area were recorded for the agronomic traits. Water stress reduced stomatal conductance which ranged from 74.0 to 100.1 mmol/m^2s at 60% FC compared to 207.7 to 287.5 mmol/m^2s at 100% FC. Similar reductions were also observed for SPAD value and leaf relative water content under water stress conditions. However, water stress significantly increased leaf canopy temperature for all the accessions. Water stress significantly increased total phenolics which ranged from 3.2 to 11.3 garlic acid equivalent (GAE)/100 g at 60% FC compared to 1.5 to 4.9 GAE/100 g at 100% FC. Total antioxidant activity increased with water stress from 17.9 to 38.3% inhibition at 60% FC compared to 13.3 to 29.3 % inhibition at 100% FC. Increased levels of fructose, glucose and sucrose were recorded at 60% FC compared to 100% FC. On the contrary, significantly lower levels of mineral nutrients (potassium, zinc, magnesium, iron and sodium), β-carotene and vitamin C were recorded at 60% FC than at 100% FC. Thus, this study revealed significant variations in morphological, agronomic, physiological and nutritional diversity among the African tomato accessions. This rich diversity could be exploited in future tomato improvement programmes.

CHAPTER 1

INTRODUCTION

1.1 Background information

Tomato (*Lycopersicon esculentum* L.) is native to South America (Blanca *et al*., 2012) and is the second most important vegetable crop cultivated in the world (Foolad, 2007). The tomato belongs to the family Solanaceae, which consists of approximately 100 genera and 2500 species, including several plants of agronomic importance such as potato, eggplant, pepper, and tobacco (Olmstead *et al*., 2008). There are more than 7500 tomato landraces and varieties successfully bred and grown for various purposes worldwide, and plant variety registration bodies in different countries keep records of most of these germplasms. Tomato consumption has gained importance due to its antioxidant property that reduces cancer incidences (Wamache, 2005). Alongside other nutrients, tomato fruit also contains β-carotene, ascorbic acid and phenolic compounds, which have nutritional benefits to consumers (Fajinmi and Fajinmi 2010; Wang *et al*. 2011).

In Kenya, tomato is mainly grown for the domestic market and ranks second after potato (HCDA, 2013). The crop is grown under both rain fed and irrigated conditions, and lately due to the high demand and especially during the low seasons farmers have extensively adopted high yielding varieties and modern technologies like greenhouse production to ensure year round production (HCDA, 2010). The area under production of tomato has been on the increase and this has been attributed to increased demand for the crop. In 2011, an area of 20,583.9 ha with a production of 396,543.6 metric tons was realized as compared to 23,865.6 ha and a production of 494,036.5 metric tons in 2013 as shown in table 1 (HCDA, 2013). The key tomato growing counties are Migori, Bungoma and Kajiado (Table 1.0).

Table 1.0: Production of tomato in selected counties in Kenya, 2012-2013

	2012			2013		
County	**Area (Ha)**	**Quantity (MT)**	**Value (Mi) Ksh**	**Area (Ha)**	**Quantity (MT)**	**Value (Mi) Ksh**
Migori	3,737	83,317	2,399.9	3,681	78,816	2,312.9
Bungoma	1,719	47,712	1,593.6	2,411	54,675	1,706.8
Kajiado	1,615	36,623	947.2	1,688	50,582	1,205.2
Kericho	502	7,566	210.9	445	5,855	945.1
Makueni	431	17,582	650.7	482	19,310	785.1
Kirinyaga	1,823	55,516	332.0	1,791	28,692	616.3
Nakuru	509	6,745	601.5	495	8,668	515.6
Lamu	185	7,617	196.7	276	11,356	454.2
Kiambu	964	18,825	811.4	691	9,139	418.7

Source: HCDA validated report 2013; Mi- million, MT- metric tons, Ha- hectare

Varieties of tomato grown in Kenya are few and highly vulnerable to yield reducing biotic and abiotic factors. The main tomato varieties grown in Kenya can be categorized into those grown in greenhouses and those grown in the open field. Varieties grown in the greenhouse include Prostar F_1, Nemoneta F_1, Chonto F_1, Corazzon F_1, Claudia F_1, Tylka F_1 and Anna F_1 while varieties commonly grown in the open fields include Riogrande and Cal-J (Monsanto, 2013).

1.2 Problem statement

Cultivated tomatoes typically have low genetic diversity due to population bottlenecks (Rick, 1976), and intensive selection of a few desired traits during domestication has led to further loss of genetic diversity among the commercial tomato varieties (Williams and Clair, 1993). Varieties of tomatoes grown in Kenya are few and highly vulnerable to yield reducing biotic and abiotic factors. Moisture stress is one of the major constraints that limit tomato productivity. Previous studies have shown that effects of moisture deficit on the growth, yield and nutritional quality in tomato vary with the crop stage at which stress is imposed (Sionit and Kramer, 1977). Similarly, studies have shown that reduction in moisture levels at reproductive stage results in nutritional changes of the tomato fruit (Kozlowski, 1972). Breakthrough in tomato genetic resource collection, preservation, exploitation, and utilization depend largely on the mastery of the genetic background and diversity that exists among these germplasm. To date, a large number of tomato landraces and local varieties have been collected (Robertson and Labate, 2007). However, very few of them have been systematically evaluated to determine their potential for increasing the genetic variation in commercial tomato varieties.

1.3 Justification

Landraces are genotypes with known origins but lack of any form of crop improvement. They are often identified with informal farming practices and have been cultivated under natural low-input farming systems (Terzopoulos and Bebeli, 2008). Wild species of tomato harbor many valuable genes, which may have been lost among cultivated tomatoes. These species can enlarge the gene pool of cultivated species and are therefore very useful in breeding programs as sources of genetic variability (Hanson *et al*., 2007). Phenotypic characterization of the tomato landraces will inform on selection of accessions with desirable traits for breeding and conservation purposes. Information on the diversity within and among closely related crop species is essential for their effective use, improvement and management. It is therefore of great importance to have a clear understanding of the genetic diversity and relationship between tomato landraces for effective conservation, classification, and further utilization of tomato germplasm resources

1.4 Objectives

The main objective of this study was to characterize the extent of phenotypic and nutrition variation among the African tomato landraces. The specific objectives were:

1. To evaluate the African tomato landraces for morphological and agronomic traits.
2. To evaluate the effect of water stress on growth, yield and nutritional quality of selected African tomato landraces.

1.5 Hypotheses

1. African tomato landraces are different in morphological, agronomic and biochemical traits.
2. African tomato landraces respond differently with respect to growth, yield and nutritional quality when exposed to water stress.

CHAPTER 2

LITERATURE REVIEW

2.1. Classification and taxonomy of tomato

The cultivated tomato, *Lycopersicon esculentum* Mill., belongs to the nightshade family *Solanaceae* which also includes other economically important crops such as pepper, potato and tobacco (Dias *et al*., 2013). Tomato is an annual herb with an erect to prostrate stems. It has a strong taproot with dense lateral and adventitious roots. The stem is solid, coarsely hairy and glandular. The leaves are arranged spirally, imparipinnate with no stipules while the petiole length varies from 3 to 6 cm (Van *et al*., 2004). The leaflets vary in size and are irregularly toothed and sometimes pinnatifid at the base. Inflorescence is a cyme but sometimes compound flowered. Flowers are bisexual and regular in shape and often with a yellow corolla (Van *et al*., 2004). Closed stigma and style enhances autogamy and reduces chances of crossing. The fruit is a berry usually red but may sometime vary from pink, orange to yellow when ripe (Van *et al*., 2004).

According to Van *et al*. (2004), tomato cultivars can be variously classified based on: Growth habit: indeterminate, semi -determinate or determinate (bushy); Fruit size: small round (cherry tomato, < 30 g; 'Moneymaker', 80 g), medium-large round (120-150 g), beefsteak and ribbed (> 200 g); Fruit shape: round, heart-shaped, pear-shaped, plum-shaped, elongated or flat; Colour of ripe fruit: red, pink, orange or yellow; Utilization: for fresh market or processing

2.2. Ecological requirements of tomato

Tomato is a moderately tolerant plant that thrives under warm conditions with temperatures of 15-25°C (Waiganjo *et al*., 2006). Low temperatures may delay fruit ripening while temperatures above 30^0C inhibit fruiting, flavor and formation of the red pigment often in tomato (Waiganjo *et al*., 2006). Prolonged exposure to temperatures below 10°C and 6°C can cause chilling injury and plant death respectively (Van *et al*., 2004). The crop thrives well under different soil types, however, it require soils that are rich in organic matter, properly aerated and with a pH range of 5 to 7.5 (Wiersinga *et al*., 2008). Higher or lower pH values can cause mineral deficiencies or toxicities. (Van *et al*, 2004). Wet conditions increase incidences of diseases such as powdery mildew (Waiganjo *et al*., 2006). However, with the greenhouse technology, farmers are now able to utilize small pieces of land to produce high quality tomato for specialized markets (Mbaka *et al*., 2013).

2.3 Uses and nutritional importance of tomato

Tomato is an economically important crop with high potentials of improving the livelihoods of small scale farmers in Kenya (Mbaka *et al*., 2013). The crop is among the most cultivated vegetable crops with the highest consumption rate and economic value worldwide. It is valuable nutritionally due to its high content of antioxidants, including carotenoids, lycopene, ascorbic acid and phenolics, which have the health promoting potential for the consumers (Wang *et al*., 2011).

2.4 Constraints to tomato production in Kenya

Key production challenges for tomato crop include pests and diseases (Singh *et al*., 2014a) as well as marketing (KHCP, 2011). According to Maerere *et al*., (2006), a number of yield reducing biotic and abiotic factors have been attributed to low yields and increased cost of production. The major insect pests attacking the crop include whiteflies, nematodes, spider mites, thrips, leaf miners, African bollworm and aphids (KARI, 2005; Waiganjo *et al*., 2006). Diseases remain the biggest challenge in tomato production. It is estimated that there are more than 200 known diseases affecting tomatoes (Jones, 2008). Tomato diseases are rampant in lowlands, highlands and tropics, and can cause 15-95% crop losses (Tahat *et al*., 2010). Some of the major diseases affecting this crop in Kenya include early and late blight, powdery mildew, yellow leaf curl virus, tobacco mosaic virus, bacterial spot, *Fusarium* wilt and septoria leaf spot (KARI, 2005; Singh *et al*., 2014b). In their effort to control pests and diseases, farmers use pesticide products excessively with over 40 applications per season recorded in some tomato fields (Waiganjo *et al*., 2006). The unregulated application of the pesticides continue to be an occupational health hazard to the farmer, causes food poisoning to the consumer and more importantly degrades the environment. Some farmers have reported health issues which have been linked to the effects of pesticide and poor use of pesticide products (Waiganjo *et al*., 2006).

Drought, salinity, cold and heat are a biotic stresses that adversely affect plant growth, development, and seed development, causing extensive losses to agricultural production (Mittler and Blumwald, 2010). Sensitivity to water deficit varies among different crops and tomato is one of the horticultural crops known to be susceptible to water stress especially at flower flowering and fruit formation (Nuruddin., 2001). Provision of the appropriate amount water to tomato plant is therefore crucial for its growth and economic production, especially in the greenhouse (Aziz *et al*., 2013). However, shortage of irrigation water results in decreased yield and quality in tomato (Aksic

et al., 2011). This has been exacerbated by changing climatic patterns that tend to influence tomato production and quality majorly by water scarcity (Abid., 2011).

2.5 Tomato characterization and its importance in crop improvement

The main goal of a tomato breeder is to sustainably develop high yielding and high quality varieties which can resist continuous pest and disease infestation as well as environmental stresses. The low diversity among commercial tomato varieties, coupled with numerous pests and diseases, poses a serious threat to tomato production (Osei *et al*., 2010). The increase in demand for high quality tomato products by consumers has resulted in the need to continually collect, characterize and evaluate unknown tomato genotypes. Characterization and documentation of tomato genotypes is therefore imperative for current and future tomato breeders.

Phenotypic characterization as used in plants is the technique used to evaluate diversity through the study of agro-morphological traits (Bajracharya *et al*., 2006). It relies on the recording and description of phenotypic and agronomic characteristics that cover the leaf, floral parts and the yield and yield components. The usual approach to characterization and evaluation of plant population involves planting of the sub-samples followed by assessing their morpho-agronomic descriptions (Pérez *et al*., 1993). Results from such description are critical in determining the genetic variability of the genotypes stored in gene banks and establishing genotypes stored in duplicate (Valls 2007).

Exploitation of traits among diverse genotypes increases research findings and knowledge of the which facilitates breeding for wider geographic adaptability, with respect to biotic and abiotic stresses. Also, genetic diversity needs to be depicted and measured if it is to be successfully integrated into crop improvement and management of plant genetic resources. The identification of variability among accessions is therefore pivotal to the maintenance, utilization and acquisition of germplasm resources (Mwirigi *et al*., 2009). The International Plant Genetic Resources Institute (IPGRI) has developed descriptors for quantitative as well as qualitative characters to ensure precise, accurate and uniform identification of genotypes (Chavez *et al*., 1990). Characterization therefore aids in the documentation of the genetic variability that exists in a population (Pérez *et al*., 1993). This is an important activity in crop improvement programmes because the amount of genetic diversity within populations determines the rate of adaptive evolution and the extent of response to traditional breeding through selection. Several research findings stress on the

morphological, agronomic, and biochemical parameters that have been widely used in the assessment of various crops (Rick *et al*., 1990; Kaemer *et al*., 1995)

2.6 Measures of genetic and phenotypic variation

Evaluation of the diversity of a given collection can be based on phenotypic traits (Yan *et al*., 2007), genetic markers (Li *et al*., 2004) or their combination (Belaj *et al*., 2012; Diez *et al*., 2012). Morphological evaluation compared to other measures, is easy and inexpensive. However, morphological estimations are more dependent on weather patterns and are more subjective than other methods. Reliability of this measure can however be boosted by performing the experiment more than once under varying environmental conditions. Phenotypic diversity based on morphological attributes has been widely used in characterization of different crops including tomato to generate valuable information to plant breeders (Terzopoulos *et al*., 2007; Gonclaves *et al*. 2009).

Two important components of diversity of a population are its "richness" and "evenness". Richness is the number of different phenotypes divided by the total number in a sample while evenness is the relative abundance of different phenotypes in a sample. The Shannon-Weaver (Shannon and Weaver 1949) and Simpson's (Simpson 1949) indices of diversity are commonly used for both phenotypes and genotypes. Both of these indices use the number and frequency of different phenotypes or genotypes and are defined in equation 2.1:

$$H' = 1 - \sum_{i=1}^{n} pi \ln pi \quad \text{.....Equation 2.1}$$

Where pi is the proportion of genotypes in the ith class of an n-class character and n is the number of phenotypic classes of the variables. Each H'value is divided by its maximum value (log n) and normalized in order to keep the values between 0 and 1.

2.7 Multivariate analysis

Multivariate analysis consists of different methods which are used to measure diversity within a given set of data. These methods include: principal component analysis (PCA), principal coordinate analysis (PCoA), multidimensional scaling (MDS) and cluster analysis (Cruz and Carneiro, 2006). Measures of dissimilarity matrix among these diversity measures can be obtained by Mahalanobis´

distance, coincidence index and Euclidean distance (Cruz and Carneiro, 2006). Results reported by various scientists on tomato (Gustavo, *et al*., 2006; Singh, *et al*., 2006) showed multivariate analysis to be a powerful method to use given a wide collection germplasm. Similarly, previous scientists working on diversity studies have advocated for multivariate analysis as a valid tool to deal with germplasm collection and characterization (Ghafoor *et al*., 2002).

2.7.1 Cluster analysis

Cluster analysis groups genotypes into specific clusters depending on their traits. Genotypes that share similar traits tend to group in the same cluster while those that are dissimilar are group separately (Mohammadi and Prsana, 2003). There are two types of cluster analysis, these are distance and model based methods. The distance method uses a pair wise distance matrix and presents the output as a dendrogram with clearly distinguished clusters and sub clusters (Johnson and Wichern, 1992). The model-based methods make use of observations retrieved from clusters and sub clusters to form different parametric models (Mohammadi and Prsana, 2003).

2.7.2 Principal component analysis

Principal component analysis (PCA) is a descriptive technique which reveals the pattern of character variation among individual accessions (Mwirigi *et al.,* 2009). This analysis brings a set of components that account for meaningful amounts of variation in a population. The first principal component (PC) explains most of the unpredictability of the first hand data relative to all residual PCs. The second PC describes most of the variability not captured by the first PC and uncorrelated with the first, and so on (Jolliffe, 1986).

2.7.3 Principal coordinate analysis

Principal coordinate analysis (PCoA) is an ordination or scaling method that compare groups of genotypes on the basis of their phylogenetic distance metrics (Gower, 1966). PCoA produces low dimensional graphical plots in such a way that original dissimilarities remain very close to the distance between points. PCoA is a critical multivariate tool that groups genotypes and representing them graphically.

2.8 Correlation of phenotypic traits

Phenotypic diversity often provides indirect information about the genetic attribute of a population and is usually easier to observe and quantify than genetic diversity. Correlation analysis is a measure of relationship or association among traits within a given data set (Steel and Torrie, 1980).

Such associations are critical and helpful in selection of important traits for crop improvement. Correlation studies have been previously used in tomato studies to draw relationships among traits. For example, Susic *et al*., 2012 reported a positive and significant association between fruit yield per plant and fruit length. This implies that fluctuations in yield could be influenced by the size of the fruit length and that accessions with high fruit length have the potential of producing higher yields

2.9 Drought stress

According to IPPC (2013), drought is defined as a prolonged period of dry weather caused by lack of precipitation that results in a serious water shortage. Drought can also be defined as an extended imbalance between precipitation and evaporation (Heim 2002). Wilhite and Glantz (1985) identified four types of drought, this include meteorological, agricultural, hydrological and socioeconomic drought. Plants experience drought stress either when the water supply to roots becomes difficult or when the transpiration rate becomes very high. These two conditions often coincide under arid and semi-arid climates (Reddy et al., 2004). Kenya is a drought prone country; this is because of its peculiar eco-climatic conditions as only about 20% of its land mass receives high and regular rainfall. The rest of its land is arid and semi-arid lands where annual rainfall varies from 200 to 500 mm (Republic of Kenya, 2008). Precipitation and irrigation are the two main sources of water in agriculture (Smith, 2000). Rain fed crops contributes to 65% of world food production and the remaining 35% of food is produced from irrigation agriculture (Smith, 2000). In recent years, there has been a major shift in global rainfall patterns leading to unprecedented drought in many crop production areas of the world (Fabeiro *et al*., 2001). Although irrigation would counteract the effects of soil moisture deficits, most crop producing areas in the tropics have limited access to irrigation water sources (Fabeiro *et al*., 2001). Therefore, plant species possessing drought avoidance mechanisms and an ability to acclimatize under moisture stressed conditions would be advantageous because of increased flexibility in response to changing environmental conditions.

2.9.1 Effect of drought stress on growth, yield and quality of tomato

Regulated supply of water is needed in tomato throughout its growing period. This is imperative in ensuring optimal fruit yield and quality. The crop is very susceptible to water stress at specific critical stages such as after transplanting, at flowering and during fruit development (Doorensbos and Kassam, 1979). According to Kirnak *et al*. (2001), water stress in tomato results in significant decreases in electrolyte leakage, chlorophyll content, and fruit yield and quality. Rudich *et al* (1977) noted that moisture deficit in tomato decreased fruit yield, flower percentage, fruit set percentage and dry matter production. Nutritionally, Veit-Kohler *et al* (1999) found that even a small reduction in moisture supply increases quality in tomato by significantly increasing sugars, titrable acids, aroma volatiles and vitamin C concentrations. In contrast, water stress has been found to reduce tomato quality by decreasing mineral uptake (Xu *et al*., 2010).

Sibomana *et al*., (2004) conducted a study on "Money Maker" tomato variety by subjecting the crop to four irrigation regimes. These were 100% pot capacity (PC), 80% PC 60% PC and 40% PC. The authors revealed that moisture deficit reduced the vegetative growth, leaf relative water content (LRWC) and chlorophyll. At 40% of PC SPAD value reduced by 32%, stem girth by 18% and plant height by 24% compared to 100% pot capacity. Fruit yield reduction of up to 69% was recorded under moisture deficit conditions. The study attributed the decrease in plant growth and yield to the negative effect that water stress has on plant physiological processes such as photosynthesis and transpiration.

A study by Morale *et al*., (2015) revealed significant variations among 20 tomato genotypes for incidence of blossom-end rot and relative water content when subjected to moisture stress. Similary, Shaheen *et al*., 2011 evaluated 191 tomato genotypes for drought tolerance and established significant variation for different morphological and physiological traits among the genotypes. Based on all the attributes studied, they found that genotypes L00090 and L00091 were the most drought tolerant as compared to other genotypes while CLN1462A and CLN 1466E were the most drought sensitive. This clearly indicates that different tomato genotypes have different mechanisms through which they respond to challenges of water deficit. It is this variation that requires documentation for future crop improvement programmes.

CHAPTER 3

EVALUATION OF AFRICAN TOMATO LANDRACES FOR MORPHOLOGICAL AND AGRONOMIC TRAITS.

3.1 ABSTRACT

Tomato is an important fruit vegetable crop in Kenya. However, the varieties grown by farmers are few and highly susceptible to biotic and abiotic stresses that reduce productivity. Hence there is need to identify new genotypes with superior morphological and agronomic traits for tomato breeding. The objective of this study was therefore to evaluate 69 African tomato landraces for morphological and agronomic traits. Field and greenhouse experiments were laid out in a randomized complete block design with three replications at the University of Nairobi's Kabete Field Station, Kenya, in 2014 and 2015. The landraces were evaluated based on International Plant Genetic Resources Institute tomato descriptor list of 14 agronomic and 10 morphological traits at flowering and fruiting stages. The first three components of Principal Component Analysis explained 78.2% of total variations among the genotypes. The results indicated that the characters contributing most to the variability among the accessions were growth type, foliage density, fruit size and fruit cross sectional shape. Estimates of Shannon-Weaver diversity index (H') showed high (H'>0.500) levels of polymorphism for all morphological characters evaluated. The indices ranged from 0.9771 (fruit shape) to 0.9995 (flower colour). All traits in both experimentsCluster analysis using unweighted pair group method with arithmetic mean classified the genotypes into two. Cluster I contained 63 accessions while cluster II had 6 accessions. Accessions collected from the different regions tended to group in different clusters and sub-clusters indicating variation among them. The analysis of variance indicated significant differences ($P<0.05$) in the accessions for all the agronomic traits evaluated. Accessions with the highest and the least number of fruits recorded means of 8.3 and 442.3 fruits per plant respectively. Similarly, fruit weight varied widely within the range of 565 g to 2759 g per plant. Yield showed a positive and significant correlation with fruit length ($r=0.42$), fruit width ($r=0.51$), fruit weight ($r=0.50$) and stem girth ($r=0.41$). Thus, this study revealed the presence of sufficient morphological and agronomic diversity among accessions evaluated that can be exploited for tomato improvement.

3.2 INTRODUCTION

Tomato (*Lycopersicon esculentum* L.) belongs to the family *Solanaceae.* Consumption of tomato fruit has gained importance because it is rich in antioxidants that are known to reduce cancer incidences (Wamache, 2005). Alongside other nutrients, tomato fruit also contains β-carotene, vitamin C and phenolic compounds, which offer a lot of health benefits for the consumers (Fajinmi and Fajinmi, 2010; Wang *et al*., 2011). However, the few modern tomato cultivars grown in Kenya have a narrow genetic base often resulting from selection during breeding efforts (Yi *et al*., 2008; Terzopoulos *et al*., 2009). This makes them vulnerable to yield reducing biotic and abiotic factors which further increase the cost of production (Maerere *et al*., 2006). There is need therefore to collect, characterize and evaluate unknown tomato germplasm so as to widen the tomato genetic base.

Phenotypic characterization as used in plants involves cultivation of sub-samples by assessing their morphological and agronomic description (Bajracharya *et al*., 2006). It relies on the recording and description of phenotypic and agronomic characteristics that cover the leaf, floral parts, yield and yield components. The International Plant Genetic Resources Institute (IPGRI) has developed descriptors for quantitative as well as qualitative characters to ensure precise, accurate and uniform identification of genotypes (Chavez *et al*., 1990). Results from morpho-agronomic description are critical in determining the genetic variability of the genotypes stored in gene banks and establishing genotypes stored in duplicate (Valls 2007).

Plant characterization is an important activity in crop improvement programmes because the amount of genetic diversity within populations determines the rate of adaptive evolution and the extent of response to traditional breeding through selection (Mwirigi *et al*., 2009). The use of such traits facilitates breeding for wider geographic adaptability especially for tolerance against biotic and abiotic stresses. The identification of variability among accessions is therefore pivotal to the maintenance, utilization and acquisition of germplasm resources (Mwirigi *et al*., 2009).

The main goal of a tomato breeder is to sustainably develop high yielding and high quality varieties which can resist continuous pest and disease infestation as well as environmental stresses. African tomatoes are landraces that are unimproved and have distinct identities. They are typically characterized by good stress tolerance and local adaptability (Newton *et al*., 2010). This provides a

potential for increasing the genetic variation in modern tomato varieties (Huang *et al*., 2012). To date, a large number of African tomato landraces have been collected, however, very few of them have been systematically evaluated (Robertson and Labate, 2007). Therefore the objective of the current study was to evaluate the African tomato landraces for morphological and agronomic traits that would aid in tomato crop improvement programmes.

3.3 MATERIALS AND METHODS

3.3.1 Site description

The study was conducted during the short and long rains of 2014 and 2015, respectively, at the University of Nairobi's Upper Kabete Field Station. The site lies at an altitude of 1940 meters above sea level and between latitude 1^0 14' 20' South and 1^0 15' 15'North and longitude 36^0 44' East. It receives with long rains from early March to late May and short rains from October to December (Appendix 1). Mean annual maximum and minimum temperatures are 23°C and 13°C, respectively (Siderus, 1976). The average annual rainfall is about 1,000 mm with a range of between 700 mm year-1 and 1,500 mm year $^{-1}$ (Mburu, 1996). Kabete soils are classified as humic nitisols according to the FAO – UNESCO System (FAO, 1990). They are deep well-drained, dark reddish brown and friable clays when moist.

3.3.2 Soil analyses

Soil testing and analysis was done at the Kenya Agricultural and Livestock Research Organization (KALRO) Laboratories (Appendix 3). Soil pH was determined using a pH meter (Schofield and Taylor, 1955). Mehlich Double Acid Method (Warnkce and Brown, 1998) was used to determine the available K, Na, Ca, Mg and Mn. Total organic carbon was determined using Calorimetric method while the Nitrogen level was estimated using Kjeldahl method (Kjedahl, 1883). Available trace elements namely; Fe, Zn and Cu were determined using atomic absorption spectrophotometer (AAS).

3.3.3 Plant materials

Sixty nine (69) tomato landraces sourced from the World Vegetable Centre (AVDRC) in Taiwan and the National Genetic Resources Institute (NGRI) in Kenya were evaluated in the study. These landraces were a collection from 11 African countries (Figure 3.1). These included: Ethiopia (16), Morocco (15), Madagascar (14), South Africa (10), Egypt (3), Mauritius (3) Kenya (2), Tanzania (2), Zimbabwe (2), Nigeria (1) and Zambia (1) (Figure 3.1). The respective gene banks coded the accessions based on collection countries as shown in Table 3.1. Apart from the codes, no characteristics were given to the accessions by the gene banks.

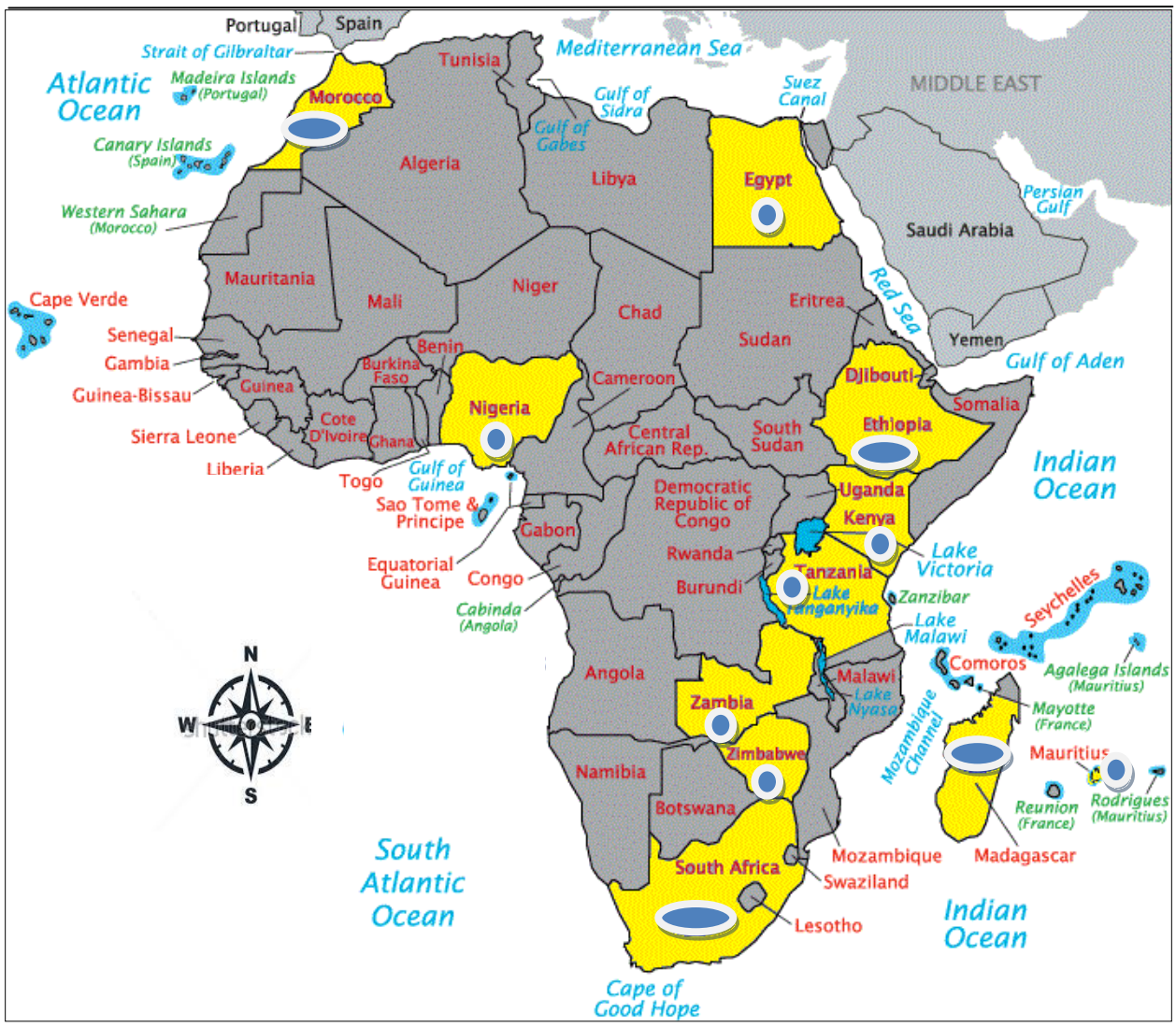


Figure 3.1: Map of Africa showing the country origins for the accessions evaluated in this study

- Countries where collections were done.
- Small circles indicate less than five collections in the country.
- Large circles indicate more than ten collections in the country.

Table 3.1: List of the African tomato accessions evaluated in the study and their countries of origin

S/no	Acc Name	Species name	Origin	S/no	Acc Name	Species name	Origin
1	GBK 050580	*S.lycopersicum*	Kenya	36	VI006481-A	*S.lycopersicum*	Zimbabwe
2	GBK 050589	*S.lycopersicum*	Kenya	37	VI006825	*S.lycopersicum*	Ethiopia
3	RV02114	*S.lycopersicum*	Tanzania	38	VI006826	*S.lycopersicum*	Ethiopia
4	RV101884	*S.lycopersicum*	Madagascar	39	VI006827	*S.lycopersicum*	Ethiopia
5	RVI01885	*S.lycopersicum*	Madagascar	40	VI006828	*S.lycopersicum*	Ethiopia
6	RVI01887	*S.lycopersicum*	Madagascar	41	VI006832	*S.lycopersicum*	Ethiopia
7	RVI01888	*S.lycopersicum*	Madagascar	42	VI006833	*S.lycopersicum*	Ethiopia
8	RVI01896	*S.lycopersicum*	Madagascar	43	VI006837	*S.lycopersicum*	Ethiopia
9	RVI01983	*S.lycopersicum*	Madagascar	44	VI006838	*S.lycopersicum*	Ethiopia
10	RVI02098	*S.lycopersicum*	Madagascar	45	VI006840	*S.lycopersicum*	Ethiopia
11	RVI02100	*S.lycopersicum*	Madagascar	46	VI006841	*S.lycopersicum*	Ethiopia
12	RVI02102	*S.lycopersicum*	Madagascar	47	VI006842	*S.lycopersicum*	Ethiopia
13	RVI02104	*S.lycopersicum*	Madagascar	48	VI006847	*S.lycopersicum*	Ethiopia
14	RVI02107	*S.lycopersicum*	Madagascar	49	VI006848	*S.lycopersicum*	Ethiopia
15	RVI02109	*S.lycopersicum*	Madagascar	50	VI006864	*S.lycopersicum*	Ethiopia
16	RVI02111	*S.lycopersicum*	Madagascar	51	VI006865	*S.lycopersicum*	Ethiopia
17	RVI02112	*S.lycopersicum*	Madagascar	52	VI006869	*S.lycopersicum*	Ethiopia
18	VI005871	*S.lycopersicum*	Morocco	53	VI006881-B	*S.lycopersicum*	Zimbabwe
19	VI005872	*S.lycopersicum*	Morocco	54	VI006892	*S.lycopersicum*	South Africa
20	VI005873	*S.lycopersicum*	Morocco	55	VI006972	*S.lycopersicum*	Tanzania
21	VI005874	*S.lycopersicum*	Morocco	56	VI007108	*S.lycopersicum*	South Africa
22	VI005875	*S.lycopersicum*	Morocco	57	VI007539	*S.lycopersicum*	South Africa
23	VI005876	*S.lycopersicum*	Morocco	58	VI007540	*S.lycopersicum*	South Africa
24	VI005877	*S.lycopersicum*	Morocco	59	VI008098	*S.lycopersicum*	South Africa
25	VI005878	*S.lycopersicum*	Morocco	60	VI008099	*S.lycopersicum*	South Africa
26	VI005889-A	*S.lycopersicum*	Egypt	61	VI008234	*S.lycopersicum*	Nigeria
27	VI005895	*S.lycopersicum*	Egypt	62	VI008916	*S.lycopersicum*	South Africa
28	VI005905	*S.lycopersicum*	Morocco	63	VI030375	*S.lycopersicum*	South Africa
29	VI005986	*S.lycopersicum*	Morocco	64	VI030379	*S.lycopersicum*	Mauritius
30	VI005987	*S.lycopersicum*	Morocco	65	VI030380	*S.lycopersicum*	Mauritius
31	VI005988	*S.lycopersicum*	Morocco	66	VI030381	*S.lycopersicum*	Mauritius
32	VI005989	*S.lycopersicum*	Morocco	67	VI030852	*S.lycopersicum*	South Africa
33	VI005990	*S.lycopersicum*	Morocco	68	VI035028	*S.lycopersicum*	South Africa
34	VI005991	*S.lycopersicum*	Morocco	69	VI037948	*S.lycopersicum*	Zambia
35	VI006480	*S.lycopersicum*	Egypt				

S/no – serial number, Acc name – Accession name

3.3.4 Experimental design and crop husbandry

Field experiments

Evaluations were performed on 69 tomato accessions using a randomized complete block design with three replications. The experimental field was ploughed and harrowed with a tractor. Each accession was planted from a seedling in two rows of four planting holes per row (eight plants in a plot). Spacing of 50 cm between plants and 75 cm between the rows was maintained. A 1.5 m path separating the blocks with a guard row spacing of 1.0 m was maintained. The experiments were carried out in two seasons (September 2014 to December 2014 and February 2015 to May 2015). Transplanting was done in the evening when the weather was cool to increase the chances of survival for the seedlings. During transplanting 150 kg/ha of di-ammonium phosphate (47% P_20_5) was used. Two weeks after transplanting, 200 kg/ha of urea (46% N) was applied followed by calcium ammonium nitrate (CAN) in the fourth, seventh and twelfth week at the rate of 200 kg/ha (27%N). The crop was kept free of weeds by manual weeding and rogueing as per normal farmers' practice. Irrigation was carried out twice every week when moisture level fell below field capacity. Crop support (trellised) was carried out as per the farmers' practice. Crops were sprayed with vapcomic® EC acaricide (active ingredient- abamectin) at the rate of 15ml/20L to control leaf miners and spider mites, karate® EC insecticide (active ingredient- L-cyhalothrin) at the rate of 50g/20L to control white flies and ridomil gold® fungicide (active ingredient- metalaxyl + mancozeb) at the rate of 50g/20L to control poudry mildew.

Glasshouse experiments

Sixty nine (69) tomato accessions were evaluated in polythene pots in three replicates. Two glasshouse experiments were carried out in a randomized complete block design with three replications in May 2014 to August 2014 and September 2014 to December 2014. Soil was collected next to the field trial and sterilized at 105^0 C for 72 hours. Planting pots (20.32 × 35.56 cm in size) were then filled with 10 kg of air-dried soil. During transplanting 5g/pot (one bottle cap) of di-ammonium phosphate (DAP) fertilizer (18:46:0) was used. Two weeks after transplanting, 5g/pot of urea (46% N) were applied followed by calcium ammonium nitrate (CAN) in the fourth, seventh and twelfth week at the rate of 2.5g/pot (27%N). The crop was kept free of weeds by manual weeding and rogueing as per normal farmers' practice. Irrigation was carried out twice every week. Crop support (trellised) was carried out as per the farmers' practice. Crops were

sprayed with karate® EC insecticide (active ingredient-L-cyhalothrin) at the rate of 50g/20L to control white flies.

3.3.5 Data collection

Qualitative traits

Ten qualitative traits namely stem colour, growth type, pubescence density, foliage density, flower colour, presence of green shoulder, fruit shape, mature fruit colour, fruit size and fruit cross-sectional shape (Table 3.2) were evaluated based on characters by IPGRI (International Plant Genetic Resources Institute) tomato descriptor (Darwin *et al*., 2003). Three plants of each accession were randomly selected and tagged for data collection in each of the plots in the field. Similarly, three plants of each accession were tagged for data collection in the greenhouse experiments. All observations for each character were made on the same day for all accessions after 50% flowering.

Table 3.2: Character, descriptor and codes used for characterization of qualitative traits in African tomato landraces

S/no.	Character	descriptor and code
1	Stem colour	Green (1), Purple (2)
2	Growth type	Determinate (2), Indeterminate (4)
3	Stem pubescence density	Sparse (3), Intermediate (5), Dense (7)
4	Foliage density	Sparse (3), Intermediate (5), Dense (7)
5	Flower colour	White (1), Yellow (2), Orange (3)
6	Mature fruit colour	Green (1), Yellow (2), Orange (3), Pink (4), Red (5)
7	Fruit shape	Flattened (1), Rounded (3), Heart-shaped (5), Pyriform (7)
8	Presence of green shoulder	Present (1), Absent (2)
9	Fruit cross-sectional shape	Round (1), Angular (2), Irregular (3)
10	Fruit size	Small 3 - 5 cm (2), Large 8.1 - 10 cm (4)

Source: International Plant Genetic Resources Institute (IPGRI) tomato descriptor, S/no-serial number

Quantitative traits

Quantitative traits, namely days to 50% flowering, SPAD values, plant height, stem girth, number of primary branches, leaf length, leaf width, single leaf area, days to flowering, number of fruits per plant, fruit weight per plant, single fruit weight per plant, fruit length and fruit width were evaluated. All measurements and counts were done on the same day for the field and glasshouse experiments to avoid bias. Days to flowering was recorded as the number of days from sowing to

when 50% of the plants in each plot had flowered. The leaf chlorophyll content was taken at flower initiation stage on a fully expanded young leaf from three plants in each stand and averaged. This value was taken using a non-destructive, hand-held chlorophyll meter Soil Plant Analysis Development (SPAD-502, Minolta Camera Co., Ltd., Japan). Height of nine plants was measured in centimeters from the base of the plant to the tip of the main stem using a meter rule. Stem girth (cm) was determined by measuring the circumference of nine plants at the main stem slightly above the second truce. Number of primary branches of nine plants was determined by counting branches emanating from the main stem. Leaf length of nine plants was measured in centimeters from the pulvinus to the tip of the leaf while leaf width (cm) was measured at the widest part of the basal leaves. The single leaf area (cm^2) of nine plants was calculated using leaf length and leaf width measurements following the formulae of Rivera *et al.,* (2007) as follows: SLA = 0.763L + 0.34W, where SLA is single leaf area, L is leaf length and W is leaf width.

All fruit characteristics were evaluated at physiological maturity. Days to maturity was recorded from sowing until when 50% of plants had at least one ripened fruit. Fruit length of nine plants was recorded from stem end to blossom end while fruit width was recorded at the largest diameter of cross-sectioned fruits. The total number of fruits per plant was determined by counting the fruits of nine plants and weighing done to obtain fruit weight per plant. Total number of fruits per plant was then divided by the total fruit weight per plant to obtain the single fruit weight per plant.

3.6.6 Data analysis

Qualitative traits

Previous studies on plant characterization majorly relied on Shannon-Weaver diversity index, clustering analysis and principal component analysis as measures of phenotypic diversity. The current study carried out phenotypic frequency distributions based on the Shannon-Weaver diversity index (H') as described by Perry and McIntosh (1991). Dissimilarities were estimated based on Euclidean distance matrix and hierarchical clustering analyses of unweighted pair group method of arithmetic averaging performed in DARwin 6.0 software as described by Perrier and Jacquemoud-Collet (2006). The clusters and relationships were displayed as a phenogram. Multivariate-principal component analysis was conducted using Genstat software programme, version 15 (Payne *et al.,* 2011) to identify the most significant descriptors in capturing the

qualitative variation within the accessions. Coded data from the ten morphological traits were used to generate cluster analysis in DARwin 6.0 software.

Quantitative traits

Analysis of variance for the quantitative data was performed using Genstat version 15 (Payne *et al.*, 2011) at 5% level of significance. Mean separation for treatment effects that were significant was done by Fisher's protected least significant difference test using Genstat version 15. Statistical measures of mean and coefficient of variation were used to estimate variability within each quantitative trait. A correlation analysis was performed in Genstat to estimate quantitative relationships among the traits and also to determine key agronomic traits of importance in breeding work.

3.4 RESULTS

3.4.1 Qualitative characteristics

Growth habit and foliage density

It was observed that 68.1% of the accessions studied in the field and in the glasshouse produced an indeterminate growth habit with only 31.9% showing determinate growth habit (Tables 3.3 and 3.4). All accessions from Egypt, Kenya, Nigeria, Tanzania, Zambia and Zimbabwe had indeterminate growth type while accessions from Mauritius had a determinate growth habit. On the other hand, accessions from Ethiopia, Madagascar, Morocco and South Africa showed both determinate and indeterminate growth types (Figures 3.2).

Figure 3.2: (A) Accession GBK 050580: indeterminate growth habit with dense foliage; (B) accession RVI02100: determinate growth habit with sparse foliage

Foliage density for accessions evaluated in the greenhouse showed that 69.6% accessions were dense while 30.4% were intermediate. In the field, 62.3% and 37.7% of the accessions had dense and intermediate foliage, respectively. It was also observed that greenhouse grown accessions had dense foliage compared to those grown in the field.

Table 3.3: Morphological descriptors of 69 tomato accessions grown in the field

S/no	Acc no.	SC	FC	GT	FD	PD	GS	EFC	Fruit shape	FCS	Fruit size
1	GBK 050580	Purple	Yellow	Indeterminate	Dense	Dense	Present	Yellow	Rounded	Round	Small
2	GBK 050589	Purple	Yellow	Indeterminate	Dense	Dense	Present	Yellow	Rounded	Round	Small
3	RV02114	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Small
4	RV101884	Green	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	Rounded	Round	Intermediate
5	RVI01885	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	High rounded	Round	Large
6	RVI01887	Purple	Yellow	determinate	Dense	Intermediate	Present	Red	High rounded	Round	Intermediate
7	RVI01888	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	High rounded	Round	Intermediate
8	RVI01896	Green	Yellow	determinate	Sparse	Intermediate	Absent	Red	Rounded	Round	Large
9	RVI01983	Green	Yellow	determinate	Sparse	Intermediate	Absent	Red	Rounded	Round	Very large
10	RVI02098	Green	Yellow	determinate	Sparse	Intermediate	Present	Red	Rounded	Round	Large
11	RVI02100	Green	Yellow	determinate	Sparse	Intermediate	Present	Red	Rounded	Round	Large
12	RVI02102	Green	Yellow	determinate	Sparse	Intermediate	Present	Red	Rounded	Round	Intermediate
13	RVI02104	Purple	Yellow	determinate	Dense	Dense	Absent	Red	Rounded	Round	Very large
14	RVI02107	Purple	Yellow	determinate	Dense	Dense	Absent	Red	Rounded	Round	Very large
15	RVI02109	Purple	Yellow	determinate	Intermediate	Dense	Absent	Red	Rounded	Round	Intermediate
16	RVI02111	Purple	Yellow	determinate	Dense	Dense	Absent	Red	Rounded	Round	Intermediate
17	RVI02112	Purple	Yellow	determinate	Dense	Intermediate	Absent	Red	Rounded	Round	Intermediate
18	VI005871	Purple	Yellow	Indeterminate	Intermediate	Dense	Absent	Red	Rounded	Irregular	Large
19	VI005872	Purple	Yellow	Indeterminate	Intermediate	Dense	Present	Red	Elipsoid	Round	Large
20	VI005873	Purple	Yellow	Indeterminate	Intermediate	Dense	Present	Red	Rounded	Round	Intermediate
21	VI005874	Purple	Yellow	Indeterminate	Intermediate	Dense	Present	Red	Rounded	Round	Large
22	VI005875	Purple	Yellow	Indeterminate	Intermediate	Dense	Present	Red	Flattened	Irregular	Large
23	VI005876	Purple	Yellow	determinate	Intermediate	Dense	Present	Red	Rounded	Round	Very large
24	VI005877	Purple	Yellow	Indeterminate	Intermediate	Dense	Absent	Red	Flattened	Irregular	Very large
25	VI005878	Purple	Yellow	Indeterminate	Intermediate	Dense	Present	Red	Rounded	Round	Large
26	VI005889-A	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Flattened	Irregular	Intermediate
27	VI005895	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Flattened	Irregular	Large
28	VI005905	Purple	Yellow	Indeterminate	Intermediate	Dense	Present	Red	Rounded	Round	Small
29	VI005986	Purple	Yellow	determinate	Dense	Intermediate	Present	Red	Rounded	Round	Very large
30	VI005987	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Flattened	Round	Large
31	VI005988	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Flattened	Round	Large
32	VI005989	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Small
33	VI005990	Purple	Yellow	determinate	Dense	Intermediate	Present	Red	Rounded	Round	Large
34	VI005991	Purple	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	Rounded	Round	Intermediate
35	VI006480	Purple	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	Flattened	Irregular	Intermediate
36	VI006481-A	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Intermediate
37	VI006825	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Flattened	Irregular	Intermediate

Table 3.3: Morphological descriptors of 69 tomato accessions grown in the field

S/no	Acc no.	SC	FC	GT	FD	PD	GS	EFC	Fruit shape	FCS	Fruit size
38	VI006826	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Very large
39	VI006827	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Small
40	VI006828	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Intermediate
41	VI006832	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Intermediate
42	VI006833	Purple	Yellow	determinate	Dense	Intermediate	Present	Red	Cylindrical	angular	Large
43	VI006837	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Elipsoid	Round	Intermediate
44	VI006838	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Intermediate
45	VI006840	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Flattened	Irregular	Very large
46	VI006841	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Intermediate
47	VI006842	Purple	White	Indeterminate	Dense	Intermediate	Present	Yellow	Rounded	Round	Large
48	VI006847	Purple	Yellow	Indeterminate	Dense	Intermediate	Absent	Red	Rounded	Round	Intermediate
49	VI006848	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Intermediate
50	VI006864	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Small
51	VI006865	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Intermediate
52	VI006869	Purple	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	Rounded	Round	Large
53	VI006881-B	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Pyriform	Round	Small
54	VI006892	Purple	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	High rounded	Round	Small
55	VI006972	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Cylindrical	Round	Intermediate
56	VI007108	Purple	Yellow	Indeterminate	Dense	Dense	Present	Red	Pyriform	Round	Intermediate
57	VI007539	Purple	Yellow	Indeterminate	Dense	Dense	Present	Red	Rounded	Round	Very large
58	VI007540	Purple	Yellow	Determinate	Intermediate	Dense	Absent	Red	Rounded	Round	Very large
59	VI008098	Purple	Yellow	Indeterminate	Intermediate	Dense	Present	Red	Rounded	Round	Intermediate
60	VI008099	Purple	Yellow	Indeterminate	Intermediate	Dense	Absent	Red	Rounded	Round	Large
61	VI008234	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Intermediate
62	VI008916	Purple	Yellow	Indeterminate	Intermediate	Dense	Present	Red	Rounded	Round	Intermediate
63	VI030375	Purple	Yellow	Determinate	Intermediate	Dense	Present	Red	Rounded	Irregular	Very large
64	VI030379	Purple	Yellow	Determinate	Dense	Intermediate	Present	Red	Heartshaped	Round	Large
65	VI030380	Purple	Yellow	Determinate	Dense	Intermediate	Present	Red	Heartshaped	Round	Intermediate
66	VI030381	Purple	Yellow	Determinate	Dense	Intermediate	Absent	Red	Heartshaped	Round	Intermediate
67	VI030852	Purple	Yellow	Determinate	Intermediate	Dense	Present	Red	Rounded	Round	Large
68	VI035028	Purple	Yellow	Determinate	Intermediate	Dense	Absent	Red	Rounded	Round	Intermediate
69	VI037948	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Small

S/no-serial number, Acc name- accession name, SC-stem colour, FC-flower colour, GT-growth type, FD-foliage density, PD-pubescence density, GS-presence of green shoulder, EFC-exterior fruit colour, FCS-fruit cross-section shape,

Table 3.4: Morphological descriptors of 69 tomato accessions grown in the glasshouse

S/no	**Acc no.**	**SC**	**FC**	**GT**	**FD**	**PD**	**GS**	**EFC**	**Fruit shape**	**FCS**	**Fruit size**
1	GBK 050580	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Yellow	Rounded	Round	Small
2	GBK 050589	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Yellow	Rounded	Round	Small
3	RV02114	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Small
4	RV101884	Green	Yellow	Indeterminate	Dense	Intermediate	Present	Red	High rounded	Round	Small
5	RVI01885	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	High rounded	Round	Large
6	RVI01887	Purple	Yellow	Determinate	Dense	Intermediate	Present	Red	High rounded	Round	Intermediate
7	RVI01888	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	High rounded	Round	Intermediate
8	RVI01896	Green	Yellow	Determinate	Sparse	Sparse	Absent	Red	Rounded	Round	Large
9	RVI01983	Green	Yellow	Determinate	Sparse	Sparse	Absent	Red	Rounded	Round	Large
10	RVI02098	Green	Yellow	Determinate	Sparse	Sparse	Present	Red	Rounded	Round	Intermediate
11	RVI02100	Green	Yellow	Determinate	Sparse	Sparse	Present	Red	Rounded	Round	Large
12	RVI02102	Green	Yellow	Determinate	Sparse	Sparse	Present	Red	Rounded	Round	Intermediate
13	RVI02104	Purple	Yellow	Determinate	Dense	Intermediate	Absent	Red	Rounded	Round	Large
14	RVI02107	Purple	Yellow	Determinate	Dense	Intermediate	Absent	Red	Rounded	Round	Very large
15	RVI02109	Purple	Yellow	Determinate	Dense	Intermediate	Absent	Red	Rounded	Round	Intermediate
16	RVI02111	Purple	Yellow	Determinate	Dense	Intermediate	Absent	Red	Rounded	Round	Intermediate
17	RVI02112	Purple	Yellow	Determinate	Dense	Intermediate	Absent	Red	Rounded	Round	Intermediate
18	VI005871	Purple	Yellow	Indeterminate	Dense	Intermediate	Absent	Red	Rounded	Irregular	Very large
19	VI005872	Purple	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	Elipsoid	Round	Intermediate
20	VI005873	Purple	Yellow	Indeterminate	Dense	Sparse	Present	Red	Rounded	Round	Intermediate
21	VI005874	Purple	Yellow	Indeterminate	Dense	Sparse	Present	Red	Rounded	Round	Intermediate
22	VI005875	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Flattened	Irregular	Large
23	VI005876	Purple	Yellow	Determinate	Intermediate	Intermediate	Present	Red	Rounded	Round	Large
24	VI005877	Purple	Yellow	Indeterminate	Intermediate	Sparse	Absent	Red	Flattened	Irregular	Large
25	VI005878	Purple	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	Rounded	Round	Intermediate
26	VI005889-A	Purple	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	Flattened	Irregular	Large
27	VI005895	Purple	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	Flattened	Irregular	Large
28	VI005905	Purple	Yellow	Indeterminate	Intermediate	Sparse	Present	Red	Rounded	Round	Small
29	VI005986	Purple	Yellow	Determinate	Intermediate	Sparse	Present	Red	Rounded	Round	Very large
30	VI005987	Purple	Yellow	Indeterminate	Dense	Sparse	Present	Red	Rounded	Round	Intermediate
31	VI005988	Purple	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	Rounded	Round	Intermediate
32	VI005989	Purple	Yellow	Indeterminate	Dense	Sparse	Present	Red	Rounded	Round	Intermediate
33	VI005990	Purple	Yellow	Determinate	Intermediate	Sparse	Present	Red	Rounded	Round	Intermediate
34	VI005991	Purple	Yellow	Indeterminate	Intermediate	Sparse	Present	Red	Rounded	Round	Intermediate
35	VI006480	Purple	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	Flattened	Irregular	Small
36	VI006481-A	Purple	Yellow	Indeterminate	Dense	Dense	Present	Red	Rounded	Round	Intermediate
37	VI006825	Purple	Yellow	Indeterminate	Intermediate	Sparse	Present	Red	Flattened	Irregular	Very large

Table 3.4: Morphological descriptors of 69 tomato accessions grown in the glasshouse

S/no	Acc no.	SC	FC	GT	FD	PD	GS	EFC	Fruit shape	FCS	Fruit size
38	VI006826	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Large
39	VI006827	Purple	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	Rounded	Round	Small
40	VI006828	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Intermediate
41	VI006832	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Intermediate
42	VI006833	Purple	Yellow	Determinate	Dense	Sparse	Present	Red	Cylindrical	angular	Small
43	VI006837	Purple	Yellow	Indeterminate	Intermediate	Sparse	Present	Red	Elipsoid	Round	Intermediate
44	VI006838	Purple	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	Rounded	Round	Intermediate
45	VI006840	Purple	Yellow	Indeterminate	Dense	Sparse	Present	Red	Flattened	Irregular	Large
46	VI006841	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Intermediate
47	VI006842	Purple	White	Indeterminate	Dense	Sparse	Present	Yellow	Rounded	Round	Large
48	VI006847	Purple	Yellow	Indeterminate	Dense	Sparse	Absent	Red	Rounded	Round	Intermediate
49	VI006848	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Intermediate
50	VI006864	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Small
51	VI006865	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Intermediate
52	VI006869	Purple	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	Rounded	Round	Large
53	VI006881-B	Purple	Yellow	Indeterminate	Dense	Dense	Present	Red	Pyriform	Round	Small
54	VI006892	Purple	Yellow	Indeterminate	Intermediate	Sparse	Present	Red	High rounded	Round	Small
55	VI006972	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Cylindrical	Round	Intermediate
56	VI007108	Purple	Yellow	Indeterminate	Intermediate	Sparse	Present	Red	Pyriform	Round	Intermediate
57	VI007539	Purple	Yellow	Indeterminate	Intermediate	Sparse	Present	Red	Rounded	Round	Large
58	VI007540	Purple	Yellow	Determinate	Intermediate	Sparse	Absent	Red	Rounded	Round	Very large
59	VI008098	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Intermediate
60	VI008099	Purple	Yellow	Indeterminate	Dense	Intermediate	Absent	Red	Rounded	Round	Intermediate
61	VI008234	Purple	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	Rounded	Round	Intermediate
62	VI008916	Purple	Yellow	Indeterminate	Dense	Intermediate	Present	Red	Rounded	Round	Intermediate
63	VI030375	Purple	Yellow	Determinate	Intermediate	Sparse	Present	Red	Rounded	Irregular	Large
64	VI030379	Purple	Yellow	Determinate	Dense	Sparse	Present	Red	Heartshaped	Round	Very large
65	VI030380	Purple	Yellow	Determinate	Dense	Sparse	Present	Red	Heartshaped	Round	Very large
66	VI030381	Purple	Yellow	Determinate	Dense	Sparse	Absent	Red	Heartshaped	Round	Intermediate
67	VI030852	Purple	Yellow	Determinate	Intermediate	Sparse	Present	Red	Rounded	Round	Large
68	VI035028	Purple	Yellow	Determinate	Intermediate	Sparse	Absent	Red	Rounded	Round	Intermediate
69	VI037948	Purple	Yellow	Indeterminate	Intermediate	Intermediate	Present	Red	Rounded	Round	Small

S/no-serial number, Acc name- accession name, SC-stem colour, FC-flower colour, GT-growth type, FD-foliage density, PD-pubescence density, GS-presence of green shoulder, EFC-exterior fruit colour, FCS-fruit cross-section shape

Flower and stem colour

Flower colour of the study accessions grown in the field and in the glasshouse were mainly yellow (98.5%) with only 1.5% showing white colour (Tables 3.3 and 3.4). The Accession with white flower was VI006842 from Ethiopia (Figure 3.3).

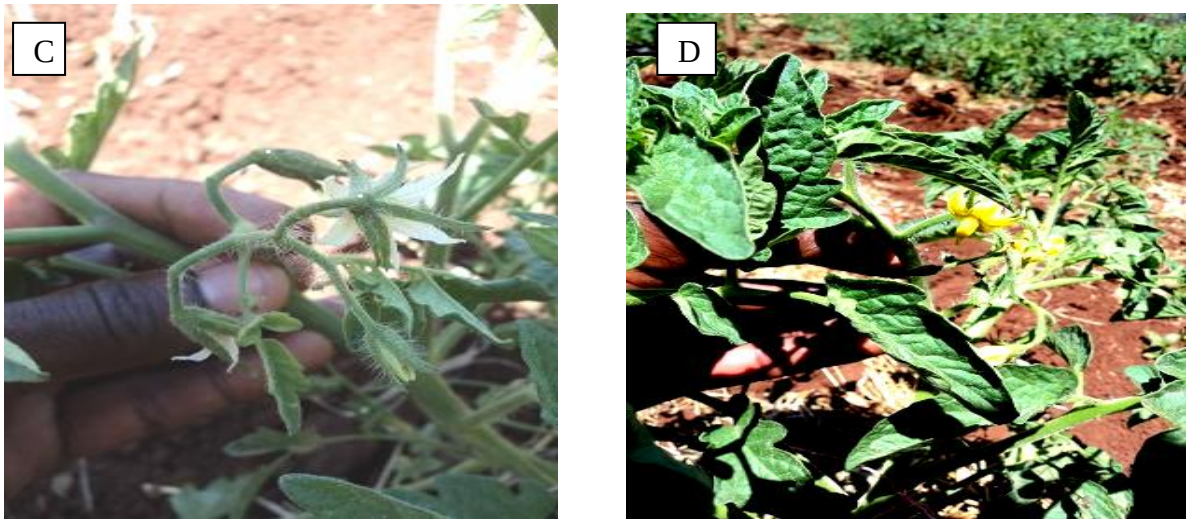


Figure 3.3: (C) AccessionVI006842: white flowers; (D) accession VI008098: yellow flowers

The study also revealed that most of the accessions evaluated had purple stem (91.3%) with only 8.7% having green stem (Tables 3.3 and 3.4). All the green stem accessions (RVI01896, RVI01983, RVI02098, RVI02100 and RVI02102) were from Madagascar (Figure 3.4).

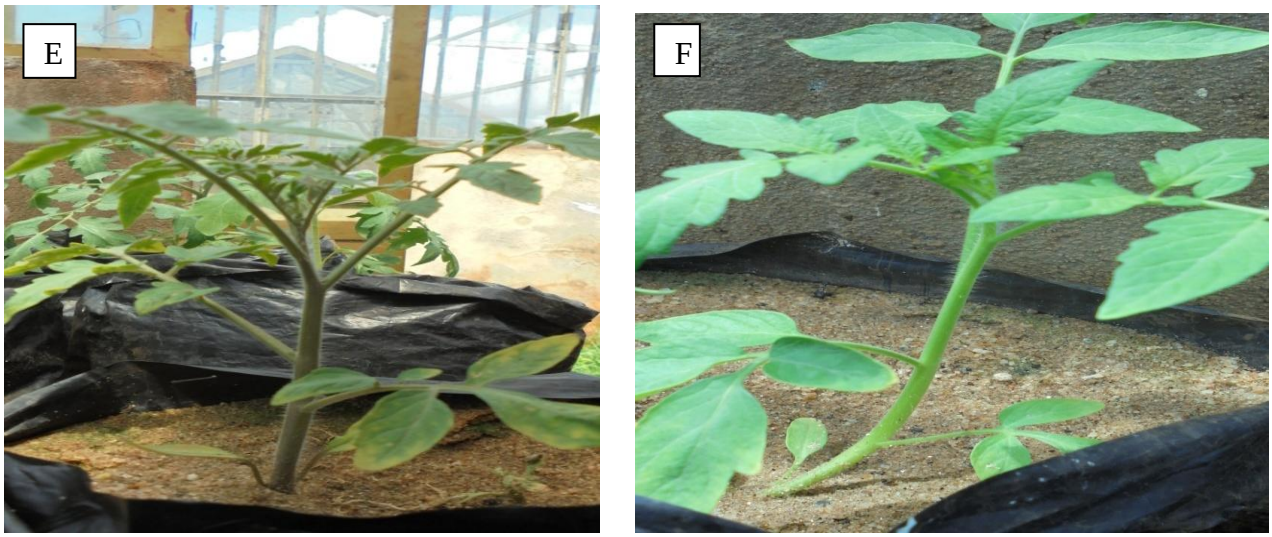


Figure 3.4: (E) Accession VI006833: purple stem; (F) accession RVI002098: green stem

Stem hairiness

Stem hairiness for the study accessions in the field were mainly intermediate at 65.2% while 34.8% were dense (Tables 3.3 and 3.4). In the greenhouse, 53.6% of accessions were intermediate, 43.5% were sparse and 2.9% dense (Tables 3.3 and 3.4). Most of the accessions were dense in the field as compared to the green house (Figures 3.5).

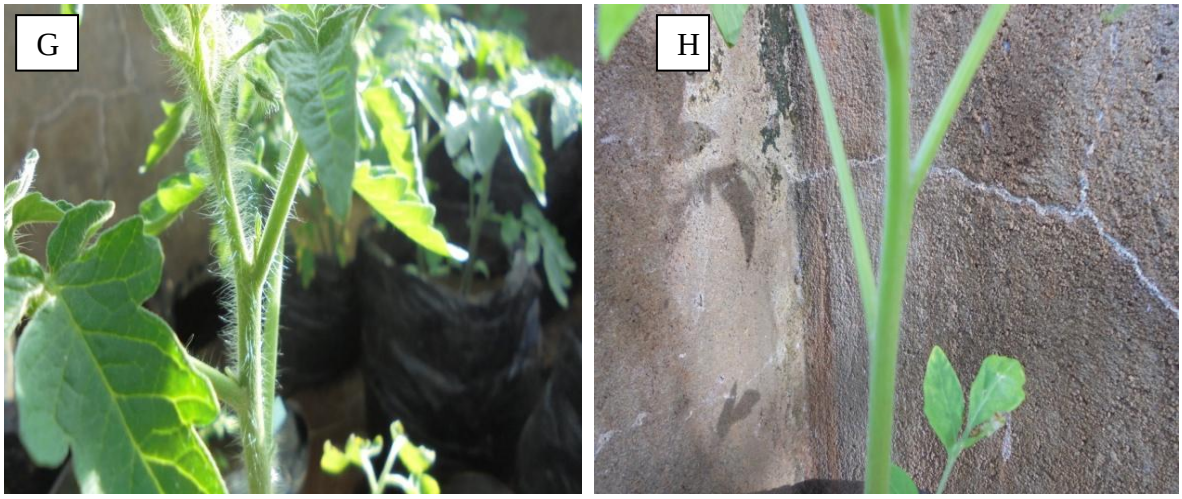


Figure 3.5: (G) Accession RVI01884: intermediate pubescence density; (H) accession: RVI02102: sparse pubescence density

Fruit characteristics

About 79.7% and 20.3% of the accessions studied in both the field and in the greenhouse showed the presence and absence of green shoulder respectively on immature tomato fruit. Of the 14 accessions that showed the absence of green shoulder, seven were from Madagascar (Figure 3.6).

Figure 3.6: (I) Accession VI008099: absence of a green shoulder; (J) accession VI006840: presence of a green shoulder

Fruit colour at maturity showed the predominance of red colour for 66 accessions (95.6%) with only three accessions (4.4%) showing the yellow colour for both greenhouse and field experiments (Tables 3.3 and 3.4). Accessions with yellow coloured fruit were GBK 050580 and GBK 050589 both from Kenya and VI006842 from Ethiopia (Figure 3.7).

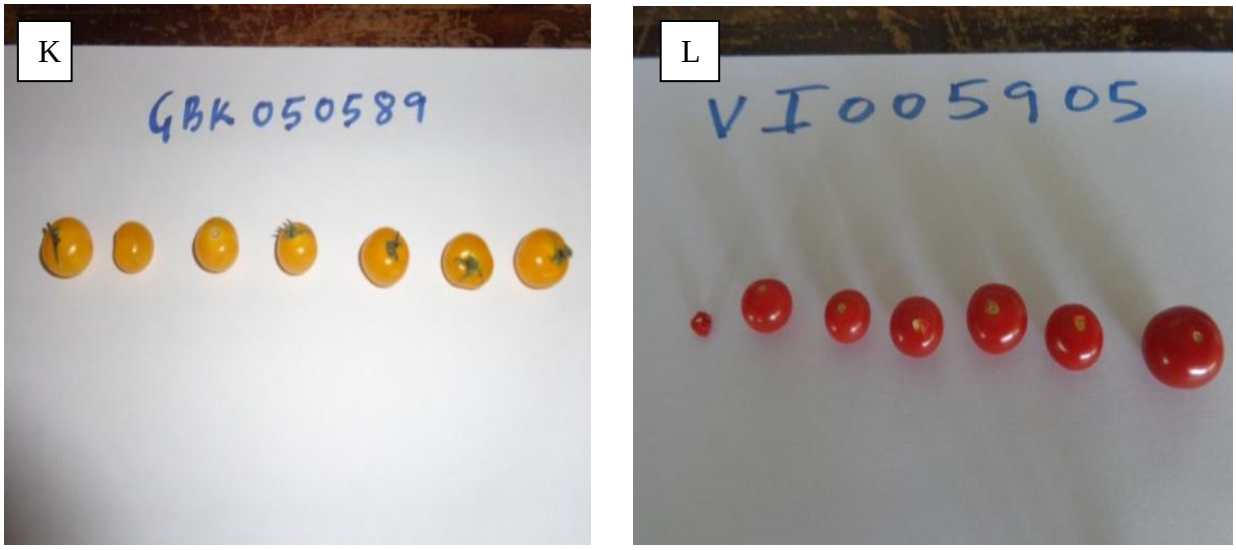


Figure 3.7: (K) Accession GBK 050589: small yellow fruits; (L) accession VI005905: small red fruits

Fruit shapes of 46 accessions (66.7%) were rounded, ten accessions (14.5%) were flattened, four (5.8%) were high rounded while three (4.4%) were heart shaped. Other shapes observed were ellipsoid, pyriform and cylindrical with each recording two accessions (2.9%).

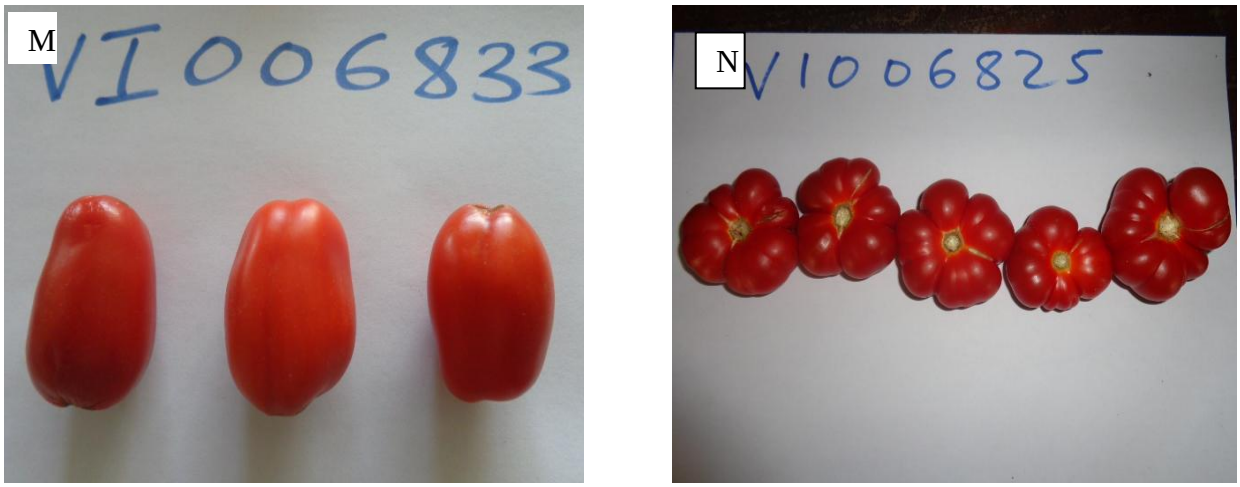


Figure 3.8: (M) Accession VI006833: cylindrical fruit shape with an angular cross-section; (N) accession VI006825: flattened fruit shape with an irregular cross-section

Fruit cross sectional shape of 59 accessions (85.51%) was round, nine accessions (13.04%) irregular and one accession (1.45%) angular for both the greenhouse and field experiments. All accessions with irregular cross sectional shape had flattened fruit (Tables 3.3 and 3.4).

Fruit sizes of most of the accessions grown in the field were intermediate (42.0%) while the rest were large (27.5%), small (14.5%) and very large (14.5%). Greenhouse results showed that 47.8% of the accessions were intermediate, while 24.6%, 17.4% and 10.1% were large, small and very large respectively (Tables 3.3 and 3.4).

Diversity index

Estimates of Shannon-Weaver diversity index (H') for the qualitative characters evaluated in the study accessions were generally high for both field and glasshouse experiments (Table 3.5). The indices ranged from 0.9771 (fruit shape) to 0.9995 (flower colour) for both the field and green house grown accessions with an average of 0.9992 and 0.9989 respectively. All traits showed high (H'>0.500) levels of polymorphism in both experiments.

Table 3.5: Standard-Shannon Weaver diversity index (H') for qualitative characters in 69 tomato accessions grown in the field and in the greenhouse

	Shannon-Weaver index (H')	
Qualitative trait	**Field**	**Greenhouse**
Exterior fruit colour	0.9976	0.9976
Foliage density	0.9945	0.9943
Flower colour	0.9995	0.9995
Fruit shape	0.9771	0.9797
Fruit cross section shape	0.9741	0.9741
Fruit size	0.9914	0.9918
Green shoulder	0.9880	0.9894
Growth type	0.9904	0.9904
Stem colour	0.9917	0.9917
Pubescence density	0.9968	0.9919
Average diversity index	**0.9992**	**0.9989**

Cluster analysis

The phenogram generated using ten morphological descriptors based on Euclidean Distance Coefficient and UPGMA clustering method clearly showed the phenetic relationships among the field and greenhouse grown accessions. Cluster analysis revealed two major clusters (Cluster I and II) for both experiments (Figure 3.9). In the field, cluster I had 63 accessions with seven sub-clusters while cluster II had six accessions all of which came from Madagascar. Sub-cluster 'a' had 17 accessions with majority of the accessions originating from Madagascar and South Africa. Most of the accessions in sub-cluster 'b' were from South Africa and Morocco while sub-cluster 'c' was dominated with accessions from Ethiopia. Sub-clusters 'd', 'e', 'f' and 'g' had the lowest number of accessions evaluated grouped together. Sub-clusters 'd' and 'g' had accessions from different origins while accessions from Morocco and Kenya dominated sub-clusters 'e' and 'f' respectively (Figure 3.9).

In the green house, cluster I had 64 accessions with six sub-clusters while cluster II had five accessions all of which came from Madagascar (Figure 3.10). Sub-cluster 'a' which had the highest number of accessions compared to other sub-clusters was dominated with accessions from Morocco, Ethiopia and South Africa. Sub-cluster 'b' majorly comprised accessions from Madagascar and South Africa. Sub-clusters 'c','d' and 'f' had the fewest number of accessions grouped together. Accessions from Morocco, Kenya and Mauritius dominated sub-clusters 'c','d' and 'e' respectively. On the other hand Sub-clusters 'f' had accessions from diverse origins.

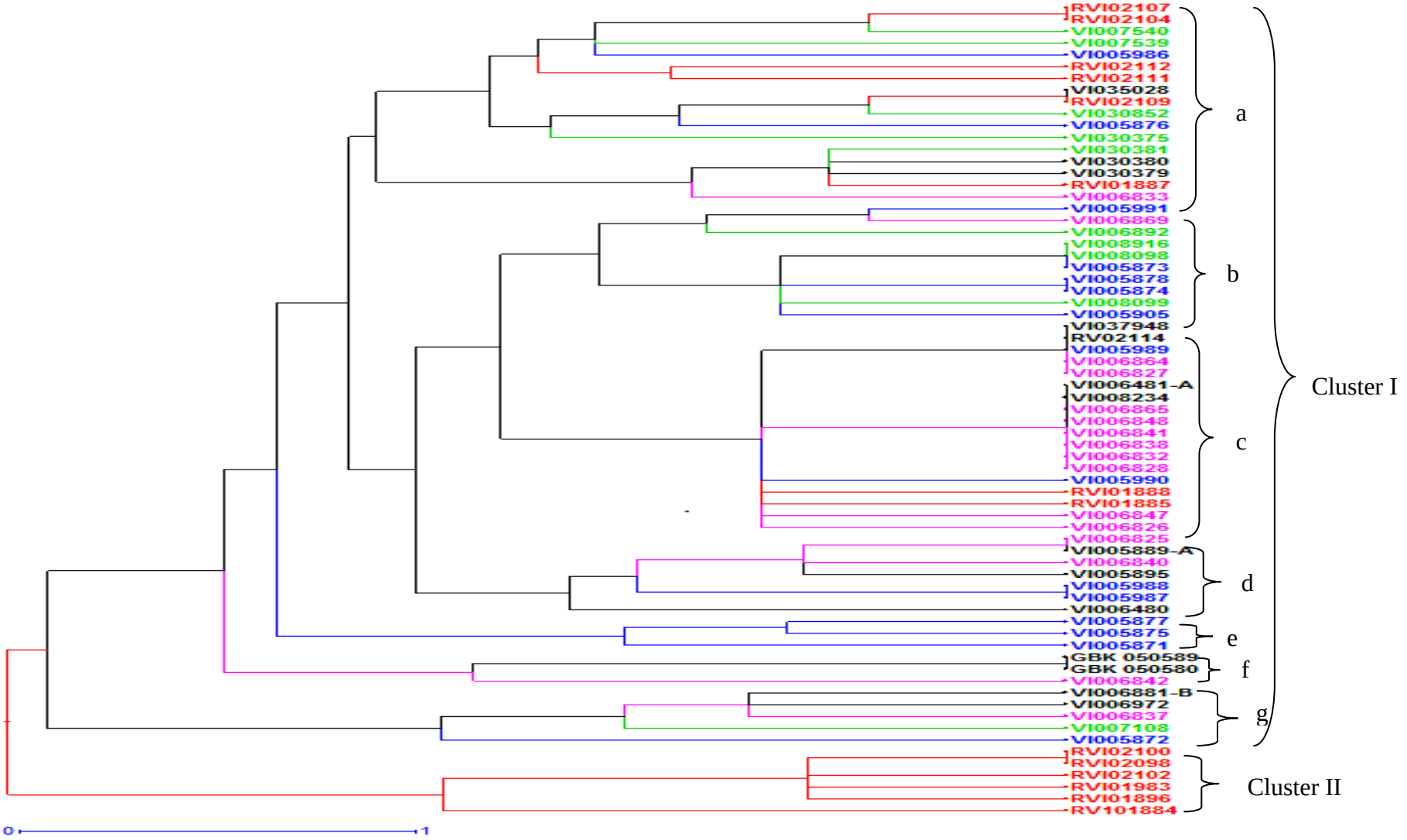


Figure 3.9: Unweighted pair-group method using arithmetic averages cluster analysis phenogram showing the relationships among the 69 African tomato accessions grown in the field

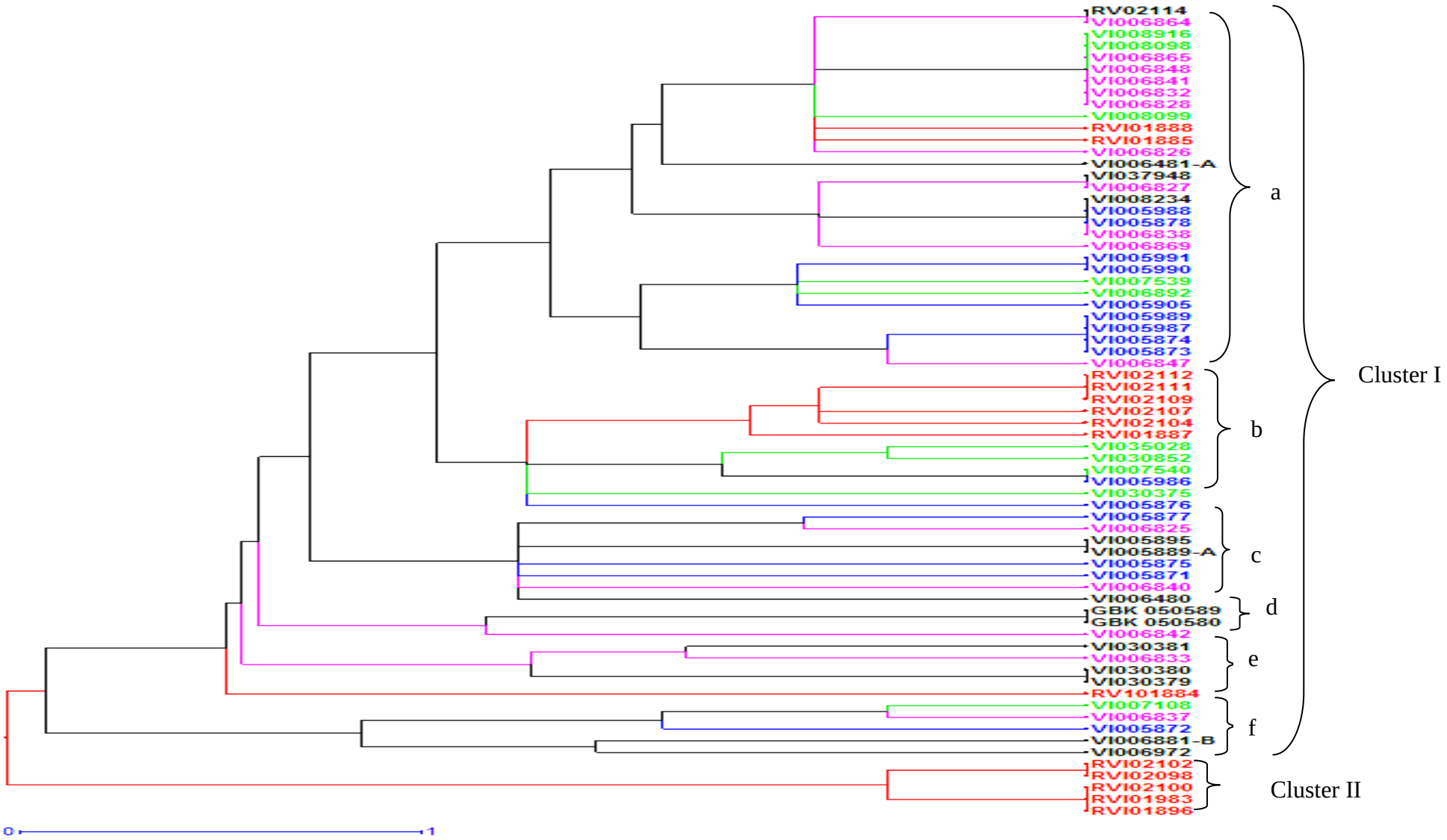


Figure 3.10: Unweighted pair-group method using arithmetic averages cluster analysis phenogram showing the relationships among the 69 African tomato accessions grown in the greenhouse

Principal component analysis

The first three PCs with eigenvalues >1 explained 71.02% of the total variation among the 69 field grown accessions (Tables 3.6). Exterior fruit colour, flower colour, fruit cross sectional shape, fruit size, presence of green shoulder and pubescence density were the main traits that contributed positively to PC1 for the accessions grown in the field. However, fruit size (0.265) contributed more positively (0.265) to this PC than the rest of the traits (Table 3.6). It was also observed that foliage density, fruit shape, growth type and stem colour had negative loadings to this component at -0.546, -0.697, -0.148 and -0.266 respectively. Traits that contributed more positively in respective PCs were namely: fruit shape (PC2), pubescence density (PC3), fruit size (PC4), growth type (PC5) and exterior fruit colour (PC6). On the other hand, traits that contributed more negatively than others were foliage (PC2), growth type (PC3 and PC4), pubescence density (PC5) and fruit size (PC6).

Table 3.6: Eigenvalues, eigenvectors and percentage of variation explained by the first six principal components for 69 tomato accessions grown in the field

Character	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Exterior fruit colour	0.041	0.068	-0.031	0.182	0.344	**0.705**
Foliage density	-0.546	**-0.536**	0.188	0.392	-0.171	-0.090
Flower colour	0.004	0.008	0.001	-0.001	0.014	0.105
Fruit shape	**-0.697**	**0.649**	0.082	-0.034	0.241	-0.014
Fruit cross section shape	0.164	-0.174	0.105	0.010	0.402	0.321
Fruit size	**0.265**	0.092	0.466	**0.485**	0.493	**-0.434**
Green shoulder	0.086	0.083	0.091	0.057	-0.185	0.154
Growth type	-0.148	-0.347	**-0.200**	**-0.554**	**0.563**	-0.271
Stem colour	-0.266	-0.327	0.418	-0.121	0.042	0.308
Pubescence density	0.132	0.119	**0.711**	-0.503	**-0.193**	0.016
Eigen values	**2.543**	**2.129**	**1.137**	**0.906**	**0.549**	**0.374**
% Variation	**31.090**	**26.030**	**13.900**	**11.070**	**6.710**	**4.570**
Cumulative	**31.090**	**57.120**	**71.020**	**82.090**	**17.760**	**93.370**

Values in bold indicate the most relevant descriptors that contributed most to the particular component.

Greenhouse results showed that the first three PCs with eigenvalues >1 explained 70.78% of the total variability among the accessions. Foliage density, fruit shape, presence of green shoulder, growth type, stem colour and pubescence density were the most important characters contributing to the first principal component (Table 3.7). However, foliage density contributed more positively (0.653) to the first PC than the rest of the traits. Traits that contributed more negatively than others were fruit size (PC1 and PC6), fruit shape (PC2), pubescence density (PC3), growth type (PC4) and foliage density (PC5).

Table 3.7: Eigenvalues, eigenvectors and percentage of variation explained by the first six principal components for 69 tomato accessions grown in the greenhouse

Character	**PC 1**	**PC 2**	**PC 3**	**PC 4**	**PC 5**	**PC 6**
Exterior fruit colour	-0.063	-0.045	0.019	0.142	0.354	**0.710**
Foliage density	**0.653**	0.238	0.502	0.020	**-0.342**	-0.024
Flower colour	-0.002	-0.004	-0.016	0.028	0.033	0.103
Fruit shape	0.384	**-0.862**	0.039	-0.041	0.253	-0.100
Fruit cross section shape	-0.109	**0.240**	0.080	-0.125	0.383	0.039
Fruit size	**-0.236**	0.068	**0.539**	0.196	**0.504**	**-0.504**
Green shoulder	0.002	0.026	0.152	0.123	-0.061	0.194
Growth type	0.263	0.220	-0.410	**-0.599**	0.275	-0.250
Stem colour	0.316	0.172	0.273	-0.293	0.361	0.324
Pubescence density	0.432	0.238	**-0.428**	**0.680**	0.286	-0.122
Eigen values	**2.560**	**2.164**	**1.085**	**0.774**	**0.583**	**0.352**
% Variation	**31.190**	**26.370**	**13.220**	**9.440**	**7.100**	**4.290**
Cumulative	**31.190**	**57.560**	**70.780**	**80.220**	**87.320**	**91.610**

Values in bold indicate the most relevant descriptors that contributed most to the particular component

3.4.2 Quantitative characteristics

Days to 50% flowering

Significant variation ($P<0.05$) among the 69 accession was recorded for the number of days to 50% flowering. Accessions grown in the field recorded a range of 38 (VI005905) to 64 (VI030375) days (Table 3.8) while a range of 36 (VI005905) to 68 (VI030375) days was observed for the greenhouse accessions (Table 3.9).

SPAD value

The SPAD values recorded for the 69 tomato accessions were significantly ($P<0.05$) different (Tables 3.8 and 3.9). SPAD ranges for the field grown accessions were 45.1 (VI030380) to 62.7 (VI030852) (Table 3.8) while the greenhouse grown accessions ranged from 38.4 (VI006837) to 59.0 (VI006825) (Table 3.9)

Plant height

Significant ($P<0.05$) differences were observed among the study accessions for plant height (Tables 3.8 and 3.9). Plant height of the field grown accessions ranged from 20.7 cm (RVI02111) to 41.8 cm (VI006827). Greenhouse grown accessions ranged in height from 25.5 cm (VI006826) to 81.2 cm (VI005905). For this character, glasshouse grown accessions were relatively taller with a mean height of 45.4 cm than the field grown accessions which had a mean of 31.7 cm.

Table 3.8: Quantitative trait means of 69 African tomato accessions grown in the field for the combined seasons

s/n	ACC.NO.	LL	LW	PH	NPB	SLA	SPAD	SG	DTF	DTM	FL	FW	NFPP	FWPP	SFWPP
1	GBK 050580	4.9	2.7	23.2	16.4	4.7	54.0	3.4	50.5	92.5	3.3	1.9	442.8	1212.0	2.7
2	GBK 050589	4.6	2.5	21.9	10.5	4.3	53.5	3.4	44.0	109.8	3.9	2.4	230.0	571.0	2.5
3	RV02114	4.7	2.4	31.0	8.6	4.4	50.8	3.6	49.0	91.2	4.8	3.0	107.7	618.0	5.7
4	RV101884	6.6	3.2	35.1	7.8	6.1	52.8	3.0	49.7	122.0	5.5	3.2	135.0	1143.0	8.5
5	RVI01885	5.8	2.5	34.8	10.3	5.2	52.2	3.8	51.2	98.2	8.9	5.4	42.7	2351.0	55.1
6	RVI01887	8.9	3.7	32.2	7.8	8.1	53.4	3.7	54.5	102.0	7.4	4.3	47.7	1636.0	34.3
7	RVI01888	6.0	3.0	34.3	9.3	5.6	58.1	3.4	62.3	116.7	7.3	4.4	19.7	789.0	40.2
8	RVI01896	6.8	3.8	33.5	8.3	6.5	55.6	4.6	53.8	113.3	9.4	5.6	28.7	1719.0	60.3
9	RVI01983	7.7	3.5	33.3	7.5	7.1	55.8	2.9	61.5	113.3	10.2	5.0	36.0	2186.0	60.8
10	RVI02098	7.3	3.2	37.0	7.1	6.6	60.4	3.1	42.0	120.5	8.2	4.4	13.0	565.0	43.4
11	RVI02100	6.5	3.3	30.6	8.3	6.1	57.9	3.6	42.0	112.3	9.1	5.8	18.8	1325.0	70.3
12	RVI02102	6.0	3.3	32.6	9.0	5.7	51.4	3.5	42.7	116.7	6.3	4.0	35.0	802.0	22.9
13	RVI02104	7.8	2.6	30.7	7.1	6.8	55.2	3.3	52.2	109.2	10.2	7.1	20.3	1210.0	59.6
14	RVI02107	4.0	2.3	32.0	7.3	3.8	52.8	3.6	40.3	92.8	10.5	6.0	27.2	2638.0	96.8
15	RVI02109	5.8	3.5	29.5	10.3	5.6	51.3	3.6	41.8	103.5	7.7	5.0	65.2	1857.0	28.5
16	RVI02111	4.7	2.2	20.7	7.0	4.3	51.1	2.4	39.8	114.2	6.8	5.8	43.0	1124.0	26.1
17	RVI02112	5.4	2.8	30.8	7.8	5.1	56.6	3.0	49.3	113.3	6.2	3.3	97.7	934.0	9.5
18	VI005871	5.5	3.1	31.6	8.4	5.3	54.8	4.4	48.8	92.7	9.3	6.1	29.8	2674.0	89.7
19	VI005872	6.2	3.1	38.2	10.4	5.8	49.9	4.4	52.7	94.2	9.0	5.6	24.0	1427.0	59.4
20	VI005873	5.8	2.7	34.4	11.3	5.3	45.9	3.4	53.2	112.7	7.3	4.5	23.2	1202.0	51.5
21	VI005874	6.3	3.0	31.1	7.4	5.8	52.3	4.4	57.2	104.2	8.5	5.8	28.7	2253.0	78.6
22	VI005875	7.0	3.0	30.9	9.8	6.3	56.7	4.3	49.5	101.0	9.9	6.9	25.7	1727.0	67.3
23	VI005876	6.0	2.5	29.4	9.3	5.4	51.9	4.0	45.7	96.0	10.4	7.3	28.0	2108.0	75.6
24	VI005877	6.1	2.6	31.7	8.5	5.5	54.4	3.2	51.0	81.8	10.1	6.9	31.7	2222.0	70.2
25	VI005878	5.1	2.6	31.5	8.8	4.8	57.1	3.3	57.5	114.5	8.5	5.3	14.3	763.0	53.0
26	VI005889A	6.0	2.8	31.0	10.9	5.6	57.9	3.8	40.7	113.8	8.0	5.7	19.0	816.0	43.0
27	VI005895	9.8	3.7	28.1	8.3	8.7	56.1	3.4	40.8	108.5	9.3	7.6	26.7	1613.0	60.5
28	VI005905	4.3	2.4	36.1	12.5	4.1	51.2	3.6	37.5	79.3	3.5	2.2	38.5	1203.0	31.3
29	VI005986	6.7	2.4	31.9	7.0	5.9	51.4	3.3	59.8	119.5	11.9	7.4	11.0	1018.0	92.6
30	VI005987	5.9	3.0	31.8	10.8	5.5	52.6	3.4	49.5	114.5	8.6	5.7	25.3	1052.0	41.7
31	VI005988	6.1	3.2	33.4	8.8	5.8	51.4	4.1	45.5	105.7	8.8	6.0	47.3	1823.0	38.5
32	VI005989	4.7	2.9	32.4	10.4	4.5	50.9	3.4	49.5	109.3	5.0	3.2	145.7	871.0	6.0
33	VI005990	7.0	3.3	32.9	10.9	6.5	58.8	4.3	51.0	115.0	8.9	5.4	21.7	1020.0	47.1
34	VI005991	5.3	3.0	31.8	10.2	5.1	55.3	4.2	53.8	112.0	7.5	4.6	34.3	1253.0	36.5
35	VI006480	5.4	3.1	31.8	11.6	5.2	56.7	4.0	50.0	97.8	5.6	3.7	125.8	1718.0	13.5
36	VI006481-A	4.3	2.3	29.4	10.9	4.0	54.6	3.1	54.3	114.3	6.9	4.5	192.3	1223.0	6.4
37	VI006825	6.6	3.2	32.3	10.5	6.2	61.4	4.4	53.2	92.5	4.3	2.2	146.8	622.0	4.2

Table 3.8: Quantitative trait means of 69 African tomato accessions grown in the field for the combined seasons

s/n	ACC.NO.	LL	LW	PH	NPB	SLA	SPAD	SG	DTF	DTM	FL	FW	NFPP	FWPP	SFWPP
38	VI006826	7.2	3.3	26.6	7.9	6.6	58.5	3.4	53.5	111.3	7.7	5.8	40.5	2759.0	68.1
39	VI006827	4.5	2.9	41.8	12.0	4.4	51.4	3.9	53.2	105.2	10.6	7.7	31.5	1637.0	51.9
40	VI006828	4.9	2.9	35.2	10.0	4.7	55.3	3.2	53.5	94.8	3.8	2.1	237.2	565.0	2.4
41	VI006832	4.7	2.5	30.8	11.4	4.5	54.0	4.0	49.3	114.7	5.3	3.2	115.5	2341.0	20.3
42	VI006833	7.9	4.4	30.9	9.4	7.5	51.3	4.2	51.8	96.8	5.5	3.6	54.8	954.0	17.4
43	VI006837	5.4	2.6	30.8	10.0	5.0	57.0	3.8	55.0	104.3	8.4	3.9	64.8	1777.0	27.4
44	VI006838	6.0	2.7	34.8	11.3	5.5	50.0	4.3	45.3	108.3	7.9	3.6	23.8	812.0	34.1
45	VI006840	6.0	3.1	33.4	10.8	5.7	56.2	4.3	53.7	88.7	5.6	3.9	129.3	1101.0	8.5
46	VI006841	5.8	2.9	34.1	11.0	5.4	52.8	4.7	55.0	118.0	11.1	7.6	12.3	1606.0	130.2
47	VI006842	6.5	2.5	30.7	10.0	5.8	57.9	2.9	53.8	89.2	5.1	3.2	162.2	2125.0	13.1
48	VI006847	5.8	3.1	32.9	11.6	5.5	51.1	4.8	51.8	116.2	9.2	6.0	15.8	1018.0	64.3
49	VI006848	5.8	2.4	32.5	11.7	5.3	54.8	3.4	47.3	103.7	5.4	3.3	106.5	1433.0	13.4
50	VI006864	5.2	2.5	40.3	11.3	4.8	51.5	4.0	51.3	101.5	5.6	3.5	91.7	1258.0	13.7
51	VI006865	5.3	3.1	33.8	9.2	5.1	54.6	3.5	51.7	93.3	5.0	4.1	126.5	2477.0	19.6
52	VI006869	7.4	3.4	33.5	7.5	6.8	46.9	3.7	52.8	103.2	5.2	3.2	104.3	1409.0	13.5
53	VI006881-B	6.0	2.8	27.8	10.9	5.5	48.6	4.4	54.7	109.2	9.3	6.1	13.3	1114.0	83.5
54	VI006892	4.6	3.0	31.5	11.8	4.6	51.3	3.1	61.2	108.2	4.9	2.4	102.7	887.0	8.6
55	VI006972	5.4	2.9	31.2	11.3	5.1	53.3	3.5	52.0	108.7	7.0	2.7	108.5	1192.0	11.0
56	VI007108	5.1	2.6	30.2	11.3	4.8	54.5	4.5	39.0	113.3	5.9	3.8	89.8	1416.0	15.8
57	VI007539	6.8	3.6	34.3	9.8	6.4	52.3	3.9	54.2	114.7	11.1	7.4	8.3	663.0	79.4
58	VI007540	5.8	3.2	28.9	7.5	5.6	56.4	3.9	56.7	118.8	10.4	7.4	10.8	1323.0	122.1
59	VI008098	7.3	3.5	32.0	11.8	6.8	56.1	3.5	58.5	119.2	7.7	4.5	41.8	1175.0	28.1
60	VI008099	4.8	2.4	30.4	8.2	4.5	53.0	3.5	50.2	105.0	8.4	5.5	53.2	1269.0	23.9
61	VI008234	6.5	3.0	29.2	11.8	6.0	55.6	3.7	38.2	94.8	7.5	4.5	48.2	1369.0	28.4
62	VI008916	5.5	3.1	32.5	7.8	5.3	54.0	3.7	50.3	115.3	7.3	4.5	65.7	1589.0	24.1
63	VI030375	7.2	2.9	33.9	9.0	6.5	60.8	3.5	63.8	127.3	10.1	5.2	30.7	1841.0	60.0
64	VI030379	6.1	3.2	22.6	8.0	5.7	51.4	4.0	51.5	100.3	8.9	6.0	17.3	1110.0	64.1
65	VI030380	6.1	3.2	32.8	8.3	5.7	45.1	4.1	48.0	106.3	7.0	4.3	53.5	2115.0	39.5
66	VI030381	4.6	2.8	28.5	10.0	4.4	48.1	3.7	50.8	109.8	7.5	4.3	42.0	1539.0	36.6
67	VI030852	9.5	3.7	34.9	7.3	8.5	62.7	3.6	60.0	115.0	10.2	6.3	49.2	1941.0	39.5
68	VI035028	5.6	2.8	30.1	8.6	5.3	53.6	3.4	49.3	91.5	6.3	3.4	28.0	881.0	31.4
69	VI037948	4.7	2.3	29.9	6.8	4.4	58.7	3.4	49.5	91.2	3.6	2.1	212.7	1222.0	5.8
	Mean	**6.0**	**2.9**	**31.7**	**9.6**	**5.6**	**53.9**	**3.7**	**50.6**	**106.1**	**7.6**	**4.8**	**68.7**	**1408.8**	**40.5**
	Fpr	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**
	$Lsd_{(p<0.05)}$	**0.6****	**0.3****	**1.5****	**1.1****	**0.5****	**1.0****	**0.3****	**1.9****	**2.3****	**0.7****	**0.5****	**4.0****	**182.7****	**1.7****
	Cv%	**8.9**	**7.6**	**4.3**	**10.3**	**8.0**	**1.6**	**7.0**	**3.2**	**1.9**	**8.0**	**8.9**	**5.1**	**11.4**	**3.7**

S/no- serial number, ACC NO- accession number, LL- single leaf length (cm), LW- leaf width (cm), PH- plant height (cm), NPB- number of primary branches, SLA- single leaf area (cm^2), SPAD- chlorophyll content, SG- stem girth (cm), DTF- days to 50% flowering, DTM-days to maturity, PH- plant height (cm) , FL- fruit length, FW-fruit width, NFPP- number of fruits per plant, FWPP- fruits weight per plant (g), SFWPP-single fruit weight per plant (g), Fpr - F probability

Table 3.9: Quantitative trait means for 69 African tomato accessions grown in the greenhouse

S/no.	ACC NO.	LL	LW	PH	NPB	SLA	SPAD	SG	DTF	DTM	FL	FW	NFPP	FWPP	SFWPP
1	GBK 050580	6.5	3.1	42.0	10.7	6.0	49.9	3.6	54.0	126.0	3.0	1.7	170.3	463.0	2.7
2	GBK 050589	6.8	3.3	60.2	10.0	6.3	43.8	3.8	46.0	105.7	3.2	1.9	157.0	420.0	2.7
3	RV02114	7.5	3.0	47.4	13.7	6.7	52.1	4.6	51.0	105.0	4.0	2.6	303.0	1728.0	5.7
4	RVI01884	8.6	5.2	61.3	4.3	8.3	57.7	3.4	54.0	121.7	4.7	2.7	90.5	678.0	7.5
5	RVI01885	10.1	4.1	54.6	6.0	9.1	45.3	4.6	54.5	99.7	8.3	4.8	42.2	2173.0	51.5
6	RVI01887	9.4	4.4	47.7	7.7	8.7	53.8	4.2	57.5	127.3	7.3	4.1	34.5	877.0	25.3
7	RVI01888	8.3	3.7	58.9	13.0	7.6	51.9	4.1	65.5	111.7	6.3	3.6	50.0	2011.0	40.3
8	RVI01896	12.5	4.9	41.8	6.7	11.2	51.9	4.4	58.5	94.3	8.4	5.2	28.0	1924.0	68.8
9	RVI01983	10.0	5.0	37.8	4.0	9.3	56.5	4.7	64.5	116.7	8.6	4.8	7.0	407.0	58.4
10	RVI02098	11.0	4.6	38.1	3.0	10.0	50.4	2.9	43.5	122.7	7.3	4.3	30.0	1069.0	35.5
11	RVI02100	8.8	5.1	36.9	2.0	8.5	50.8	3.9	45.0	104.3	9.9	6.2	19.0	1576.0	83.0
12	RVI02102	10.1	5.9	42.1	7.0	9.7	54.0	3.5	45.0	122.7	7.0	4.0	48.5	1131.0	23.4
13	RVI02104	10.0	4.1	40.1	6.7	9.1	54.1	5.9	56.0	112.0	10.0	6.5	27.0	1576.0	58.4
14	RVI02107	9.9	3.6	37.1	8.7	8.8	43.5	4.9	41.5	100.3	10.7	5.5	14.7	1651.0	112.6
15	RVI02109	7.4	4.2	41.8	10.7	7.0	48.7	4.6	47.0	105.0	6.5	3.9	71.0	1872.0	26.4
16	RVI02111	9.3	4.5	63.6	6.7	8.6	42.8	3.4	41.0	99.7	6.7	5.6	61.5	1640.0	26.8
17	RVI02112	7.9	3.9	33.7	8.0	7.3	47.2	4.3	51.5	105.7	5.1	2.5	90.0	825.0	9.2
18	VI005871	9.0	3.9	39.7	11.7	8.2	54.9	4.6	51.0	106.7	10.7	7.1	24.3	2171.0	89.2
19	VI005872	8.9	3.7	44.6	12.7	8.0	47.9	4.5	54.5	104.7	7.7	4.3	40.0	2370.0	59.3
20	VI005873	9.8	3.6	48.4	7.7	8.7	45.3	4.0	56.5	114.0	7.4	4.3	44.8	1854.0	41.4
21	VI005874	11.0	5.6	50.9	11.0	10.3	39.9	4.3	59.0	84.3	7.5	4.6	19.5	1635.0	83.4
22	VI005875	8.5	3.6	32.0	9.3	7.7	50.1	4.1	51.5	98.7	9.0	5.5	26.7	1766.0	66.6
23	VI005876	6.9	2.4	38.8	8.7	6.1	52.3	4.6	49.0	105.0	9.8	6.3	21.0	1546.0	73.9
24	VI005877	10.9	3.6	54.1	9.0	9.5	45.2	4.6	55.5	123.3	8.9	7.4	23.0	1638.0	71.0
25	VI005878	9.9	3.4	32.1	12.7	8.7	52.1	4.4	60.0	109.3	8.0	5.0	44.8	2022.0	45.1
26	VI005889A	10.2	4.5	48.3	11.7	9.3	46.0	5.1	41.5	117.3	8.4	5.8	20.5	909.0	44.6
27	VI005895	10.1	3.9	38.7	4.7	9.0	46.5	3.8	43.0	92.3	9.3	8.1	30.2	1711.0	56.5
28	VI005905	8.3	3.3	81.2	23.3	7.4	41.4	2.5	38.0	90.0	3.4	2.2	42.5	974.0	22.6
29	VI005986	10.2	3.5	35.2	9.3	9.0	44.0	4.9	63.0	104.7	11.3	6.3	22.3	1537.0	68.9
30	VI005987	7.7	3.9	31.1	10.0	7.2	53.3	4.9	53.0	109.0	7.8	4.9	57.3	2343.0	40.9
31	VI005988	8.0	3.4	37.3	8.7	7.3	46.9	5.6	47.0	107.0	7.5	4.7	45.3	1905.0	42.0
32	VI005989	8.2	3.8	48.8	9.7	7.5	47.9	5.5	51.0	111.0	4.2	2.9	154.3	1298.0	8.4
33	VI005990	7.8	3.9	39.3	10.0	7.3	46.8	4.8	54.5	108.7	7.2	4.7	46.5	2165.0	46.6
34	VI005991	9.0	4.6	30.1	5.7	8.4	42.7	3.8	57.0	105.7	6.8	3.3	30.5	1182.0	38
35	VI006480	8.2	3.9	60.1	10.0	7.5	40.4	3.6	50.5	95.0	4.9	2.9	126.8	1432.0	11.3
36	VI006481-A	9.3	3.9	55.3	13.7	8.4	53.7	5.5	57.0	87.0	5.9	3.4	208.0	1682.0	8.1
37	VI006881-B	7.2	3.2	42.0	17.3	6.6	48.9	4.7	56.0	116.7	3.8	2.0	192.2	716.0	3.7

Table 3.9: Quantitative trait means of 69 African tomato accessions grown in the greenhouse

S/no.	ACC NO.	LL	LW	PH	NPB	SLA	SPAD	SG	DTF	DTM	FL	FW	NFPP	FWPP	SFWPP
38	VI006825	9.2	3.7	46.8	11.0	8.3	59.0	5.2	58.0	108.7	10.1	6.2	43.3	2526.0	58.4
39	VI006826	9.7	3.3	25.5	9.7	8.5	49.2	4.8	55.0	108.0	9.8	6.0	32.3	1778.0	54.9
40	VI006827	6.0	2.9	51.1	14.3	5.5	46.4	4.0	55.5	103.0	3.5	1.9	267.3	946.0	3.5
41	VI006828	9.5	4.2	55.5	12.3	8.6	45.7	4.9	52.5	98.0	5.2	2.9	114.8	2346.0	20.4
42	VI006832	7.6	3.9	47.5	12.0	7.1	46.4	4.8	57.0	108.0	5.3	3.2	83.5	1012.0	12.1
43	VI006833	9.3	4.1	37.4	11.7	8.5	48.3	4.7	58.0	105.0	5.0	2.5	58.3	1597.0	27.4
44	VI006837	10.6	4.1	56.0	4.0	9.5	38.4	3.9	47.0	103.0	7.4	3.6	34.7	968.0	28.0
45	VI006838	10.1	4.3	52.5	14.0	9.2	52.9	4.5	57.5	101.0	5.2	3.1	134.7	1331.0	9.9
46	VI006840	8.4	3.3	59.9	12.0	7.5	47.9	5.1	57.0	114.0	9.6	7.6	32.0	3126.0	97.7
47	VI006841	7.7	4.0	54.5	12.7	7.2	46.0	5.8	56.5	91.0	5.1	3.1	142.0	1360.0	9.6
48	VI006842	10.3	3.6	45.5	10.0	9.1	52.7	4.9	56.5	114.0	9.3	6.2	26.0	1724.0	66.2
49	VI006847	7.7	3.3	55.5	14.3	7.0	51.6	5.4	52.0	110.3	5.1	3.2	103.7	1094.0	10.6
50	VI006848	7.2	2.8	55.4	13.0	6.4	51.7	5.4	56.0	95.7	5.6	3.6	71.8	1270.0	17.7
51	VI006864	7.7	4.0	52.9	14.0	7.2	49.6	4.3	54.0	87.7	4.7	3.0	145.8	1591.0	10.9
52	VI006865	9.2	4.0	43.9	14.7	8.3	47.9	4.2	57.0	108.0	5.1	3.1	114.5	1386.0	12.1
53	VI006869	9.3	3.4	43.7	12.0	8.2	49.1	5.0	59.0	107.0	9.3	5.7	26.3	2216.0	84.3
54	VI006892	7.7	4.4	39.9	19.7	7.4	50.0	3.7	66.2	88.3	4.2	2.2	117.0	844.0	7.2
55	VI006972	8.5	4.0	52.9	17.3	7.9	55.5	4.7	55.0	89.0	5.2	2.4	128.0	1534.0	11.9
56	VI007108	8.7	4.1	62.1	8.0	8.0	44.2	3.7	41.0	99.3	5.5	3.5	86.0	1393.0	16.2
57	VI007539	9.7	4.2	31.5	8.7	8.8	46.1	3.8	57.0	121.0	9.7	6.0	9.3	723.0	77.6
58	VI007540	10.4	3.2	38.7	9.0	9.0	46.4	4.5	58.5	105.0	10.7	7.8	16.7	1784.0	107.2
59	VI008098	10.3	4.1	35.6	11.7	9.3	45.8	4.5	62.0	105.0	6.3	3.8	43.0	1215.0	28.3
60	VI008099	10.3	3.9	40.0	13.7	9.2	48.4	5.4	54.0	106.0	6.9	4.6	64.7	2136.0	33.1
61	VI008234	9.6	4.3	41.0	7.0	8.8	44.1	4.6	40.0	91.0	7.6	4.5	55.0	1684.0	30.7
62	VI008916	10.4	4.2	51.5	12.7	9.4	44.3	4.0	55.5	106.0	5.8	3.5	62.0	1384.0	22.3
63	VI030375	11.1	3.5	41.5	14.7	9.7	50.9	5.9	68.0	131.0	10.0	5.6	38.7	2390.0	61.8
64	VI030379	9.1	3.4	30.3	6.0	8.1	51.3	4.8	55.5	110.7	10.2	6.3	21.5	1312.0	61.1
65	VI030380	9.5	3.8	37.4	5.7	8.5	52.7	3.2	49.5	107.0	15.2	3.3	53.0	1163.0	21.8
66	VI030381	7.3	3.1	32.9	9.0	6.6	52.8	5.8	55.0	108.0	7.2	4.3	46.0	1264.0	27.5
67	VI030852	11.6	4.1	42.3	6.7	10.2	50.0	5.2	63.0	123.0	9.0	5.8	42.0	2004.0	47.7
68	VI035028	5.3	3.5	38.0	11.7	5.2	56.4	4.2	52.0	111.3	5.4	3.1	44.5	774.0	17.3
69	VI037948	8.3	4.5	63.5	16.3	7.9	53.5	4.0	53.0	109.0	3.4	1.9	228.3	850.0	3.7
	Mean	**9.0**	**3.9**	**45.4**	**10.4**	**8.2**	**48.9**	**4.5**	**53.6**	**106.4**	**7.2**	**4.3**	**71.8**	**1501.5**	**38.5**
	Fpr	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**
	l.s.d$_{(p<0.05)}$	**0.3****	**0.3****	**1.3****	**1.1****	**0.3****	**6.6****	**0.3****	**2.4****	**1.3****	**0.4****	**0.4****	**8.1****	**235.2****	**3.1****
	cv%	**2.1**	**5.3**	**1.8**	**6.6**	**2.0**	**8.4**	**4.0**	**2.7**	**0.8**	**3.2**	**5.6**	**7.0**	**9.7**	**5.0**

S/no- serial number, ACC NO- accession number, LL- single leaf length (cm), LW- leaf width (cm), PH- plant height (cm), NPB- number of primary branches, SLA- single leaf area (cm^2), SPAD- chlorophyll content, SG- stem girth (cm), DTF- days to 50% flowering, DTM-days to maturity, PH- plant height (cm) , FL-fruit length, FW-fruit width, NFPP- number of fruits per plant, FWPP- fruits weight per plant (g), SFWPP-single fruit weight per plant (g), Fpr - F probability

Stem girth

Stem girth significantly varied ($P<0.05$) among the study accessions for both the field and greenhouse experiments (Tables 3.8 and 3.9). Stem girth values for the field grown accessions ranged from 2.4 cm (RVI02111) to 4.8 cm (VI006847) while greenhouse grown accessions registered a stem girth range of 2.5 cm (VI005905) to 5.9 cm (RVI02104).

Number of primary branches

Significant ($P<0.05$) variation was recorded for the number of primary branches among the field and greenhouse grown accessions (Tables 3.8 and 3.9). In the field, the number of primary branches ranged from 6.8 (VI037948) to 16.4 (GBK 050580) branches. On the other hand, the greenhouse grown accessions recorded a range of 2.0 (RVI02100) to 23.3 (VI005905) branches.

Leaf length

Leaf length varied significantly ($P<0.05$) among the field and greenhouse grown tomato accessions (Tables 3.8 and 3.9). A range of 4.0 cm (RVI02107) to 9.8 cm (VI005895) leaf length was recorded for the field grown accessions. Greenhouse grown accessions had a leaf length range of 5.3 cm (RVI01896) to 12.5 cm (VI035028).

Leaf width

Significant ($P<0.05$) differences among accessions were noted in the field and in the green house (Tables 3.8 and 3.9). A range of 2.2 cm (RVI02111) to 4.4 cm (VI006833) leaf width was recorded for accessions in the field. Greenhouse grown accessions posted a range of 2.4 cm (VI005876) to 5.9 cm (RVI02102) leaf width.

Leaf area

Significant ($P<0.05$) variations in single leaf area were observed for both the field and glasshouse grown accessions (Tables 3.8 and 3.9). Leaf area for the field grown accessions ranged from 3.8 cm^2 (RV102107) to 8.7 cm^2 (VI005895) while accessions grown in the greenhouse ranged from 4.2 cm^2 (VI0135028) to 11.2 cm^2 (RV101896).

Days to maturity

Significant ($P<0.05$) variations were observed for days to maturity among the greenhouse and field grown accessions (Tables 3.8 and 3.9). Days to maturity for the field grown accessions ranged from 79.3 (VI005905) to 127.3 (VI030375) while a range of 84.3 (VI005874) to 131 (VI030375) days to maturity was recorded for the greenhouse grown accessions.

Fruit length

Fruit length varied significantly ($P<0.05$) for both the field and green house grown accessions (Tables 3.8 and 3.9). A fruit length range of 3.3 cm (GBK 050580) to 11.9 cm (VI005986) was recorded in the field accessions. Fruit length for the greenhouse grown accessions ranged from 3.0 cm (GBK 050580) to 15.2 cm (VI030380).

Fruit width

There was a significant ($P<0.05$) variation in fruit width among the field and green house grown accessions (Tables 3.8 and 3.9). Field grown accessions recorded a fruit width range of 1.9cm (GBK 050580) to 10.6cm (VI006826) while the greenhouse grown accessions posted a fruit width range of 1.7 cm (GBK 050580) to 8.1 cm (VI005895) for accessions and respectively.

Number of fruits per plant

Significant ($P<0.05$) variations were observed for the number of fruits per plant among the field and green house grown accession (Tables 3.8 and 3.9). Number of fruits per plant for the field grown ranged from 8.3 (VI007539) to 442.3(GBK 050580) fruits. In the green house, a range of 7.0 (RVI001983) to 303.0 (RV02114) fruits per plant was recorded.

Fruit weight per plant

Significant ($P<0.05$) variations were registered for fruit weight per plant among the field and green house grown accessions (Tables 3.8 and 3.9). Fruit weight per plant ranged from 565.0 g (RVI02098 and VI006827) to 2759.0 g (VI006826) for the field grown accessions. In the green house, a range of 407.0 g (RVI01983) to 3126.0 g (VI006840) fruit weight per plant was registered. However, it was noted that the green house accessions had a higher fruit weight per plant with a mean of 1501.5 g compared to the field experiment that recorded a mean weight of 1408.8 g.

Single fruit weight per plant

There was a significant ($P<0.05$) variation in single fruit weight per plant among the field and green house grown accessions (Tables 3.8 and 3.9). Single fruit weight per plant ranged from 2.4 g (VI006828) to 130.2 g (VI006841) for the field grown accessions. On the other hand, a range of 2.7 g (GBK 050580 and GBK 050589) to 112.6 g (RVI02107) was recorded for the greenhouse grown accessions.

3.4.3 Correlation among the quantitative traits

Fruit yield for the field grown accessions showed significant positive correlations with fruit length (r=0.28), fruit width (r=0.30), leaf length (r=0.16), leaf width (r=0.14), single leaf area (r=0.16), plant height (r=0.16), single fruit weight per plant (r=0.34) and stem girth (r=0.27) (Table 3.10). However, days to maturity (r=-0.20), number of fruits per plant (r=-0.13) and number of primary branches (r= -0.13) were negatively correlated with yield. Significant positive correlations were also realized between fruit yield and days to flowering (r=0.15), fruit length (r=0.42), fruit width (r=0.51), leaf length (r=0.28), number of fruits per plant (r=0.26), single fruit weight per plant (r=0.50), stem girth (r=0.41) and single leaf area (r=0.23) for the green house experiment (Table 3.11). However, negative but significant correlation was observed between fruit yield leaf width (r= -0.13)

Table 3.10: Correlation table for the quantitative traits in combined seasons recorded for accessions grown in the field

	DTF	DTM	FL	FW	LL	LW	NFPP	NPB	SLA	FWPP	PH	SFWPP	SPAD	SG
DTF	-													
DTM	0.243**	-												
FL	0.20**	0.35**	-											
FW	0.09	0.27**	0.90**	-										
LL	0.22**	0.28**	0.50**	0.45**	-									
LW	0.19**	0.26**	0.26**	0.18**	0.64**	-								
NFPP	-0.02	-0.30**	-0.71**	-0.66**	-0.38**	-0.22**	-							
NPB	-0.07	-0.24**	-0.45**	-0.42**	-0.31**	-0.12*	0.46**	-						
SLA	0.23**	0.30**	0.49**	0.43**	0.99**	0.72**	-0.37**	-0.30**	-					
FWPP	0.04	-0.20**	0.28**	0.30**	0.16**	0.14*	-0.13*	-0.13*	0.16*	-				
PH	0.22**	-0.02	-0.02	-0.10	0.11*	0.15*	-0.13*	0.04	0.12*	0.16*	-			
SFWPP	0.15*	0.21**	0.82**	0.82**	0.33**	0.17**	-0.65*	-0.37**	0.32**	0.34**	0.02	-		
SPAD	0.10	0.32**	0.24**	0.21**	0.29**	0.10*	-0.12*	-0.13*	0.28**	0.066	-0.02	0.15*	-	
SG	0.03	-0.25**	0.02**	0.04	0.07	0.25**	-0.05	0.22**	0.10*	0.27**	0.20**	0.14*	-0.11*	-

DTF- days to 50% flowering, DTM-days to maturity, FL-fruit length (cm), FW-fruit width(cm), LL- leaf length (cm), LW- leaf width (cm), NFPP-number of fruits per plant , NPB- number of primary branches, SLA- single leaf area (cm^2), FWPP- fruits weight per plant (g), PH- plant height (cm), SFWPP-single fruit weight per plant (g), SPAD- chlorophyll content, SG- stem girth (cm)

Table 3.11: Correlation table for the quantitative traits in combined seasons recorded for accessions grown in the greenhouse

	DTF	DTM	FL	FW	FWPP	LL	LW	NFPP	NPB	PH	SFWPP	SG	SLA	SPAD
DTF	-													
DTM	0.20*	-												
FL	0.07	0.19*	-											
FW	0.03	0.18*	0.81**	-										
FWPP	0.15*	-0.12	0.42**	0.51**	-									
LL	0.15*	0.11	0.51**	0.49**	0.28**	-								
LW	-0.06	-0.01	0.01	-0.04	-0.13**	0.45**	-							
NFPP	-0.001	-0.19*	-0.71**	-0.69**	0.26**	-0.50**	-0.19*	-						
NPB	0.21*	-0.27**	-0.49**	-0.42**	0.03	-0.34**	-0.33**	0.47**	-					
PH	-0.22*	-0.24**	-0.49**	-0.35**	-0.07	-0.12	0.04	0.37**	0.36**	-				
SFWPP	0.10	0.11	0.79**	0.86**	0.50**	0.47**	-0.001	-0.71**	-0.33**	-0.36**	-			
SG	0.35**	0.04	0.18*	0.27**	0.41**	0.03	-0.28	-0.01**	0.12	-0.22*	0.19*	-		
SLA	0.13	0.10	0.46**	0.43**	0.23**	0.99**	0.59**	-0.49**	-0.37**	-0.10	0.42**	-0.03	-	
SPAD	0.31**	0.18*	0.12	0.05	0.03	-0.07	0.16*	0.03	0.03	-0.18**	0.04	0.19*	-0.03	-

DTF- days to 50% flowering, DTM-days to maturity, FL-fruit length (cm), FW-fruit width(cm), FWPP- fruits weight per plant (g), LL- leaf length (cm), LW- leaf width (cm), NFPP- number of fruits per plant , NPB- number of primary branches, PH- plant height (cm), SFWPP-single fruit weight per plant (g), SG- stem girth (cm), SLA- single leaf area (cm^2), SPAD- chlorophyll content

3.5 DISCUSSION

The current study revealed that most (68.1%) of the 69 accessions evaluated had an indeterminate growth type compared to 31.9% which were determinate. This implies that most of the tomato landraces in Africa are bushy types. This could be attributed to the lack of any form of crop improvement among these accessions. Similar results were obtained by Adriana *et al*., (2015) who characterized 125 tomato accessions, out of which 95 (77.2%) were indeterminate whereas the others determinate. This finding agrees with the international plant genetic resource institute (2003) descriptor that characterizes tomato as either indeterminate or determinate.

Despite the diverse collection sites of the accessions evaluated, the study revealed a narrow diversity within accessions with respect to flower, stem and fruit colour. Sixty eight accessions were observed to have produced red flowers with only one accession (VI006842) having white flowers. This implies that a majority of the study accessions had yellow flowers and that the white flower observed in this study could have been a result of gene mutation over time. Similar results were observed for the stem colour and fruit colour where 91.3% of the accessions had purple stem while only 8.7% had green stem. Of the 69 accessions evaluated, 66 produced red fruits with only three accessions having yellow fruits. This variation could be attributed to genotypic variation among the accessions as well as environmental factors. According to Khachick *et al*., (2002) different kinds of pigments majorly chlorophyll, carotenoids and anthocyanins are the cause of variations in colours observed on stems, flowers and fruits.

This study revealed that 79.7% of the accessions evaluated showed the presence of the green shoulder on immature tomato fruits. This implies that a greater number of the tomato landraces in Africa show the presence of green shoulder at their immature stage. Similar observation was made by Maria *et al*,. (2014) following characterization of 69 local varieties of tomato in Spain. Green shoulder also known as green back is a disorder in tomato fruit often characterized by a persistent, firm green area around the calyx end due to undegraded chlorophyll, while the rest of the fruit is ripe. The disorder is genetically controlled and can be abolished by incorporating the ‘uniform ripening’ gene (Grieson and Kader 1986). This implies that high yielding accessions with, green shoulders need to undergo breeding efforts to introgress the uniform ripening gene.

Variations were observed for stem hairiness among the accessions. Stem hairiness ranged from sparse, intermediate to dense. However, it was observed that field grown accessions were more hairy than those grown in the green house. Pubescence (hairiness) provides a coating on leaves, stems and fruits. It thus reduces transpiration and reflects sunlight, protecting the more delicate tissues underneath in hot, dry and open habitats (Subhash, 2010). Compared to the controlled greenhouse environment, field conditions were often associated with strong winds, fluctuations in temperatures, erratic rainfall and varying relative humidity (Appendix 3). This may explain why most of the study accessions in the field had more dense hairs on stems than accessions grown in the glasshouse.

Shape and size constitutes integral quality parameters in fruits. The current study revealed variations in fruit shape, fruit cross-section shape and fruit size. Seven different fruit shapes were recorded. These were rounded, flattened, high rounded, heart shaped, ellipsoid, pyriform and cylindrical. However, 81.2% of the accessions evaluated had rounded and flattened fruits. On the other hand, three shapes of fruit cross-section were observed in this study. These were: round, irregular and angular. Of the three shapes, most (85.51%) of the accessions produced fruits with a round cross-section. Fruit size varied from small (3 - 5 cm), intermediate (5.1 - 8 cm), large (8.1 - 10 cm) to very large (>10 cm). However, intermediate and large fruit sizes dominated among the accessions studied. This could be attributed to preferential selection where most of the farmers prefer intermediate and large fruit tomatoes as opposed to those that are small sized. These variations are in consonance with the findings of Maria *et al*, (2014) who observed significant variations for fruit shape, fruit size and fruit cross section shape in Spanish local tomato varieties. Variation in fruit size and shape has the potential of creating new marketing nitches for tomato producers.

Estimates of Shannon-Weaver diversity index (H‟) for the qualitative characters assessed in the field and glasshouse were generally high (H‟>0.500). Diversity indices ranged from 0.9771 (fruit shape) to 0.9995 (flower colour) for all the traits evaluated in the field and in the glasshouse. This could be attributed to the fact that these accessions were found in relatively complex and heterogeneous ecologies (farm, forest and wild) and the non-uniform climatic conditions (Chweya, 1997). The dendogram obtained from the cluster analysis further revealed the existence of diversity among the 69 tomato accessions for the morphological traits studied.

Based on cluster analysis, the accessions were grouped into two major clusters. Cluster I had most of the accessions which were further grouped into six and seven sub-clusters for the green house and field grown accessions respectively. The clustering pattern shows that some of the accessions (RVI02100, RVI02098, RVI02102, RVI0983, RVI1896, and RVI01884) from Madagascar (cluster II) were significantly different from the rest of the accessions for stem colour. It is likely that continuous recycling of tomato seeds by farmers and selections leading to massive segregation might have contributed to the wide phenotypic variability among the accessions from the same collection sites. Divergent accessions may be good for breeding while accessions in the same cluster may represent members of one heterotic group. According to Bhatt (1970) the maximum variability for segregation in a segregating population may be achieved by utilizing accessions from different clusters as parents of crosses.

Principal component analysis have used in several crops to identify the most important trait for characterizing genotypes. Example of such crop are pigeon pea (Upadhyaya *et al.*, 2007), sweet potato (Yada *et al*., 2010) and wheat (Al Khanjari *et al.*, 2008). In the present study, PCA identified six traits namely exterior fruit colour, flower colour, fruit cross section shape, fruit size, green shoulder and pubescence density for the field grown accessions and five traits namely foliage density, fruit shape, green shoulder, growth type, stem colour, and pubescence density for the green house grown accessions as traits that had greater contribution to the variability among the accessions. From the findings, the first three principal components PC1, PC2 and PC3 with eigenvalues >1 contributed more than 70% of the total variation for both the field and green house experiments. This implies that the study accessions were highly diverse in most of the traits evaluated. This finding is in consonance with those of Agong *et al*. (2001) who reported that the first three principal components were adequate in explaining more than 70% of the phenotypic variation in the tomato germplasm.

Significant differences were observed for SPAD value among the study accessions. Accessions VI030852 and VI006825 recorded the highest SPAD values for the field and green house grown accessions respectively. Several authors have shown a relationship between chlorophyll and N content in plant leaves (Sexton and Carol, 2002; Wang et. al, 2004). Chlorophyll contents can be used as an alternative measure of plant N status (Fontes, 2001). This implies that breeders interested in improving nitrogen should select accessions with high SPAD value.

Significant differences ($P<0.05$) were observed among the 69 accessions for all the agronomic traits evaluated. This implies an existent in variation among the Africa tomato landraces for the agronomic traits evaluated. Mohanty (2003) reported significant differences in plant height, number of primary branches, and days to maturity, number of fruits per plant and average fruit weight among tomato accessions. In trying to unravel the genetic diversity for quantitative traits in tomato, Shushay *et al*., (2014) also reported significant differences for all characters studied. Yield components were highest in accessions VI005986 and VI030380 (fruit length), VI006827 and VI005895 (fruit width), GBK 050580 and RVI02114 (total number of fruits per plant), VI006826 and VI006840 (total fruit weight per plant), and VI006841 and RV102107 (single fruit weight per plant) for the field and green house accessions respectively. Similarly, earliness was recorded in accession VI005905 (days to flowering) both in the field and in the green house, and accessions VI005905 and VI005874 (days to maturity) in the field and green house respectively. Variations in the agronomic traits in the current study could be attributed to the differences in genetic and environmental conditions from which the accessions were obtained. This is expected since different genotypes perform differently in the same environment (Blay *et al.* 1999). This finding implies the existent of a rich diversity among the African tomato accessions and their potential for use in crop improvement.

Positive and significant association of fruit yield per plant with plant height, number of primary branches, leaf length, leaf width, single leaf area and stem girth shows that tall plants, bearing many branches, with large leaf area and wide stem girths tend to yield higher than shorter plants. This may be explained by the greater photosynthetic products available for partitioning to fruit production. Similar findings were reported by Singh *et al.,* (2006), Sivaprasad, (2008) and Gosh *et al., (*2010). This implies that tall accessions with higher number of primary branches, larger single leaf area and wider stem girth have the potential of producing higher yields and should subsequently be selected for crop improvement.

Accessions of tomato with more branches tended to flower and mature late as shown in the negative and significant association of number of branches per plant with days to maturity for both the field and green house grown accessions. This may be due to the fact that much time is spent by the plant in growing more vegetative branches, hence extending its lifespan. This

implies that breeders interested in improvement for early maturity in tomato may select plants with fewer branches (Mohanty, 2002).

Weight per fruit which is a function of fruit size had predictably positive and significant association with fruit length and fruit diameter. Islam *et al*. (2010) in study of 39 tomato genotypes also concluded that yield has significant positive correlation with fruit diameter. A negative significant correlation was observed between number of fruits per plant and single fruit weight. This association could be due to the large number of small fruits in germplasm studied. Although the number of fruits per plant was high in most of the accessions, yields were low. Similar results were also reported by Agong *et al*. (2001). Significant but negative correlation was also observed for number of fruits per plant with days to maturity. This could be explained by the fact that with the increase of number of days to 50% fruit maturity, yield decreased and this demonstrates that early maturing cultivars had higher yield than late maturing cultivars. This implies that breeders interested in improvement for yield may select early maturing accessions with wider fruit diameter.

3.6 CONCLUSION

Analysis of variance showed significant variation amongthe tomato accessions for all parameters evaluated. Important traits identified in this study were fruit size, fruit shape, presence of green shoulder, days to maturity, fruit width, fruit weight per plant, single fruit weight per plant and SPAD value. Some of the accessions with outstanding performance included VI005905 (Days to maturity), VI006827 and VI005895 (fruit width), VI006826 and VI006840 (fruit weight per plant) and accessions VI006841 and RVI02107 (single fruit weight per plant). Accessions VI030852 and VI006825 recorded high values for SPAD. Significant associations of various traits with yield were also observed in this study. Such associations help in the identification of important traits that can be used for yield enhancement through multiple trait selection. Positive and significant correlations between yield and yield components such as fruit length, fruit width and single fruit weight clearly indicates that crop improvement for yield in tomato should focus on these traits.

CHAPTER 4

EFFECTS OF WATER STRESS ON AGRO-PHYSIOLOGICAL AND NUTRITIONAL TRAITS AMONG SELECTED AFRICAN TOMATO LANDRACES

4.1 ABSTRACT

Tomato (*Solanum lycopersicum*) is an important fruit vegetable often associated with a wide range of health benefits due to its rich nutritional quality. Wild relatives and unimproved accessions of crops are often better adapted to biotic and abiotic stresses and serve as a source of desirable genes for crop improvement. However abiotic stresses such as water stress are known to affect nutritional quality of fruits and vegetables. The objective of this study was therefore to determine the effect of water stress on agronomic, physiological and nutritional traits among selected African tomato accessions. The experiment was conducted at the University of Nairobi's Kabete Field Station in 2015.Twenty (20) tomato accessions from the World Vegetable Centre (AVRDC) and the National Genebank of Kenya were used in the study. The 20 accessions were selected for their desirable agronomic traits from an initial list of 69 accessions. The tomato accessions were planted in the greenhouse and subjected to four watering levels: 100% 80%, 60% and 40% field capacity. Agronomic traits evaluated were plant height, single leaf area, stem girth, number of fruits per plant and weight of fruits per plant. Physiological traits included SPAD value, leaf relative water content (LRWC), stomatal conductance and canopy temperature. Fully ripe tomatoes harvested from all the accessions at 100% and 60% field capacity were evaluated for selected nutritional quality attributes including β-carotene, vitamin C, minerals, simple sugars, total phenolics and total antioxidant activity at the Jomo Kenyatta university food science laboratory. Significant ($P<0.05$) interactions among accessions and water levels were observed for both agronomic and physiological traits evaluated. Water stress significantly reduced fruit yield which ranged from 127.3 to 1487.7 g under stress and 521.0 to 2404.3 g under unstressed conditions. Similar reductions were recorded in stem girth, plant height and leaf area under stressed conditions. Water stress reduced stomatal conductance, which ranged from 74.0 to 100.1 mmol/m^2s under water stress and 207.7 to 287.5 mmol/m^2s in unstressed conditions. Reductions were also observed in SPAD value and leaf relative water content. However water stress significantly increased the canopy temperature. Fruit yield correlated positively with relative water content ($r=0.33$) and stomatal conductance ($r=0.40$).

Water stress significantly affected nutritional quality of the fruits. Water stress significantly increased total phenolics, antioxidant activity and soluble sugars. Significantly lower levels of mineral nutrients (potassium, zinc, magnesium, iron and sodium), β-carotene and vitamin C levels were recorded under water stress than unstressed conditions. The study has revealed that water stress has significant effect on agronomic, physiological and nutritional quality traits of tomato accessions. This effect should be taken into consideration when selecting tomato accessions with desirable agronomic, physiological and nutritional traits for crop improvement programmes.

4.2 INTRODUCTION

Environmental stresses, such as water stress, salinity, extreme temperatures and radiation, represent the most limiting factors in agricultural production. In Kenya, agriculture is mainly rain-fed and is possible in about 16 per cent of the landmass which is of high and medium agricultural potential with adequate and reliable rainfall. Of this potentially arable land, cropland occupies 31 percent. The rest of the country (84%) is arid or semi arid and is not suitable for rain-fed farming due to low and erratic rainfall (Republic of Kenya, 2010). The current global warming, which causes fluctuations in precipitation distribution further increases the risk of plants being exposed repeatedly to drought (Miyashita *et al*., 2005)**.**

Tomato is an economically important horticultural crop in Kenya and has the potential of improving the livelihood of the rural poor farmers (Mbaka *et al*., 2013). However, the crop is very sensitive to water deficits and studies indicate reduction in fruit yields may be as high as 69 per cent of the total production Sibomana *et al*., (2004). The supply of the appropriate amount of water to the tomato plants is crucial for growth and fruit production (Aziz *et al*., 2013). According to Nuruddin (2003) and Kirnak *et al*. (2001) water deficit has significant effects on chlorophyll content, electrolyte leakage, leaf relative water content and vegetative growth. This therefore calls for the need to develop tomato varieties that can withstand moisture deficits. However, there is limited research on drought tolerance that has been carried out on the crop.

According to Torrecillas *et al.*, (1995), tolerance to water stress is found in wild species of crops. These genotypes have the potential of growing under conditions that present minimum water. This characteristic is important and therefore can be introduced into commercial varieties (Ashraf., 2010). The cross between these landraces with the cultivated species may be a potential means to obtain drought tolerant cultivars. Materials from diverse geographical origin of the crop species can therefore be of help in conservation of co-adapted genotypes with desirable traits.

African tomatoes are landraces with dynamic populations, distinct identities and lack of formal crop improvement. They are typically characterized by good stress tolerance and local adaptability (Newton *et al*., 2010). This provides a potential for increasing the genetic variation in modern tomato varieties (Huang *et al*., 2012). To date, a large number of African tomato

landraces have been collected, however, very few of them have been systematically evaluated for their adaptability to drought (Robertson and Labate, 2007). The objective of the current study was to evaluate the extent of variability among the African tomato landraces under different irrigation regimes.

4.3 MATERIALS AND METHODS

4.3.1 Site description

A greenhouse study was conducted at the University of Nairobi Upper Kabete campus field station in the year 2015. The site lies at an altitude of 1940 metres above sea level and between latitude 1^0 14' 20' south and 1^0 15' 15'North and longitude 36^0 44' East to 36^0 45' East.

4.3.2 Soil analyses

Soil was collected from kabete field station and subjected to analysis at the Kenya Agricultural and Livestock Research Organization (KALRO) Laboratories (Appendix 2). Soil pH was determined using a pH meter (Schofield and Taylor, 1955) and found to be slightly acidic. Mehlich Double Acid Method (Warnkce and Brown, 1998) was used to determine the available K, Na, Ca, Mg and Mn. K and Mn were found to be high while Na, Ca and Mg were adequate. Total organic carbon was determined using Calorimetric method and found to be adequate. Nitrogen levels were estimated using the Kjeldahl method (Kjedahl, 1883) and found to be adequate. Fe, Zn and Cu were determined using Atomic Absorption Spectrophotometer (AAS) and were also found to be adequate.

4.3.3 Experimental design

Twenty (20) tomato landraces (Table 4.1) selected from the 69 landraces in chapter three were studied. The 20 landraces were selected based on the following criteria: high SPAD value, days to maturity (earliness to maturity), high fruit width and high single fruit weight per plant. The trial was performed in the greenhouse in a randomized complete block design with three replications in January 2015 to April 2015 and a repeat done in May 2015 to August 2015. Treatments included subjecting the 20 accessions to different watering regimes namely: watering at 100% field Capacity (FC) while stress levels were achieved at 80%, 60% and 40% FC respectively.

The amount of water to give the plants was calculated based on the amount of water in the soil at field capacity. Tensiometers were used to determine the field capacity of the soil. Ten (10) kilograms plastic pots were filled with air dried soil and watered to saturation. Tensiometers were inserted at depths of 15 cm corresponding to root depth in tomato (Zekri *et al*., 1999).

Tensiometer readings were then recorded after 24 hours to obtain pressure at field capacity. It was observed that 2.5 litres of water was required to saturate the dry soil to field capacity.

One tomato seedling (four weeks old) was transplanted per pot**.** The transplanted tomato seedlings were watered daily for 14 days to allow for root development. Tomato plants were then subjected thereafter to different water treatment levels throughout their growth cycle. The control (100% FC) received 2.5 liters of water while the stressed plants received 2 litres, 1.5 litres and 1 litre for the 80% FC, 60% FC and 40% FC, respectively.

Table 4.1: List of selected African tomato landraces evaluated in the study

S/no	Acc name	Origin	SPAD	DTM	FW	SFWPP
1	GBK 050580	Kenya	49.9	126.0	1.7	2.7
2	GBK 050580	Kenya	43.8	105.7	1.9	2.7
8	RVI01896	Madagascar	51.9	94.3	5.2	68.8
11	RVI02100	Madagascar	50.8	104.3	6.2	83.0
14	RVI02107	Madagascar	43.5	100.3	5.5	112.6
18	VI005871	Morocco	54.9	106.7	7.1	89.2
21	VI005874	Morocco	39.9	84.3	4.6	83.4
23	VI005876	Morocco	52.3	105.0	6.3	73.9
27	VI005895	Egypt	46.5	92.3	8.1	56.5
37	VI006826	Ethiopia	48.9	116.7	2.0	3.7
39	VI006841	Ethiopia	49.2	108.0	6.0	54.9
47	VI006847	Ethiopia	46.0	91.0	3.1	9.6
49	VI006881-B	Zimbabwe	51.6	110.3	3.2	10.6
55	VI006972	Tanzania	55.5	89.0	2.4	11.9
57	VI007539	South Africa	46.1	121.0	6.0	77.6
58	VI007540	South Africa	46.4	105.0	7.8	107.2
61	VI008234	Nigeria	44.1	91.0	4.5	30.7
64	VI030379	Mauritius	51.3	110.7	6.3	61.1
67	VI030852	South Africa	50.0	123.0	5.8	47.7
69	VI037948	Zambia	53.5	109.0	1.9	3.7

S/no-serial number, Acc name-accession name, SPAD- chlorophyll content, DTM-days to maturity, FW- fruit width (cm), SFWPP-single fruit weight per plant (g)

4.3.4 Management practices

During transplanting 5g/pot (one bottle cap) of di-ammonium phosphate (DAP) fertilizer (18:46:0) was used. Two weeks after transplanting, 5g/pot of urea (46% N) were applied followed by calcium ammonium nitrate (CAN) in the fourth, seventh and twelfth week at the rate of 2.5g/pot (27%N). Watering was done by uniformly spreading the measured amount of water over the soil in each plot by hand. Hand weeding was done twice before flowering while insect pests were controlled by spraying Irrigation was carried out twice every week when moisture level fell below field capacity. Crop support (trellised) was carried out as per the farmers' practice. Crops were sprayed with karate® EC insecticide (active ingredient- L-cyhalothrin) at the rate of 50g/20L to control white flies.

4.3.5 Data collection

Growth and yield traits

Growth and yield data collected included: plant height, single leaf area, stem girth, number of fruits per plant and weight of fruits per plant. Plant height (cm) was measured at flowering from the base of the plant to the tip of the main stem using a meter rule. The single leaf area (cm^2) was calculated at flowering using leaf length and leaf width measurements following the formulae of Rivera *et al.,* (2007) as follows: SLA = 0.763L + 0.34W, where SLA is single leaf area, L is leaf length and W is leaf width. Stem girth (cm) was determined at flowering by measuring the circumference of the main stems slightly above the second truce. The total number of fruits per plant was determined at physiological maturity by counting and weighing done to obtain fruit weight per plant.

Physiological traits

Physiological traits measured included: SPAD value, leaf relative water content (LRWC), stomatal conductance and canopy temperature. Chlorophyll measurements were done at flowering on two fully opened leaves in each plant using SPAD (Minolta SPAD 502 chlorophyll meter). SPAD value of each treatment was obtained by averaging all the readings from each plant.

The leaf relative water content (LRWC) was estimated according to Yamasaki and Dillenburg (1999). Four leaves were picked at flowering from the mid-section of tagged branches. The

leaves were weighed for fresh mass (FM). The same leaves were dipped in de-ionized water for 24 hours and later bloat dried. The leaves were then re-weighed to obtain turgid mass (TM). The leaves were then oven dried at 80^{o}C for 48 hours and dry mass (DM) recorded. All mass measurements were made using an analytical scale, with precision of 0.001 g. Values of FM, TM, and DM were used to calculate LRWC, using the following equation as proposed by Yamasaki and Dillenburg (1999):

$$LRWC\ (\%) = [(FM - DM)/(TM - DM)] \times 100 \quad \text{.....Equation 4.1}$$

Stomatal conductance was determined at flowering using a leaf porometer and expressed in millimoles per meter squared seconds (mmol/m^{2}s). Stomatal measurements were taken at mid morning. Two fully mature leaves from selected plants were randomly picked and their stomatal conductance determined.

Canopy temperature was measured at flowering using an infra-red thermometer (Model THI-500, TASCO, Japan). The thermometer was held slightly above the plant so that the sensor viewed only the canopy at an oblique angle above the horizontal; this position gives an elliptical canopy target (O'Toole and Real, 1984) and prevents the thermometer from sensing the soil surface when the leaves are rolled. All canopy temperature measurements were made within two hours of solar noon, and in a south-facing direction as suggested by Turner *et al*. (1986) to minimize sun angle effects.

Fruit nutritional traits

Nutritional traits of the fruits evaluated included: Vitamin C (ascorbic acid), minerals (Fe, Zn, Ca and K), simple sugars (fructose, glucose and sucrose), β-carotene, total phenolics and antioxidant activity. Ascorbic acid content was determined by the HPLC method according to Vikram *et al*. (2005). Five grams of the fruit sap was weighed and mixed in 20 mL of 0.8% metaphosphoric acid. The mixture was then centrifuged at 10000 revolutions per minute. The supernatant was filtered and diluted with 10 mL of 0.8% metaphosphoric acid. This was passed through 0.45 µ micro-filter and 20 µL injected into the HPLC machine. Various concentrations of ascorbic acid standards were also made to make a calibration curve (Appendix 4). HPLC analysis was done using Shimdzu UV-VIS detector. The samples were run using a mobile phase of 0.8%

metaphosphoric acid, at 1.2 mL/min flow rate and at a wavelength of 266.0 nm. Peak areas from HPLC output that corresponded to Vitamin C retention time (of the standard), were used to calculate the amount of ascorbic acid in milligram per 100 g for all the samples.

β-carotene was extracted using the column chromatography method as described by Rodriguez-Amaya and Kimura, (2004). Approximately 2 g was ground in a mortar with about 10 mL of acetone. The acetone extract was then transferred into 100 mL volumetric flask and the residue further grounded with 10 mL acetone and the extract added to the contents of the volumetric flask. The extraction process was continued with acetone until the final residue became colourless. The combined extract was made to a volume of 100 mL with acetone.

About 25 mL of the extract was evaporated to dryness using a rotary evaporator. The residue was then dissolved with 10 mL petroleum ether and the solution introduced into a chromatographic column. This was eluted with petroleum ether and beta carotene collected in a flask. The beta carotene elute was made to a volume of 25 mL with petroleum ether and the absorbance was read at 440 nm in a UV-Visible spectrophotometer (Shimadzu model UV – 1601 PC, Kyoto, Japan). β-carotene standard was also prepared to make a calibration curve which was used to obtain the regression equation (Appendix 15). Absorption readings from each sample were fit into the equation and used to calculate the amount of β-carotene in milligram per 100 g for each accession.

Analyses for minerals were done by dry ashing of the fresh samples. Iron, zinc and calcium were determined using atomic absorption spectrophotometer (AAS), while atomic emission spectrophotometer (AES) was used to determine potassium according to AOAC, (1984); Osborne and Voogt, (1978). A clean dry crucible was weighed and about 5 g of sample weighed into it. The crucible was placed on a hot plate under a fume hood and the temperature increased slowly until smoking ceased and the samples were thoroughly charred. They were then put in a muffle furnace and temperature increased gradually to 250^0 and heated for one hour. The temperature was increased to 550^0 and samples incinerated for about five hours. The temperature was then decreased to 300^0c and the crucibles removed and cooled to room temperature. All the ash was transferred to 100 ml beaker using 20 mL of 1N HCL, then heated at 80-90^0C on a hot

plate for five minutes. This was then transferred to 100 mL volumetric flask and filled to the mark using 1N HCL. Insoluble matter was filtered and the filtrate kept in a labeled polyethylene bottle. The absorbance of the solutions was read by an atomic absorption spectrophotometer (AAS). The various mineral standards were also prepared to make the calibration curves (Appendices 10-14) which were used to obtain the regression equations. Absorption readings from each sample were fit into the equation and used to calculate the amount of each mineral in milligram per 100 g for all the accession.

Total phenolics content was estimated by a calorimetric assay based on the procedure by Escarpa and Gonzalez (2001) with slight modifications. About 5 g of the fresh sample was crushed and weighed into a 250 mL conical flask and about 50 mL methanol added. The flask was closed securely using parafilm and covered with aluminum foil. The samples were put in a shaker and shaken for about three hours. They were then kept in the dark and left to extract for 72 hours. After 72 hours, the samples were filtered through Whatman No. 4 filter paper, and the filtrate concentrated to dryness using a rotary evaporator, then redissolved in 12.5 mL of methanol and kept frozen until analysis for total phenols. This extract was also used for analysis of anti-oxidative activity.

A 100- µL aliquot of the extracted sample was added to 500 µL of 0.2N Folin-Ciocalteu reagent and 6 ml of distilled water. The content was mixed using a vortex mixer for one minute then 4 ml of saturated Na_2CO_2 was added. Samples were left to stand at room temperature for 90 minutes and absorbance measurements taken at 725 nm using a UV-VIS 1800 Shimadzu spectrophotometer (Shimadzu, Kyoto, Japan). Gallic acid was used as a reference standard (Appendix 14), and the results expressed as milligram Gallic acid equivalents (mg GAE) per 100 g fresh basis.

The total antioxidant activity of the fruit pulp methanolic extracts was measured on the basis of the scavenging activities. Stable 2, 2-Diphenyl-1-picryl hydrazyl (DPPH) radicals (Sigma-Aldrich) were determined using UV spectrophotometer at 517 nm (Molyneux, 2004). Methanol was used to zero the spectrophotometer and the absorbance was read at 517 nm after five minutes in UV-Vis spectrophotometer (Shimadzu model UV – 1601 PC, Kyoto, Japan). The

radical scavenging activity was estimated using the following formula as proposed by Molyneux (2004):

$$\% \text{ inhibition of DPPH} = \{(A_B - A_A)/A_B\} \times 100 \quad \text{Equation 4.2}$$

Where A_B is the absorption of blank sample and A_A is the absorption of tested extract solution. The results were expressed as a percentage inhibition of DPPH.

Simple sugars were determined using the HPLC method. Approximately 10 g of finely ground sample was weighed into 100 ml conical flask and 50 ml of 96% ethanol was added and mixed well using a vortex mixer. The content was then refluxed at 100^{o}C for one hour. The slurry was filtered and the filtrate collected. The conical flask was rinsed three times with 5 ml of 96% alcohol and the content was transferred to 100 pear-shaped flasks and all the solvent evaporated at 60^{o}C to dryness. Ten (10) ml of 50% acetonitrile was added to the dried sample and the content shaken vigorously. The content was micro filtered and injected into HPLC. Peak areas from HPLC graphs were used to calculate the sugar levels in the samples. This procedure was also used to prepare standards of fructose, glucose and sucrose which were used to obtain the retention time for each sugar. Peaks from several concentrations of each simple sugar were used to generate standard curves (Appendices 5-7) which were used to obtain the regression equations.

4.3.6 Data analysis

Data for each parameter were pooled before the statistical analysis was carried out. Analysis of variance (ANOVA) was performed on agronomic, physiological and nutritional traits using Genstat version 15 at 5% level of significance. Mean separation for treatment effects that were significant was done by Fisher's protected least significant difference test using Genstat version 15.

4.4 RESULTS

4.4.1 Agronomic traits

Plant height

Accessions, moisture level and accessions × moisture level interaction significantly ($P<0.05$) affected plant height (Table 4.2). The mean plant height ranged from 29.7 cm (VI006826) to 61.9 cm (VI037948). Plant height ranges of 32.7cm to 65.7 cm (100% FC), 31.0 cm to 63.7 cm (80% FC), 28.0 to 60.0 cm (60% FC) and 27.0 to 58.3 cm (40% FC) were recorded for different moisture levels. Reduction of moisture content to 80% FC significantly ($P<0.05$) reduced plant height in all accessions except for GBK 050580, RVI01896, RVI02100, RVI02107, VI005874, VI005876, VI006826 and VI0006847. Similarly, reduction of moisture from 80% FC to 60% FC significantly ($P<0.05$) reduced plant height in all accessions except for GBK 050580, VI005871, VI005895. Further reduction in moisture from 60% FC to 40% FC significantly ($P<0.05$) reduced plant height in all accessions except RVI02100, VI005876, VI006826, VI030379 and VI037948. Accessions VI037948, VI006972, VI006847, VI006841, VI005874 and GBK 050589 recorded plant height means of more than 50 cm while accessions VI006826, VI030379 and VI007539 registered plant height means of lower than 35 cm.

Stem girth

Accessions, moisture level and accessions × moisture level interaction significantly ($P<0.05$) affected stem girth (Table 4.2). The mean stem girth varied from 3.0 cm (GBK 050589) to 4.9 cm (VI006841). Variation among accessions for stem girth in different moisture levels ranged from 3.7cm to 5.6 cm (100% FC), 3.2cm to 5.0 cm (80% FC), 2.5 cm to 4.9 cm (60% FC) and 2.2 cm to 4.7 cm (40% FC). Reduction of moisture content to 80% FC significantly reduced the stem girth for accessions GBK 050589, VI006841, VI006847, VI007539, VI030379, VI030852, and VI037948, but had no effect on other accessions. Reduction of moisture from 80% FC to 60% FC significantly reduced stem girth in all accessions except GBK 050580, RVI02107, VI005874, VI005876, VI006841, VI006881-B and VI030379. Further reduction in moisture from 60% FC to 40% FC significantly reduced stem girth in all accessions except RVI02100, RVI02107, VI005871, VI005874, VI006881-B, VI030852 and VI037948. Accessions VI006841 and RVI02107 had stem girth means of more than 4.50 cm while accessions GBK 050589,

VI005895, VI007540, VI030852, and VI037948 recorded stem girth means of lower than 3.5 cm.

Table 4.2: Mean values for plant height and stem girth means among the 20 selected tomato accessions grown in the greenhouse under different water levels

	Plant height (cm)					Stem girth (cm)				
Accession name	**100%FC**	**80%FC**	**60%FC**	**40%FC**	**Mean**	**100%FC**	**80%FC**	**60%FC**	**40%FC**	**Mean**
GBK 050580	49.00	48.00	47.67	45.00	**47.42**	3.70	3.57	3.43	3.13	**3.46**
GBK 050589	64.33	60.67	50.00	42.33	**54.33**	3.93	3.47	2.53	2.23	**3.04**
RVI01896	45.00	43.67	40.00	35.33	**41.00**	4.40	4.27	3.97	3.67	**4.08**
RVI02100	41.00	40.33	38.33	36.67	**39.08**	4.13	4.00	3.27	3.07	**3.62**
RVI02107	43.33	43.00	40.33	37.67	**41.08**	5.13	5.03	4.93	4.70	**4.95**
VI005871	44.00	41.67	40.00	37.67	**40.83**	4.53	4.43	4.00	3.90	**4.22**
VI005874	55.67	54.33	50.67	48.00	**52.17**	4.53	4.27	4.03	3.90	**4.18**
VI005876	45.00	44.67	39.00	39.67	**42.08**	4.30	4.07	3.93	3.63	**3.98**
VI005895	45.00	42.00	40.33	37.67	**41.25**	3.63	3.40	3.10	2.80	**3.23**
VI006826	32.67	31.00	28.00	27.00	**29.67**	4.60	4.43	3.97	3.60	**4.15**
VI006841	59.67	57.33	54.00	50.00	**55.25**	5.63	5.00	4.77	4.37	**4.94**
VI006847	59.00	57.33	53.67	50.67	**55.17**	4.70	4.30	3.80	3.27	**4.02**
VI006881-B	48.67	43.67	40.67	38.33	**42.83**	4.33	4.10	3.90	3.70	**4.01**
VI006972	55.33	52.67	50.33	44.00	**50.58**	4.43	4.20	3.80	3.33	**3.94**
VI007539	38.67	35.00	31.00	28.33	**33.25**	4.57	4.27	3.93	3.53	**4.08**
VI007540	44.00	41.00	39.00	37.00	**40.25**	4.27	4.07	2.80	2.43	**3.39**
VI008234	48.33	46.00	42.67	38.67	**43.92**	4.33	4.10	3.80	3.30	**3.88**
VI030379	36.00	34.00	29.00	28.00	**31.75**	4.57	4.27	4.03	3.67	**4.13**
VI030852	47.33	43.67	41.33	38.33	**42.67**	3.77	3.20	2.73	2.83	**3.13**
VI037948	65.67	63.67	60.00	58.33	**61.92**	3.87	3.37	3.03	2.97	**3.31**
MEAN	**48.38**	**46.18**	**42.80**	**39.93**		**4.37**	**4.09**	**3.69**	**3.40**	
Fpr Acc	**< .001****					**< .001****				
Fpr ML	**< .001****					**< .001****				
Fpr Acc*ML	**< .001****					**< .001****				
l.s.d(P<0.05) Acc	**0.92**					**0.14**				
l.s.d.(P<0.05)ML	**0.41**					**0.06**				
l.s.d.(P<0.05)Acc*ML	**1.84**					**0.29**				
CV%	**2.60**					**4.60**				

Acc - accession, ML-moisture level, FC-field capacity, ** highly significant

Single leaf area

Accession, moisture level and accessions × moisture level interaction significantly ($P<0.05$) affected single leaf area (Table 4.3). The mean single leaf area range for varieties was 5.8 cm^2 (GBK 050589) to 11.3 cm^2 (RVI01896). Single leaf area in different moisture levels ranged from 6.3 cm^2 to 11.9 cm^2 (100% FC), 5.8 cm^2 to 11.7 cm^2 (80% FC), 5.5 cm^2 to 11.1 cm^2 (60% FC) and 5.3 cm^2 to 10.4 cm^2 (40% FC). Reduction of moisture content to 80% FC significantly reduced single leaf area in all accessions except GBK 050589. Similarly, reduction of moisture from 80% FC to 60% FC significantly reduced single leaf area in all the accessions. Further reduction in moisture from 60% FC to 40% FC significantly reduced single leaf area in all accessions except GBK 050580. Accession RVI01896 was exceptionally different from the rest of the accessions for leaf area. It registered a mean leaf area of 11.3 cm^2. However, accessions GBK 050589 and VI005876 recorded leaf area means of lower than 6.5 cm^2.

Table 4.3: Mean values for single leaf area means among the 20 selected tomato accessions grown in the greenhouse under different moisture levels

	Moisture level				
Accession name	**100%FC**	**80%FC**	**60%FC**	**40%FC**	**Mean**
GBK 050580	6.74	6.69	6.39	6.32	**6.54**
GBK 050589	6.27	5.89	5.59	5.32	**5.77**
RVI01896	11.97	11.75	11.10	10.41	**11.31**
RVI02100	9.60	9.06	8.78	8.57	**9.00**
RVI02107	8.04	7.84	7.54	7.12	**7.64**
VI005871	9.83	9.56	8.80	8.51	**9.18**
VI005874	10.07	9.69	9.27	8.99	**9.51**
VI005876	6.73	6.43	5.93	5.52	**6.15**
VI005895	8.74	8.39	7.43	6.88	**7.86**
VI006826	9.07	8.81	8.16	7.91	**8.49**
VI006841	8.03	7.79	7.37	7.07	**7.57**
VI006847	7.07	6.75	6.32	6.01	**6.54**
VI006881-B	9.51	9.04	8.65	8.29	**8.87**
VI006972	9.44	9.16	8.61	8.40	**8.90**
VI007539	9.58	9.16	8.82	8.48	**9.01**
VI007540	8.48	8.29	7.75	7.37	**7.97**
VI008234	8.84	8.41	8.00	7.60	**8.22**
VI030379	8.48	8.14	7.75	7.47	**7.96**
VI030852	9.93	9.64	9.01	8.41	**9.25**
VI037948	8.21	7.70	7.38	7.05	**7.58**
Mean	**8.73**	**8.41**	**7.93**	**7.58**	
Fpr Acc	**< .001****				
Fpr ML	**< .001****				
Fpr Acc*ML	**< .001****				
l.s.d(P<0.05) Acc	**0.09**				
l.s.d.(P<0.05)ML	**0.04**				
l.s.d.(P<0.05)Acc*ML	**0.18**				
CV%	**1.4**				

Acc - accession, ML- moisture level, FC-field capacity, ** highly significant

Number of fruits per plant

Accessions, moisture level and accessions × moisture level interaction significantly ($P<0.05$) affected the number of fruits per plant (Table 4.4). The mean number of fruits per plant ranged from 10.8 (VI007539) to 184.0 (VI037948). Average fruit count per plant in different moisture levels ranged from 15.0 to 243.6 (100% FC), 12.6 to 211.0 (80% FC), 9.0 to 158.3 (60% FC) and 5.6 to 126.6 (40% FC). Reduction of moisture content to 80% FC significantly reduced the number of fruits per plant in all accessions except GBK 050580, RV102100, RVI02107, VI005871, VI005874, VI005876, VI005895, VI006826, VI007539, VI007540, VI008234 and VI030379. Similarly, reduction of moisture content from 80% FC to 60% FC significantly reduced the number of fruits per plant in all accessions except GBK 050589, RVI02100, RVI02107, VI005871, VI005874, VI005876, VI005895, VI006826, VI006847, VI007539, VI007540, VI008234, VI030379 and VI030852. Further reduction in moisture from 60% FC to 40% FC significantly reduced the number of fruits per plant in accessions GBK 050580, GBK 050589, RVI01896, VI006841, VI006881-B and VI006972 but had no effect on the rest of the accessions. Accessions VI037948, VI006881-B, GBK 050589 and GBK 050580 recorded means of more than 140 fruits per plant while accessions VI007539 and VI007540 means of less than 15 fruits per plant.

Fruit weight per plant

Accession, moisture level and accessions × moisture level interaction significantly ($P<0.05$) affected fruit weight per plant (Table 4.4). The Mean fruit weight per plant ranged from 392.0 (GBK 050589) to 1869.0 (VI030852). Variations in fruit weight per plant among accessions ranged from 521 g to 2404.3 g (100% FC), 421.3 g to 2020.7 g (80% FC), 359.3 g to 1768.3 g (60% FC) and 127.3 g to 1487.7 g (40% FC). Reduction of moisture content to 80% FC significantly reduced fruit weight in all accessions except GBK 050580, GBK 050589, RVI01896, VI005876 and VI006841. Reduction of moisture content from 80% FC to 60% FC and from 60% FC to 40% FC significantly reduced fruit weight per plant in all accessions except GBK 050580, GBK 050589, RVI01896 and VI006881-B. Accessions VI030852, VI005895, VI002107, VI005871 and VI005874 recorded fruit weight means of more than 1500g per plant while accessions GBK 050589, VI006881-B and RVI01896 recorded fruit weight means of lower than 500 g per plant. Accessions VI030852, VI006826, VI005895, VI005874, VI005871 and RVI02107 recorded fruit weight means of more than 1500g per plant.

Table 4.4: Mean values for the total number of fruits per plant and total fruit weight per plant among the 20 selected tomato accessions grown under different moisture levels

	Total number of fruits per plant					Total fruit weight per plant (g)				
Accession name	**100%FC**	**80%FC**	**60%FC**	**40%FC**	**Mean**	**100%FC**	**80%FC**	**60%FC**	**40%FC**	**Mean**
GBK 050580	189.83	181.33	112.33	87.00	**142.62**	574.70	532.00	504.70	466.30	**519.00**
GBK 050589	164.67	152.33	144.67	123.33	**146.25**	521.00	421.30	359.30	268.30	**392.00**
RVI01896	105.67	98.00	86.00	71.67	**90.33**	639.70	567.00	440.00	347.30	**498.00**
RVI02100	20.67	19.00	15.67	12.00	**16.83**	1759.70	1536.70	1205.30	874.00	**1344.00**
RVI02107	19.00	18.33	15.67	11.33	**16.08**	2225.00	2020.70	1623.30	1131.70	**1750.00**
VI005871	21.33	20.33	18.67	15.00	**18.83**	1917.00	1743.70	1450.70	1142.00	**1563.00**
VI005874	21.67	20.33	17.67	16.00	**18.92**	1864.00	1723.00	1421.70	1232.70	**1560.00**
VI005876	17.67	17.33	15.67	13.33	**16.00**	1019.00	966.30	787.00	127.30	**725.00**
VI005895	41.00	38.33	35.33	32.00	**36.67**	2228.30	1979.00	1768.30	1487.70	**1866.00**
VI006826	37.00	34.33	29.67	27.00	**32.00**	1947.70	1744.00	1431.70	1184.70	**1577.00**
VI006841	147.00	130.67	115.67	101.00	**123.58**	1334.00	1259.00	1057.00	782.70	**1108.00**
VI006847	114.33	105.33	95.67	86.00	**100.33**	1168.30	1000.70	842.00	616.00	**907.00**
VI006881-B	180.67	151.67	130.33	109.67	**143.08**	610.30	460.00	366.70	253.00	**422.00**
VI006972	145.00	133.67	109.33	99.00	**121.75**	1781.30	1537.30	1108.30	974.70	**1350.00**
VI007539	15.00	12.67	9.00	6.67	**10.83**	1109.30	852.30	567.00	299.00	**707.00**
VI007540	19.67	16.33	11.00	8.33	**13.83**	2174.70	1783.70	1091.30	817.30	**1467.00**
VI008234	52.67	48.33	42.33	38.00	**45.33**	1560.30	1359.70	1117.70	891.70	**1232.00**
VI030379	23.67	18.67	15.67	12.00	**17.50**	1468.30	1128.00	897.70	655.30	**1037.00**
VI030852	49.67	46.67	43.67	39.67	**44.92**	2404.30	1985.70	1651.00	1436.00	**1869.00**
VI037948	243.67	211.00	158.33	126.67	**184.92**	1000.30	769.30	510.70	371.70	**663.00**
MEAN	**81.49**	**73.73**	**61.12**	**51.78**		**1465.40**	**1268.50**	**1010.10**	**768.00**	
Fpr Acc	**< .001****					**< .001****				
Fpr ML	**< .001****					**< .001****				
Fpr Acc*ML	**< .001****					**< .001****				
l.s.d(P<0.05) Acc	**4.88**					**66.40**				
l.s.d.(P<0.05)ML	**2.18**					**29.70**				
l.s.d.(P<0.05)Acc*ML	**9.75**					**132.80**				
CV%	**9.00**					**7.30**				

Acc - accession, ML- moisture level, FC-field capacity, ** highly significant

4.4.2 Physiological traits

SPAD Value

Significance differences ($P<0.05$) for SPAD value were recorded for accessions and moisture level, however, accessions × moisture level interaction was not significant (Table 4.5). The mean SPAD value ranged from 47.2 (VI008234) to 57.2 (VI005876. SPAD Values for the different moisture levels ranged from 48.3 to 58.1 (100% FC), 47.6 to 57.1(80% FC), 46.8 to 56.9 (60% FC) and 46.3 to 56.8 (40% FC) among the accessions. Reduction in moisture to 80% FC significantly reduced the SPAD values for accessions RVI02100, VI005895, VI006847 and VI006881-B but had no effect on SPAD value of other accessions. Reduction in moisture content from 80% FC to 60% FC reduced the SPAD value in accession VI006972 but had no effect on the parameter in other accessions. Further reduction in moisture from 60% FC to 40% FC significantly reduced the SPAD value for accessions RVI01896, VI005871, VI006847, VI030852 and VI037948 but had no effect on the rest of the accessions.

Relative water content

Accessions, moisture level and accessions × moisture level interaction significantly ($P<0.05$) affected leaf relative water content (Table 4.5). The mean relative water content ranged from 63.5% (VI005876) to 76.4% (VI006826). Values for RWC ranged from 76.8 to 94.4% (100% FC), 68.2 to 92.9% (80% FC), 52.4 to 74.1% (60% FC) and 42.9 to 63.6% (40% FC). Reduction in moisture to 80% FC had no significant effect on relative water content. However, reduction in moisture from 80% FC to 60% FC significantly reduced leaf relative water content in all accessions except RVI01896, VI005874, VI006826, VI006847, VI007540, VI030852 and VI037948. Further reduction in moisture level from 60% FC to 40% FC significantly reduced relative water content in all accessions except RVI01896, RVI02107, VI005871, VI005876, VI006826, VI006841, VI006881-B, VI006972, VI008234 and VI030379. Compared to other accessions, the highest RWC mean (76.4%) was recorded in accession VI006826 while accessions RVI01896, RVI02107 and VI005876 registered means of lower than 65% RWC.

Table 4.5: Mean values for SPAD value and leaf relative water content among the 20 selected tomato accessions grown in the greenhouse under different water levels

	SPAD value					Percentage Leaf Relative Water Content				
Accession name	**100%FC**	**80%FC**	**60%FC**	**40%FC**	**Mean**	**100%FC**	**80%FC**	**60%FC**	**40%FC**	**Mean**
GBK 050580	52.00	50.67	50.03	49.97	**50.67**	94.38	92.73	62.24	43.05	**73.10**
GBK 050589	52.27	51.77	50.60	50.27	**51.23**	92.94	92.86	58.93	42.86	**71.90**
RVI01896	55.80	54.07	51.73	47.57	**52.29**	77.17	68.24	58.34	54.82	**64.64**
RVI02100	53.97	51.57	51.20	50.27	**51.75**	85.12	77.55	65.78	47.31	**68.94**
RVI02107	51.73	50.37	50.07	49.30	**50.37**	80.10	75.34	52.41	47.14	**63.75**
VI005871	54.77	53.53	51.73	49.27	**52.33**	77.94	75.76	60.65	56.00	**67.59**
VI005874	51.30	51.00	49.77	48.57	**50.16**	86.15	81.11	74.13	49.86	**72.81**
VI005876	57.67	57.60	56.93	56.77	**57.24**	80.55	69.29	54.61	49.35	**63.45**
VI005895	56.67	54.23	53.70	52.63	**54.31**	86.79	83.80	67.87	47.88	**71.58**
VI006826	52.10	50.73	49.73	49.40	**50.49**	89.27	80.50	72.25	63.62	**76.41**
VI006841	49.83	48.47	47.63	47.60	**48.38**	88.40	87.43	53.06	47.21	**69.02**
VI006847	57.27	54.17	53.53	50.27	**53.81**	84.14	76.36	65.81	46.36	**68.17**
VI006881-B	51.40	49.10	47.97	47.30	**48.94**	85.40	82.16	57.40	55.40	**70.09**
VI006972	55.43	54.87	52.43	51.73	**53.62**	84.04	82.91	54.62	49.85	**67.85**
VI007539	50.70	49.50	48.20	46.87	**48.82**	85.63	76.32	61.61	48.98	**68.14**
VI007540	53.63	52.37	50.60	50.30	**51.73**	76.75	72.02	68.18	53.91	**67.72**
VI008234	48.30	47.57	46.80	46.30	**47.24**	81.38	75.57	64.47	59.43	**70.21**
VI030379	56.43	55.87	53.87	51.60	**54.44**	86.98	80.35	58.74	53.50	**69.89**
VI030852	52.83	52.20	51.30	47.77	**51.02**	85.04	83.51	73.33	51.40	**73.32**
VI037948	58.10	56.13	55.83	50.93	**55.25**	87.92	73.31	66.53	46.81	**68.64**
MEAN	**53.61**	**52.29**	**51.18**	**49.73**		**84.80**	**79.36**	**62.55**	**50.74**	
Fpr Acc	**< .001****					**< .001****				
Fpr ML	**< .001****					**< .001****				
Fpr Acc*ML	**< .110 ^{ns}**					**< .001****				
l.s.d(P<0.05) Acc	**1.22**					**5.50**				
l.s.d.(P<0.05)ML	**0.55**					**2.46**				
l.s.d.(P<0.05)Acc*ML	**ns**					**10.99**				
CV%	**2.90**					**9.80**				

Acc - accession, ML- moisture level, FC-field capacity, ns-not significant, ** highly significant, ns-not significant

Canopy temperature

Accessions, moisture level and accessions × moisture level interaction significantly ($P<0.05$) affected canopy temperature (Table 4.6). The mean canopy temperature ranged from 27.5^0C (RVI01896) to 31.1^0 C (VI005871). Canopy temperatures for the different moisture levels ranged from 21.6^0 C to 28.9^0 C (100% FC), 25.0^0 C to 31.0^0 C (80% FC), 27.0^0 C to 30.8^0 C (60% FC) and 30.8^0 C to 34.6^0 C (40% FC). Reduction in moisture to 80% FC significantly increased the leaf canopy temperature in all accessions except GBK 050580, RVI02100, RVI02107, VI005871 and VI006972. Similarly, reduction in moisture from 80% FC to 60% FC significantly increased canopy temperature in al accessions except GBK 050580, GBK 050589, RVI02100, RVI02107 and VI006826. However, further reduction in moisture from 60% FC to 40% FC significantly increased canopy temperature for accessions GBK 050589, RVI01896, VI006826, VI006841, VI006972, VI030852 and VI037948 but had no effect on canopy temperature of other accessions. Compared to other accessions, high canopy temperatures with means of more than 30^0 C were in accessions VI005871, GBK 050589, VI006841 and VI008234. However, lower means for canopy temperature were recorded in accessions RVI01896 and VI005876.

Stomatal conductance

Accessions, moisture level and accessions × moisture level interaction significantly ($P<0.05$) affected stomatal conductance (Table 4.6). The mean stomatal conductance ranged from 133.4 mmol/m^2s (VI006847) to 173.2 mmol/m^2s (VI005874). Stomatal conductance for the different moisture level ranged from 207.7 mmol/m^2s to 287.5 mmol/m^2s (100% FC), 115.5 mmol/m^2s to 196.7 mmol/m^2s (80% FC), 104.0 mmol/m^2s to 100.1 mmol/m^2s (60% FC) and 74.0 mmol/m^2s to 100.1 mmol/m^2s (40% FC). Reduction in moisture level to 80% FC significantly reduced stomatal conductance in all the accessions. Moisture reduction from 80% FC to 60% FC significantly reduced stomatal conductance in all accessions except VI005871, VI006847 and VI030379. Further reduction in moisture from 60% FC to 40% FC significantly reduced stomatal conductance in all the accessions evaluated. Accessions VI005874, VI007539 and VI006972 registered high stomatal conductance with means of more than 170.0 mmolm^{-2}s while accessions VI006847, VI030379, VI007540, VI005871 and RVI01896 had means lower than 150.0 mmolm^{-2}s.

Table 4.6: Mean values for canopy temperature and stomatal conductance among the 20 selected tomato accessions grown in the greenhouse under different water levels

	Canopy temperature (^{0}C)					Stomatal conductance (mmolm^{-2}s)				
Accession number	**100%FC**	**80%FC**	**60%FC**	**40%FC**	**Mean**	**100%FC**	**80%FC**	**60%FC**	**40%FC**	**Mean**
GBK 050580	28.23	28.93	30.00	30.77	**29.48**	228.57	183.83	119.00	90.40	**155.40**
GBK 050589	25.60	31.03	31.43	34.43	**30.62**	235.05	168.33	119.63	90.63	**153.40**
RVI01896	23.47	25.03	27.73	33.87	**27.52**	207.67	166.87	128.00	93.23	**148.90**
RVI02100	27.70	29.33	30.90	31.60	**29.88**	215.20	196.67	133.73	86.67	**158.10**
RVI02107	28.30	29.27	30.20	30.77	**29.63**	227.13	183.95	126.08	93.65	**157.70**
VI005871	28.87	29.63	32.27	33.43	**31.05**	261.87	127.62	112.55	90.38	**148.10**
VI005874	23.50	27.30	30.33	31.53	**28.17**	260.20	194.78	137.75	100.10	**173.20**
VI005876	21.60	26.57	30.77	32.80	**27.93**	231.97	174.95	118.18	95.98	**155.30**
VI005895	24.00	27.87	31.63	33.50	**29.25**	238.47	191.80	128.07	94.22	**163.10**
VI006826	24.00	28.60	30.50	33.93	**29.26**	287.47	165.10	127.57	86.37	**166.60**
VI006841	24.60	29.93	32.50	34.60	**30.41**	264.17	184.27	133.67	90.05	**168.00**
VI006847	25.33	27.53	31.37	32.13	**29.09**	223.92	115.50	103.97	90.05	**133.40**
VI006881-B	22.13	27.03	32.37	33.23	**28.69**	275.97	134.65	110.65	92.12	**153.30**
VI006972	25.37	26.03	30.67	33.30	**28.84**	245.80	195.13	155.67	86.47	**170.80**
VI007539	23.97	28.17	31.87	32.50	**29.12**	283.13	176.57	137.13	87.45	**171.10**
VI007540	22.50	28.60	32.43	33.37	**29.23**	254.16	135.58	107.97	87.55	**146.30**
VI008234	25.50	29.73	32.33	32.80	**30.09**	254.63	175.22	134.05	73.95	**159.50**
VI030379	22.63	27.27	31.90	33.33	**28.78**	231.10	126.47	113.27	89.30	**140.00**
VI030852	24.80	27.57	31.10	34.13	**29.40**	248.63	153.65	115.93	86.40	**151.20**
VI037948	24.33	27.63	31.53	33.70	**29.30**	271.55	183.32	115.52	92.97	**165.80**
MEAN	**24.82**	**28.15**	**31.19**	**32.99**		**247.33**	**166.71**	**123.92**	**89.90**	
Fpr Acc	**< .001****					**< .001****				
Fpr ML	**< .001****					**< .001****				
Fpr Acc*ML	**< .001****					**< .001****				
l.s.d(P<0.05) Acc	**1.02**					**8.82**				
l.s.d.(P<0.05)ML	**0.46**					**3.94**				
l.s.d.(P<0.05)Acc*ML	**2.04**					**17.63**				
CV %	**4.30**					**7.00**				

Acc-accession, ML-moisture level, Acc*ML- interaction, ** highly significant

4.4.3 Nutritional traits

Minerals

Accessions, moisture level and accessions × moisture level interaction significantly ($P<0.05$) affected iron content (Table 4.7). The mean iron levels ranged from 0.007 mg $100g^{-1}$ (GBK 050580) to 0.084 mg $100g^{-1}$ (VI030379). Variation among accessions in different moisture levels ranged from 0.009 mg $100g^{-1}$ (GBK 050580) to 0.092 mg $100g^{-1}$ (RVI01896) at 100% FC and 0.006 mg $100g^{-1}$ (GBK 050580) to 0.078 mg $100g^{-1}$ (VI030379) at 60% FC. Reduction in moisture stress from 100% FC to 60% FC significantly reduced iron levels in all accessions except GBK 050580, VI006826, VI006847 and VI006972.

The amount of calcium significantly ($P<0.05$) varied among the accessions, moisture level and accessions × moisture level interaction (Table 4.7). Calcium levels ranged from 0.052 mg $100g^{-1}$ (VI008234) to 0.304 mg $100g^{-1}$ (RVI02107) at 100% FC and 0.036 mg $100g^{-1}$ (VI008234) to 0.146 mg $100g^{-1}$ (VI006841) at 60% FC. Reduction in moisture stress from 100% FC to 60% FC significantly reduced the amount of calcium in all accessions except RVI02100, VI005876, VI005895, VI006826, VI006841, VI006847, VI006881-B, VI006972, VI007539, VI007540, VI008234, VI030852 and VI037948. The mean calcium level ranged from 0.044 mg $100g^{-1}$ (VI008234) to 0.199 mg $100g^{-1}$ (RVI02107).

The levels of zinc significantly varied among accessions, moisture level and accessions × moisture level interaction (Table 4.7). The mean zinc values for accessions ranged from 0.028 mg $100g^{-1}$ (VI030379) to 0.125 mg $100g^{-1}$ (VI006841). Variation in zinc levels among the accessions ranged from 0.037 mg $100g^{-1}$ (VI030379) to 0.146 mg $100g^{-1}$(RVI01896) at 100% FC and 0.018 mg $100g^{-1}$ (RVI02100) to 0.117 mg $100g^{-1}$(VI006841) at 60% FC. Moisture reduction from 100% FC to 60% FC significantly reduced the amount of zinc in all accessions except VI030379, VI005895, VI006881-B, VI006847, VI037948 and VI006841.

Accessions, moisture level and accessions × moisture level interaction significantly ($P<0.05$) affected potassium content (Table 4.7). The mean potassium levels ranged from 0.529 mg $100g^{-1}$ (VI007539) to 1.553 mg $100g^{-1}$ (GBK 050589). Levels of Potassium in the different moisture levels ranged from 0.723 mg $100g^{-1}$ (VI007539) to 2.054 mg $100g^{-1}$(GBK 050580) at 100% FC

and 0.335 mg $100g^{-1}$ (VI007539) to 1.481 mg $100g^{-1}$(GBK 050589) at 60% FC . Reduction in moisture stress from 100% FC to 60% FC significantly reduced the amount of potassium in all accessions except VI030852, VI037948, VI008234 and GBK 050589.

Table 4.7: Mean values for minerals among the 20 selected tomato accessions grown in the greenhouse under different water levels

	Iron (Fe) mg 100 g^{-1}			Calcium (Ca) mg 100 g^{-1}			Zinc (Zn) mg 100 g^{-1}			Potassium (K) mg 100 g^{-1}		
Accession code	**100%FC**	**60%FC**	**Mean**	**100%FC**	**60%FC**	**Mean**	**100%FC**	**60%FC**	**Mean**	**100%FC**	**60%FC**	**Mean**
GBK 050580	0.009	0.006	**0.007**	0.133	0.065	**0.099**	0.099	0.070	**0.084**	2.054	0.554	**1.304**
GBK 050589	0.069	0.027	**0.048**	0.132	0.055	**0.094**	0.137	0.062	**0.099**	1.626	1.481	**1.553**
RVI01896	0.092	0.050	**0.071**	0.191	0.101	**0.146**	0.146	0.051	**0.098**	1.509	1.067	**1.288**
RVI02100	0.069	0.049	**0.059**	0.096	0.070	**0.083**	0.088	0.018	**0.053**	1.458	0.705	**1.082**
RVI02107	0.064	0.024	**0.044**	0.304	0.093	**0.199**	0.129	0.037	**0.083**	1.149	0.729	**0.939**
VI005871	0.033	0.023	**0.028**	0.156	0.082	**0.119**	0.074	0.038	**0.056**	1.147	0.533	**0.840**
VI005874	0.043	0.018	**0.031**	0.162	0.116	**0.139**	0.091	0.034	**0.063**	1.681	1.342	**1.512**
VI005876	0.052	0.019	**0.036**	0.115	0.082	**0.098**	0.078	0.033	**0.056**	1.157	0.899	**1.028**
VI005895	0.026	0.010	**0.018**	0.159	0.116	**0.137**	0.042	0.021	**0.032**	1.113	0.79	**0.951**
VI006826	0.028	0.023	**0.026**	0.090	0.057	**0.073**	0.086	0.042	**0.064**	1.69	0.723	**1.206**
VI006841	0.083	0.036	**0.059**	0.148	0.146	**0.147**	0.133	0.117	**0.125**	0.873	0.474	**0.674**
VI006847	0.032	0.028	**0.030**	0.093	0.066	**0.079**	0.063	0.048	**0.055**	1.657	0.863	**1.260**
VI006881-B	0.073	0.031	**0.052**	0.111	0.088	**0.100**	0.063	0.046	**0.055**	1.538	1.077	**1.307**
VI006972	0.040	0.031	**0.035**	0.061	0.056	**0.059**	0.086	0.056	**0.071**	1.461	1.06	**1.260**
VI007539	0.083	0.038	**0.061**	0.121	0.084	**0.103**	0.072	0.020	**0.046**	0.723	0.335	**0.529**
VI007540	0.051	0.029	**0.040**	0.098	0.061	**0.080**	0.087	0.059	**0.073**	1.078	0.574	**0.826**
VI008234	0.074	0.016	**0.045**	0.052	0.036	**0.044**	0.061	0.033	**0.047**	1.146	1.101	**1.123**
VI030379	0.090	0.078	**0.084**	0.116	0.045	**0.081**	0.037	0.020	**0.028**	1.278	0.503	**0.890**
VI030852	0.046	0.028	**0.037**	0.070	0.062	**0.066**	0.080	0.031	**0.056**	0.871	0.681	**0.776**
VI037948	0.077	0.051	**0.064**	0.133	0.094	**0.113**	0.097	0.087	**0.092**	1.235	1.075	**1.155**
Mean	**0.057**	**0.031**		**0.127**	**0.079**		**0.088**	**0.046**		**1.322**	**0.828**	
Fpr Acc	**< .001****			**< .001****			**< .001****			**< .001****		
Fpr ML	**< .001****			**< .001****			**< .001****			**< .001****		
Fpr Acc*ML	**< .001****			**< .001****			**< .001****			**< .001****		
Lsd acc	**0.007**			**0.032**			**0.016**			**0.147**		
Lsd ML	**0.002**			**0.010**			**0.005**			**0.046**		
Lsd acc*ML	**0.010**			**0.046**			**0.023**			**0.208**		
CV %	**14.600**			**27.300**			**20.900**			**11.900**		

Acc-accession, ML-moisture level, Acc*ML- interaction, ** highly significant

Accessions, moisture level and accessions × moisture level interaction significantly ($P<0.05$) affected total phenols (Table 4.8). The mean total phenols for accessions ranged from 2.91 GAE/100 g (VI030852) to 7.49 GAE/100 g (VI030379). Levels of total phenols ranged from 1.56 GAE/100 g (RVI02100) to 4.94 GAE/100 g (VI030379) at 100% FC and 3.21 GAE/100 g (VI005876) to 11.3 GAE/100 g (RVI01896) at 60% FC. Moisture reduction from 100% FC to 60% FC significantly increased the amount of total phenols in all accessions except GBK 050580, VI005876, VI006847 and VI006881-B.

Total antioxidant activity varied significantly ($P<0.05$) among accessions, moisture level and accessions × moisture level interaction (Table 4.8). The mean values for accessions ranged from 18.06% (RVI02100) to 31.77% (VI030379). At 100% FC, total antioxidant activity ranged from 13.25% (RVI02100) to 29.30% (VI030379) while at 60% FC a range of 20.12% (VI030852) to 38.33% (RVI01896) was observed. Reduction in moisture from 100% FC to 60% FC significantly increased the antioxidant capacity in all accessions except GBK 050589, VI007539 and VI030852.

Table 4.8: Means values for total phenols and total antioxidant activity among the 20 selected tomato accessions grown in the greenhouse under different moisture levels

	Total phenolics (GAE/100 g)			Total antioxidant activity (%inhibition)		
Accession code	**100%FC**	**60% FC**	**Mean**	**100% FC**	**60% FC**	**Mean**
GBK 050580	4.86	5.13	**4.99**	21.69	26.02	**23.85**
GBK 050589	4.21	6.86	**5.54**	23.50	25.39	**24.45**
RVI01896	2.13	11.35	**6.74**	20.63	38.33	**29.48**
RVI02100	1.56	5.98	**3.77**	13.25	22.88	**18.06**
RVI02107	1.61	7.62	**4.61**	14.09	25.51	**19.80**
VI005871	1.79	5.16	**3.48**	15.89	22.04	**18.96**
VI005874	2.13	8.43	**5.28**	20.20	33.51	**26.85**
VI005876	2.99	3.21	**3.10**	17.99	22.45	**20.22**
VI005895	1.86	6.81	**4.33**	16.03	25.23	**20.63**
VI006826	1.74	4.94	**3.34**	14.54	21.61	**18.07**
VI006841	2.05	7.92	**4.99**	19.91	27.55	**23.73**
VI006847	3.76	4.42	**4.09**	20.47	23.47	**21.97**
VI006881-B	4.43	4.79	**4.61**	21.08	25.12	**23.10**
VI006972	2.32	8.13	**5.22**	20.76	29.41	**25.08**
VI007539	2.95	5.33	**4.14**	21.49	22.16	**21.82**
VI007540	1.91	4.50	**3.20**	16.90	20.79	**18.85**
VI008234	2.01	6.55	**4.28**	18.83	25.18	**22.00**
VI030379	4.94	10.03	**7.49**	29.30	34.23	**31.77**
VI030852	1.94	3.87	**2.91**	18.50	20.12	**19.31**
VI037948	2.60	7.20	**4.90**	21.38	25.45	**23.41**
Mean	**2.69**	**6.41**		**19.32**	**25.82**	
Fpr Acc	**< .001****			**< .001****		
Fpr ML	**< .001****			**< .001****		
Fpr Acc*ML	**< .001****			**< .001****		
l.s.d.acc	**0.62**			**1.63**		
l.s.d ML	**0.19**			**0.52**		
acc*ML	**0.87**			**2.30**		
CV %	**11.80**			**12.50**		

Acc-accession, ML-moisture level, Acc*ML- interaction, ** highly significant

Accessions, moisture level and accessions × moisture level interaction significantly ($P<0.05$) affected the amount of β-carotene (Table 4.9). The mean for β-carotene among accessions varied from 0.628 mg $100g^{-1}$ (GBK 050580) to 4.422 mg $100g^{-1}$ (VI006847). β-carotene content ranged from 0.898 mg 100 g^{-1} (GBK 050580) to 4.944 mg $100g^{-1}$ (VI006847) at 100% FC and 0.359 mg $100g^{-1}$ (GBK 050580) to 3.900 mg $100g^{-1}$(VI006847) at 60% FC. Reduction in moisture content from 100% FC to 60% FC significantly reduced the amount of β-carotene in all accessions except RVI01896.

Accessions and moisture level significantly ($P<0.05$) affected the amount of Vitamin C, however, accessions × moisture level interaction had no effect on the levels of vitamin C (Table 4.9). Mean vitamin C content varied from 6.83 mg100 g^{-1} (VI006826) at 100% FC to 26.26 mg100 g^{-1} (VI030852) at 60% FC. Reduction in moisture level from 100% FC to 60% FC significantly reduced vitamin C content. Accessions VI030852 and RVI01896 had significantly higher vitamin C content than the rest of the accessions while accession VI006826 had significantly the lowest vitamin C content.

Table 4.9: Means values for β-carotene and vitamin C levels among the 20 selected tomato accessions grown in the greenhouse under different water levels

	β-carotene (mg100 g^{-1})			Vitamin C (mg100 g^{-1})		
Accession code	**100% FC**	**60% FC**	**Mean**	**100% FC**	**60% FC**	**Mean**
GBK 050580	0.898	0.359	**0.628**	10.920	10.220	**10.570**
GBK 050589	0.965	0.635	**0.800**	13.900	12.260	**13.080**
RVI01896	2.538	2.292	**2.415**	32.060	18.840	**25.450**
RVI02100	1.805	1.327	**1.566**	21.450	16.040	**18.750**
RVI02107	2.173	0.846	**1.509**	15.800	10.330	**13.070**
VI005871	1.633	1.014	**1.323**	15.890	14.850	**15.370**
VI005874	2.267	1.500	**1.883**	20.080	19.050	**19.570**
VI005876	3.248	2.631	**2.940**	17.570	15.310	**16.440**
VI005895	1.721	1.093	**1.407**	12.120	9.070	**10.600**
VI006826	2.570	0.743	**1.656**	6.900	6.770	**6.830**
VI006841	3.165	2.388	**2.776**	20.640	13.890	**17.260**
VI006847	4.944	3.900	**4.422**	22.890	18.120	**20.510**
VI006881-B	2.667	1.089	**1.878**	14.430	9.810	**12.120**
VI006972	2.404	1.613	**2.008**	20.880	18.820	**19.850**
VI007539	2.167	1.462	**1.814**	22.040	19.380	**20.710**
VI007540	2.667	1.700	**2.184**	14.130	11.930	**13.030**
VI008234	2.588	1.792	**2.190**	24.060	20.810	**22.440**
VI030379	2.306	1.779	**2.043**	18.680	15.750	**17.220**
VI030852	1.497	0.798	**1.147**	27.250	25.270	**26.260**
VI037948	1.900	1.146	**1.523**	16.380	14.040	**15.210**
Mean	**2.306**	**1.505**		**18.400**	**15.030**	
Fpr Acc	**< .001****			**< .001****		
Fpr ML	**< .001****			**< .001****		
Fpr Acc*ML	**< .001****			**< .001****		
l.s.d.acc	**0.180**			**2.468**		
l.s.d ML	**0.057**			**0.780**		
acc*ML	**0.255**			**3.490**		
CV %	**8.200**			**12.900**		

Acc-accession, ML-moisture level, Acc*ML- interaction, ** highly significant

Accessions, moisture level and accessions × moisture level interaction significantly ($P<0.05$) affected sugar levels (Table 4.10). The mean fructose levels among studied accessions varied from 1.120 mg $100g^{-1}$ (VI007539) to 4.742 mg $100g^{-1}$ (VI030379). Fructose ranged from 0.965 mg $100g^{-1}$ (VI007539) to 4.009 mg $100g^{-1}$ (VI037948) at 100% FC and 1.276 mg $100g^{-1}$ (VI007539) to 6.519 mg $100g^{-1}$ (VI030379) at 60% FC (Table 4.10). Reduction in moisture level from 100% FC to 60% FC significantly increased fructose levels in all accessions except VI007539 and RVI02100.

The mean glucose levels among studied accessions varied from 1.100 mg $100g^{-1}$ (VI007539) to 6.088 mg $100g^{-1}$ (VI030379). Glucose levels ranged from 0.843 mg $100g^{-1}$ (VI007539) to 4.867 mg $100g^{-1}$ (VI006841) at 100% FC and 1.356 mg $100g^{-1}$ (VI007539) to 8.709 mg $100g^{-1}$ (VI030379) at 60% FC (Table 4.10). Moisture reduction from 100% FC to 60% FC significantly increased the amount of glucose in all the accessions evaluated.

Sucrose levels among accessions ranged from 0.000 mg $100g^{-1}$ (11 accessions) to 1.617 mg $100g^{-1}$ (VI006881-B). Sucrose levels varied from 0.000 mg $100g^{-1}$ (11 accessions) to 0.265 mg $100g^{-1}$(VI006881-B) at 100% FC and 0.000 mg $100g^{-1}$ (11 accessions) to 2.969 mg $100g^{-1}$(VI006881-B) at 60 % FC (Table 4.10). Reduction in moisture levels from 100% FC to 60 % FC significantly increased the sucrose levels in all accessions except VI005876 and VI006841.

Table 4.10: Mean values for fructose, glucose and sucrose among the 20 selected tomato accessions grown in the greenhouse under different water levels

	Fructose (mg100 g^{-1})			Glucose (mg100 g^{-1})			Sucrose (mg100 g^{-1})		
Accession code	**100%FC**	**60%FC**	**Mean**	**100%FC**	**60%FC**	**Mean**	**100%FC**	**60%FC**	**Mean**
GBK 050580	1.977	2.293	**2.135**	2.233	3.539	**2.886**	0.000	0.000	**0.000**
GBK 050589	3.229	4.361	**3.795**	4.400	7.533	**5.967**	0.000	0.000	**0.000**
RVI01896	2.301	3.249	**2.775**	3.043	3.912	**3.477**	0.222	1.380	**0.801**
RVI02100	2.752	3.024	**2.888**	3.467	4.367	**3.917**	0.000	0.000	**0.000**
RVI02107	2.474	2.911	**2.692**	2.638	3.471	**3.055**	0.133	0.414	**0.274**
VI005871	2.248	3.012	**2.630**	3.767	4.400	**4.083**	0.000	0.000	**0.000**
VI005874	2.837	3.531	**3.184**	4.233	5.400	**4.817**	0.227	0.400	**0.313**
VI005876	2.128	2.574	**2.351**	2.967	3.400	**3.183**	0.031	0.130	**0.080**
VI005895	2.450	2.779	**2.615**	3.433	4.333	**3.883**	0.122	0.500	**0.311**
VI006826	2.402	2.838	**2.620**	3.067	3.867	**3.467**	0.000	0.000	**0.000**
VI006841	3.283	4.474	**3.878**	4.867	5.300	**5.083**	0.133	0.226	**0.180**
VI006847	2.117	2.960	**2.539**	3.267	4.100	**3.683**	0.000	0.000	**0.000**
VI006881-B	1.907	2.291	**2.099**	3.000	3.500	**3.250**	0.265	2.969	**1.617**
VI006972	2.792	3.480	**3.136**	3.798	4.401	**4.099**	0.000	0.000	**0.000**
VI007539	0.965	1.276	**1.120**	0.843	1.356	**1.100**	0.000	0.000	**0.000**
VI007540	1.577	2.056	**1.817**	2.033	2.427	**2.230**	0.000	0.000	**0.000**
VI008234	2.367	2.862	**2.614**	3.184	3.760	**3.472**	0.000	0.000	**0.000**
VI030379	2.964	6.519	**4.742**	3.467	8.709	**6.088**	0.000	0.000	**0.000**
VI030852	2.892	3.809	**3.351**	4.209	4.830	**4.519**	0.200	0.395	**0.297**
VI037948	4.009	4.729	**4.369**	4.500	5.144	**4.822**	0.094	0.333	**0.214**
Mean	**2.484**	**3.251**		**3.321**	**4.387**		**0.071**	**0.337**	
Fpr Acc	**< .001****			**< .001****			**< .001****		
Fpr ML	**< .001****			**< .001****			**< .001****		
Fpr Acc*ML	**< .001****			**< .001****			**< .001****		
l.s.d acc	**0.222**			**0.169**			**0.079**		
l.s.d ML	**0.070**			**0.053**			**0.025**		
l.s.d acc*ML	**0.314**			**0.239**			**0.112**		
CV %	**6.700**			**3.800**			**34.300**		

Acc-accession, ML-moisture level, Acc*ML- interaction, ** highly significant

4.4.4 Correlation analysis for fruit yield, physiological traits and quality parameters

Significant relationships between fruit yield with physiological traits, fruit yield with nutritional traits and physiological traits with nutritional traits were observed in this study (Table 4.11). Fruit yield correlated positively with relative water content (r=0.33), stomatal conductance (r=0.40) and calcium level (r=0.22). However, fruit yield negatively correlated with total antioxidant activity (r=-0.48), total phenols (r=-0.48), canopy temperature (r=-0.28) and sucrose level (r=-0.26).

Relative water content correlated positively with calcium (r=0.33), iron (r=0.37), zinc (r=0.44), potassium (r=0.56), vitamin C (r=0.19) and β-carotene (r=0.25) while it recorded a negative correlation with total phenols (r=-0.61) and total antioxidant activity (r=-0.50). SPAD correlated positively with β-carotene (r=0.31), potassium (r=0.30) and iron (r=0.20). However, it registered a negative but significant correlation with total phenols (r=-0.27) and sucrose (r=-0.21).

Canopy temperature showed a positive correlation with total antioxidant activity (r=0.37), total phenols (r=0.57), fructose (r=0.35), glucose (r=0.35) and sucrose (r=0.19) but negatively correlated with β-carotene (r=-0.47), vitamin C (r=-0.29), calcium (r=-30), iron (r=-0.55), zinc (r= -0.44) and potassium (r= -0.48). Stomatal conductance recorded a positive correlation with β-carotene (r=0.39), vitamin C (r=0.25), calcium (r=0.39), iron (r=0.50), zinc (r=0.52) and potassium (r=0.55) but showed a negative correlation with total antioxidant activity (r= -0.51), total phenols (r=-0.67), fructose (r=-38), glucose (r=-0.38) and sucrose(r=-0.27).

Table 4.11: Correlation table for the fruit yield, physiological traits and quality parameters among selected African tomato accessions

	FWPP	RWC	SPAD	CT	SC	AA	βC	TP	Vit C	Ca	Fe	Zn	K	F	G	S
FWPP	-															
RWC	0.33**	-														
SPAD	0.12	0.27*	-													
CT	-0.28*	-0.68**	-0.37**	-												
SC	0.40**	0.76**	0.26*	-0.84**	-											
AA	-0.48**	-0.50**	-0.15	0.37**	-0.51**	-										
βC	0.10	0.25*	0.31**	-0.47**	0.39**	-0.18*	-									
TP	-0.48**	-0.61**	-0.27*	0.57**	-0.67**	0.82**	-0.31**	-								
Vit C	0.11	0.19*	0.16	-0.29*	0.25*	-0.06	0.37**	-0.22*	-							
Ca	0.22*	0.33**	0.17	-0.30**	0.39**	-0.21*	0.15	-0.32**	0.09	-						
Fe	-0.02	0.37**	0.20*	-0.55**	0.50**	-0.09	0.33*	-0.25*	0.44**	0.29*	-					
Zn	0.02	0.44**	0.11	-0.44**	0.52**	-0.30**	0.21*	-0.43**	0.20*	0.58**	0.40**	-				
K	0.01	0.56**	0.30**	-0.48**	0.55**	-0.20*	0.23*	-0.30**	0.09	0.27*	0.11	0.42**	-			
F	-0.15	-0.29*	0.07	0.35**	-0.38**	0.47**	-0.20*	0.52**	-0.03	-0.17	0.08	-0.07	-0.15	-		
G	-0.14	-0.30*	0.02	0.35**	-0.38**	0.44**	-0.22*	0.48**	-0.06	-0.22*	-0.03	-0.12	-0.09	0.92**	-	
S	-0.26*	-0.27*	-0.21*	0.19*	-0.27*	0.28*	-0.15	0.24*	-0.14	0.02	-0.09	-0.12	-0.02	0.01	0.02	-

FWPP-fruit weight per plant, RWC-relative water content, SPAD-chlorophyll content, CT-canopy temperature, SC-stomatal conductance, AA-antioxidant activity, βC-β-carotene, TP-total phenols, Vit C-vitamin C, Ca-calcium, Fe-iron, Zn-zinc, K-potassium, F-fructose, G-glucose, S-sucrose, ** highly significant, * significant

4.5 DISCUSSION

Moisture stress reduced plant height and stem diameter, however, the level of response to moisture stress varied with the genotype. Water stress suppresses cell expansion and cell growth due to low tugour pressure (Shao *et al*., 2009; Neera *et al*., 2011). Similar findings were observed by Kinark *et al*. (2001). Accessions VI037948, VI006841 and VI006847 recorded a plant height of more than 55.0 cm while accessions VI006826, VI030379 and VI007539 had plant height means of lower than 35.0 cm. Accessions VI006841and RVI02107 recorded stem girth means of more than 4.5 cm compared to accessions GBK 050589 and VI030852 that had stem girth means of lower than 3.2 cm. This implies that accessions with minimal variation in plant height and stem diameter when subjected to moisture stress have the potential of being selected for breeding of drought tolerant tomato varieties.

Leaf area reduced under moisture however, the extent of reduction was dependent on genotype. According to Shao *et al*., (2008), decrease in turgor pressure caused by the reduced soil water potential results in the reduction of cellular expansion and vegetative growth. Similar findings were recorded by Turner *et al.* (1978). Reduction in leaf area under water stressed condition implies a decrease of radiation interception, decrease of photosynthesis and, consequently, decreases in yield (Anjum *et al*., 2011). Compared to other accessions, accession RVI01896 recorded a leaf area mean of more than 10.0 cm^2 while accessions GBK 050589, GBK 050580, VI005876 and VI006847 had leaf area means of less than 7.0 cm^2. This implies that water stressed accessions with high leaf area have the potential of maintaining photosynthetic capacity and being used for breeding of drought tolerant tomato varieties.

According to Yamasaki and Dillenburg (1999), relative water content (RWC) is an appropriate physiological measure of plant water status under water stress condition. In the current study, relative water content reduced with increase in moisture stress. Decreased leaf water potential leads to stomatal closure and ultimately results in low transpiration which in turn increases leaf temperature (Fukai *et al*., 1999). Similar findings were reported in tomato by Sibomana *et al.* (2013). Maintenance of high LRWC under moisture deficit conditions is a measure of plant's ability to withstand drought (Anjum *et al*., 2011). Accessions VI006826, VI030852, GBK 050580, VI005874, GBK 050589, VI005895, VI006881-B and VI008234 had high leaf relative

water content with a mean of more than 70% while accessions VI005876, RVI02107 and RVI01896 had means lower than 65%. This implies that water stressed accessions with high LRWC have the potential of being selected for the breeding of drought tolerant tomato varieties.

SPAD value decreased with increase in moisture stress and varied among the study accessions. Reduction in chlorophyll content could be attributed to the fact that water stress damages the photosynthetic apparatus by causing changes in the chlorophyll contents and components (Becana *et al.*, 1998; Gong *et al.*, 2005). This conforms to the findings by Ramadasan *et al*. (1993) and Sibomana *et al*. (2013). Destruction of photosynthetic apparatus results in the inhibition of the process of photosynthesis and consequent reduction in yield. Accessions VI005876 and VI037948 recorded high SPAD means of more than 55.0 while accessions VI008234, VI007539, VI006881-B and VI006841 had SPAD means of lower than 50.0.This implies that accessions that are able to maintain their chlorophyll levels under different intensities of water stress have the potential of selection for tomato crop improvement.

Stomatal conductance declined with increase in moisture stress and was dependent on the genotype. According to Turan *et al*. (2009), during a water stress, plants respond by closing their stomata to protect themselves from extensive water loss during transpiration. These findings are in agreement with those of Sibomana, *et al*., (2013). Accessions VI005874, VI007539 and VI006972 had high stomatal conductance recording means of more than 170.0 $mmolm^{-2}s$ while accessions VI006847, VI030379, VI007540, VI005871 and RVI01896 had means lower than 150.0 $mmolm^{-2}s$. This implies that accession that highly resisted stomatal opening under different intensities of moisture stress have the potential for use in tomato improvement.

Canopy temperature varied among the accessions and was significantly reduced with increase in moisture stress. The increase in temperature probably occurred due to the decrease in plant transpiration caused by the closure of stomata; this being the main cooling mechanism for plants (Siddique *et al.*, 2001). Similar findings were observed by Jackson (1982). Compared to other accessions, lower means for canopy temperature were recorded in accessions RVI01896 and VI005876. However, accessions VI005871, GBK 050589, VI006841 and VI008234 recorded high canopy temperatures with means of more than 30^0 C. This implies that accessions with low

canopy temperature under moisture deficit conditions are tolerant and therefore have the potential of being used to develop drought tolerant tomato.

Fruit yield reduced with increase in moisture stress. This could be attributed to a decrease in photosynthesis. According to Ramadasan *et al*. (1993), the final yield of the crop is a product of combined effects of stress on growth and physiological processes. Reduction of photosynthesis under moisture deficit can be attributed to the decreases in chlorophyll content, leaf area, and efficiency of carbon fixation and closure of stomata. Yield reduction could also be associated to decline in nutrient uptake under moisture stress condition. According to Kozlowski, (1972), most of the water is required for the development of reproductive organs since growth of the flower and fruit involves rapid accumulation of dry matter and water. This therefore implies that water stress imposed during this critical stage has detrimental effect on fruit yield. In the current study, accessions VI030852, VI005895, VI002107, VI005871 and VI005874 recorded high fruit weights per plant with means of more than 1500g per plant. Accessions with high fruit yield under moisture stress have therefore the potential of being used to develop drought tolerant tomato variety.

The level of vitamin C reduced with increase in moisture deficit; however, level response to water stress was dependent on genotype. Similar findings were reported by Vijitha and Mahendran (2010). This could be attributed to low synthesis of vitamin C during fruit development due a decreased in photosynthesis under reduced moisture levels. Accessions VI030852, VI007539, RVI01896 and VI006847 were less responsive to water stress and recorded more than 20.0 mg 100 g^{-1}. β-carotene response to water stress was dependent on genotype. Similar findings were reported by Vijitha and Mahendran (2010). β-carotene synthesis is very sensitive to changes in temperatures during fruit development (Davies *et al.*, 1991). This reduction can therefore be attributed to the high temperatures observed among the water stressed accessions. Compared to other accessions, high mean levels of β-carotene were recorded in accession VI006847. This implies that accessions that maintained high levels of vitamin C and β-carotene under reduced water levels have the potential of improving the nutritional quality of drought tolerant tomato varieties through breeding.

The response of potassium, calcium, zinc and iron levels to water stress were dependent on the accessions. Water stress reduced the mineral levels among the studied genotypes. Accessions with high mineral levels were VI030379 and RVI01896 (iron), RVI02107, VI006841 and RVI01896 (calcium), VI006841 (zinc) and GBK 050589 and VI005874 (potassium). Similar findings were documented by Kaya *et al*., (2006), Khalid (2006) and Yu et at., (2007). Decrease in minerals might be attributed to the mobilization of mineral ions from the leaves to the roots in response to water stress to increase the osmotic potential of the sap of the roots to help the plant withstand the effects of water stress (Xu *et al*., 2002). Similarly, this apparent reduction might also be related to the reduction in root activity and leaf water potential. This implies that accessions that were able to maintain high minerals level under reduced moisture levels have the potential of being used to breed varieties with high β-carotene levels for water deficit regions.

Water stress increased levels of glucose, fructose and sucrose among the accessions. However, the increase was dependent on the genotype. Accessions with outstanding performance were VI037948 and VI030379 (fructose), VI030379, VI006841 and GBK 050589 (glucose) and VI006881-B and RV101896 (sucrose). This result confirms the findings of Adejare and Umebese (2008). According to Lobato *et al.* (2008), plants synthesize and accumulate osmolytes such as simple sugars which act as osmotica and play an important role in osmotic adjustment in plants at reduced potential. This implies that accessions with high levels of glucose, fructose and sucrose under reduced moisture level have the potential of being used to improve the sugar levels of drought tolerant tomato varieties.

Water stress resulted to an increased antioxidant capacity among the tomato accessions. Accessions VI030379, RVI01896, VI005874 and VI006972 recorded high antioxidant capacity of more than 25.0% compared to accessions RVI02100, RV102107, VI005871, VI006826, VI007540 and VI030852. Studies have shown that drought stress can induce a wide range of antioxidants in a number of plant species (Bray, 2002; Sofo *et al*., 2005). According to Oh *et al*., (2009), abiotic stresses such as water stress have been shown to activate genes involved in the biosynthesis of antioxidants. Variations among accessions could be attributed to the differences in genetic and environmental conditions from which the accessions were obtained. This is expected since different genotypes perform differently in same environment (Blay *et al.* 1999).

This implies that accessions that are able to maintain high levels of these antioxidants under reduced moisture level have the potential of being used to improve the nutritional quality of drought tolerant tomato varieties.

Positive and significant association of fruit yield per plant with relative water content (RWC), stomatal conductance shows that plants with both high relative water content and high stomatal conductance tend to yield higher than those with lower RWC and restricted stomatal conductance. These findings are in agreement with the results of David (2002), in which a positive correlation between relative water content and gas exchange activities was observed. This author reported that the reduction of relative water content caused a strong reduction in photosynthesis, transpiration and stomatal conductance. Besset *et al*. (2001) reported that drought resistant varieties showed consistently higher leaf water potential in their tissues than susceptible types under soil moisture deficit. In the present studies, accessions VI005874, VI007539 and VI006972 registered higher levels of stomatal conductance while accessions VI006826 recorded the highest relative water content.

Relative water content showed negative but significant relationship with simple sugars and secondary metabolites. These findings indicate an increase in the production of plant secondary metabolites and simple sugars under low relative water content. Similar observations were also reported by Schreiner *et al.* (2009), Xiao *et al.* (2009) and Szabo *et al.* (2008). The exposure of plants to water stresses often leads to the generation of reactive oxygen species (ROS) (Ashraf and Akram, 2009). Increasing ROS levels cause oxidative damage to cell components such as lipids, proteins, and nucleic acids (Smirnoff, 1993). When plants are exposed to stress, antioxidant systems become active and begin to scavenge ROS thus providing plant tolerance to water stress (Hayat *et al.,* 2010).

4.6 CONCLUSION

Agronomic, physiological and nutritional quality responses to water stress were dependent on genotypes. Reduction in moisture led to a decrease in the plant height, leaf area, stem girth, fruit yield, SPAD value, leaf relative water content, stomatal conductance, vitamin C and β-carotene. However, canopy temperature, fructose, glucose, sucrose, total phenols and total antioxidant activity increased with the reduction in moisture levels. Relative water content and stomatal conductance were identified as the most important physiological traits for the selection of drought tolerant genotypes. This is because of their effect on both fruit yield and nutritional quality. A high level of stomatal conductance was registered in accessions VI005874, VI007539 and VI006972 while accessions VI006826 recorded the highest relative water content. Variation among accessions to different moisture levels as observed in this study provides an opportunity to select genotypes that have the potential of being used to breed drought tolerant tomato varieties with high nutritional quality. Significant associations of various traits with yield were also observed in this study. Such associations help in the identification of important traits that can be used for the selection of drought tolerant accessions. Positive and significant correlations between fruit yield and stomatal conductance and leaf relative water content clearly indicates that crop improvement for drought tolerance in tomato should focus on these traits

CHAPTER 5

GENERAL DISCUSSION, CONCLUSION AND RECOMMEDATIONS

5.1 GENERAL DISCUSSION

This study demonstrated high levels of variation among the 69 accessions for morphological traits evaluated. Based on cluster analysis, the accessions were grouped into two major clusters. Cluster I had most of the accessions which were further grouped into seven sub-clusters for the green house and field grown accessions respectively. The clustering pattern showed that some of the accessions (RVI02100, RVI02098, RVI02102, RVI0983, RVI1896, and RVI01884) from Madagascar (cluster II) were significantly different from the rest of the accessions for stem colour. The first three components of Principal Component Analysis explained 78.2% of total variations among the genotypes. Findings indicated that the traits contributing most to the variability among the study accessions were fruit size, foliage density, growth type and fruit cross sectional shape. Estimates of Shannon-Weaver diversity index (H') for the qualitative traits showed high (H'>0.500) levels of polymorphism. The indices ranged from 0.9771 (fruit shape) to 0.9995 (flower colour) for both the field and green house grown accessions.

Significant variations were observed for all agronomic traits as well as the SPAD value. For example, accessions VI005905, VI005986, VI030380, VI006827, VI005895, VI006826, VI006840, VI006841, RVI02107, VI030852 and VI006825 performed differently from the other accessions for important traits. They were superior in flowering and maturity, fruit length, fruit width, total fruit weight per plant, single fruit weight per plant and SPAD content. Variations in the agronomic traits and SPAD value in the current study is expected since different genotypes perform differently in the same environment (Blay *et al.* 1999).

Moisture level affected agronomic, physiological and nutritional traits of the selected tomato accessions. For example, water stress reduced fruit yield under moisture stress compared to unstressed conditions. This could be attributed to the reduction in growth due to slowed photosynthesis and translocation of assimilates to the sinks where water plays a critical role. Accessions VI030852, VI005876, VI0006826, VI005874, VI030379, VI030852 and VI037948

recorded the highest means in following the important traits; fruit weight, SPAD value, leaf relative water content, stomatal conductance, iron, antioxidants and vitamin C when subjected to varying moisture levels. This shows that the accessions evaluated have diverse mechanisms through which they respond to effects of water stress.

Variation observed in this study confirms a rich source of genetic diversity among the African tomato accessions. This implies that the studied accessions have the potential of being used for future tomato crop improvement. Some of the important morphological and agronomic traits identified in this study include fruit size, presence of green shoulder, days to maturity, fruit width, total fruit weight per plant, single fruit weight per plant and SPAD content. Similarly, significant variations were observed among the selected accession when subjected to water stress. This variation demonstrates that these accessions have adapted different mechanisms through which they respond to effects of water stress. Stomatal conductance and leaf relative water content were identified as the most important physiological traits that determined drought adaptability among the accessions. This implies that accessions that recorded high stomatal conductance and relative water content have the ability to withstand effects of water deficit and therefore carry the potential of being used for tomato crop improvement.

5.2 CONCLUSION

This study confirms the presences of sufficient morphological and agronomic diversity among the African tomato landraces. Estimates of Shannon-Weaver diversity index (H') showed high (H'>0.500) levels of polymorphism for morphological characters. The indices ranged from 0.9771 (fruit shape) to 0.9995 (flower colour). Cluster analysis classified the genotypes into two, Cluster I contained 63 accessions while cluster II had 6 accessions. Principal component analysis identified growth type, foliage density, fruit size and fruit cross sectional shape the characters contributing most to the variability among the accessions. Accessions with the highest and the least number of fruits recorded means of 8.3 (VI007539) to 442.3(GBK 050580) fruits per plant respectively. Similarly, fruit weight varied widely within the range of 565.0 g (RVI02098 and VI006827) to 2759.0 g (VI006826) per plant. Fruit yield showed a positive and significant correlation with fruit length (r=0.42), fruit width (r=0.51), fruit weight (r=0.50) and stem girth (r=0.41).

Water stress significantly reduced fruit yield which ranged from 127.3 g (VI005876) to 1487.7 g (VI005895) at 40% FC and 521.0 g (GBK 050589) to 2404.3 g (VI037948) at 100% FC. Similar reductions were recorded in stem girth, plant height and leaf area under stressed conditions. Water stress reduced stomatal conductance, which ranged from 73.9 mmol/m^2s (VI008234) to 100.1 mmol/m^2s (VI005874) at 40% FC and 207.7 mmol/m^2s (RVI01896) to 287.5 mmol/m^2s (VI006826) at 100% FC. Reductions were also observed in SPAD value and leaf relative water content under water stress conditions. However water stress significantly increased the canopy temperature.

Water stress significantly increased total phenolics, antioxidant activity and soluble sugars. Significantly lower levels of mineral nutrients (potassium, zinc, magnesium, iron and sodium), β-carotene and vitamin C levels were recorded under water stress than unstressed conditions. The study has revealed that water stress has significant effect on agronomic, physiological and nutritional quality traits of tomato accessions. This effect should be taken into consideration when selecting tomato accessions with desirable agronomic, physiological and nutritional traits for crop improvement programmes.

5.3 RECOMMENDATIONS

This study identified 11 accessions namely VI005905, VI005986, VI030380, VI006827, VI005895, VI006826, VI006840, VI006841, RVI02107, VI030852 and VI006825 that were different from the other accessions for important traits. They were superior in days to flowering and maturity, fruit length, fruit width, total fruit weight per plant, single fruit weight per plant and SPAD content. However, the current study focused on landraces only. There is need therefore to conduct a similar study using both the landraces and commercial varieties grown in Kenya and other parts of Africa

Accessions VI030852, VI005876, VI0006826, VI005874, VI030379, VI030852 and VI037948 recorded the highest means for fruit weight, SPAD value, leaf relative water content, stomatal conductance, iron, antioxidants and vitamin C when subjected to varying moisture levels. These accessions therefore have the potential of being used for the future programmes of tomato crop improvement. However, the current study on the effect of water stress on agronomic, physiological and nutritional traits was conducted in the greenhouse. It is advisable to conduct a similar study under field conditions in different agro-ecological conditions.

REFERENCES

Adriana Sacco ,Valentino Ruggieri , Mario Parisi, Giovanna Festa, Maria Manuela Rigano, Maurizio Enea Picarella,Andrea Mazzucato, Amalia Barone. (2015). Exploring a Tomato Landraces Collection for Fruit-Related Traits by the Aid of a High-Throughput Genomic Platform http://dx.doi.org/10.1371/journal.pone.0137139.

Agong S. G., Schittenhelm S. and Friedt. W. (2001). Genotypic variation of Kenyan tomato (*Lycopersicon esculentum* L.) germplasm. Plant Genetic Resources Newsletter, 123: 61-67.

Aksic M, Gudzic S, Deletic N, Gudzic N, Stojkovic S. (2011). Tomato fruit yield and evapo-transpiration in the conditions of South Serbia. Bulgarian Journal of Agricultural Sciences, 17:150 157.

Al Khanjari S, Filatenko AA, Hammer K and Buerkert A. (2008). Morphological diversity of Omani wheat. Journal of Genetic Resources and Crop Evolution, 46: 419-425.

Anjum SA; Xie X; Wang L; Saleem MF; Man C; Lei W. (2011). Morphological, physiological and biochemical responses of plants to drought stress. African Journal of Agricultural Research, 6: 2026-2032.

Ashraf M. (2010). Inducing drought tolerance in plants: Recent advances. Biotechnology Advances Journal, 28: 169-183.

Ashraf M., Akram N. A. (2009). Improving salinity tolerance of plants through conventional breeding and genetic engineering: an analytical comparison. Journal of advanced biotechnology. ,27: 744–752. 10.1016/j.biotechadv.2009.05.026.

Ashraf, M., S. Ala, S.Bhatti. (1998). Nutrtional imbalance in wheat (*Triticun gestivum L*) genotypes grown at soil water stress. Acta Physilogae Plantarum, 20 (3):307-311.

Association Of Analytical Communities (AOAC). (1984). Official methods of analysis, Association of Official Analytical Chemist: 14th edition, Washington D. C.

Bajracharya J, Steele KA, Jarvis DI, Sthapit BR, W I tcombe JR. (2006). Rice landrace diversity in Nepal: Variability of agro-morphological traits and SSR markers in landraces from a high-altitude site. Field Crops Research Journal, 95: 327-335.

Becana, M., Iturbe-Ormaetxe, I., Escuredo, P. R. and Arrese-Igor, C. (1998). Oxidative damage in pea plants exposed to water deficit or paraquat. Plant Physiology Journal, 116:173-181.

Belaj, A., Dominguez-Garcia, M.D., Atienza, S.G., Urdiroz, N.M., De la Rosa, R.,Satovic, Z., Martin, A., Kilian, A., Trujillo, I., Valpuesta, V., Del Rio, C. (2012). Developing a core collection of olive (Olea europaea L.) based on molecularmarkers (DArTs, SSRs, SNPs) and agronomic traits. Tree Genetics and Genomes Journal, 8 (2) 365–378.

Besset J., M. Genard T. Girard V. Serra and C. Bussi, C. (2001). Effects of water stress applied during the final stage of rapid growth on peach trees. Scientia Horticulturae, 91: 289-303.

Bhatt GM. (1970). Multivariate analysis approach to selection of parents for hybridization aiming at yield improvement in self-pollinating crops. Australian Journal of Soil Research, 21:1-7.

Black, L. L., Wu, D. L., Wang, J. K., Kalb, T., Abass, D., Chen, J. H. (2003). Grafting tomatoes for production in hot-wet season: In International cooperators' s guide. Asian Vegetable Research and Development Center. The Bureau of Animal and Plant Quarantine and Health Inspection, Council of Agriculture, China.

Blanca J, Can˜izares J, Cordero L, Pascual L, Diez MJ, Nuez F. (2012). Variation revealed by SNP genotyping and morphology provides insight into the origin of the tomato. PLoS ONE, 7(10):e48198. doi:10.1371/Journal.Pone.

Blanca, J., Canizares, J., Cordero, L., Pascual, L., Diez, M.J. and Nuez, F. (2012). Variation revealed by SNP genotyping and morphology provides insight into the origin of the tomato. PLoS ONE, 7, e48198

Blay ET (1999). Crop rotation to control nematode in tomato. Ghana journal of agricultural sciences, 6:137- 139.

Bray, E.A. (2002). Classification of genes differentially expressed during water-deficit stress in *Arabidopsis thaliana: An* analysis using microarray and differential expression data. Annals of Botany Journal (London), 89:803–811.

Chiorato AF, Carbonell SAM, Benchimol LL, Chiavega TOMB, Dias LAS and Colombo CA. (2007). Genetic diversity in common bean accessions evaluated by means of morpho-agronomical and RAPD data. Scientia Agricola Journal, 64: 256-262.

Chiorato AF, Carbonell SAM, Colombo CA and Dias LAS.(2005). Genetic diversity of common bean accessions in the germplasm bank of the Instituto Agronômico – IAC. Crop Breeding and Applied Biotechnology Journal, 5:1-9.

Chweya JA and Mnzava NA. (1997). Cat's whiskers, Spider plant: Promoting the conservation and use of underutilized and neglected crops. Institute of plant genetics and crop plant research, gatersleben/International Plant Genetic Resources Institute, Rome, Italy.

Cruz CD and Carneiro PCS. (2006). Modelos Biométricos Aplicados ao Melhoramento Genético.v. 2, Editora UFV, Viçosa, 585p.

Darwin SC, Knapp S, Peralta IE .(2003). Tomatoes in the Galapagos Islands: morphology of native and introduced species of Solanum section Lycopersicon (Solanaceae). Systems and Biodiversity Journal, 1:29 54.

David W. (2002). Limitation to photosynthesis in water stressed leaves: stomata vs. metabolism and the role of ATP. Annals of botany, 89: 871-885.

Davies, M.B., J. Austin & D.A Partridge. (1991). Vitamin C; Its Chemistry and Biochemistry. The Royal Society of Chemistry, Cambridge.

Dias, D. M., J. T. V. Resende, *et al*. (2013). "Selection of processing tomato genotypes with high acyl sugar content that is resistant to the tomato pinworm." Genetics and Molecular Research Journal, 12(1): 381 – 389.

Diez, C.M., Imperato, A., Rallo, L., Barranco, D., Trujillo, I. (2012). Worldwide core collection of olive cultivars based on Simple Sequence Repeat and Morphological Markers. Crop Science Journal, 52 (1), 211–221.

Doorenbos, J. and Kasssam, A.H. (1979). Yield response to Water. FAO Irrigation and Drainage Paper No. 33. Rome, FAO.

Escarpa, A., and M.C. Gonzalez. (2001). Approach to the content of total extractable phenolic compounds from different food samples by comparison of chromatographic and spectrophoto metric methods. Analytica Chimica Acta, 427(1): 119–127.

Fabeiro C, Martín de Santa Olalla F and de Juan, J.A. (2001). Yield and size of deficit irrigated potatoes. Journal of Agricultural Water Management, 48:255-266.

Fajinmi, A. A. and Fajinmi, O. B. (2010). An overview of bacterial wilt disease of tomato in Nigeria Agricultural Journal, 5 (4): 242-247.

Fontes, P.C.R. (2001). Diagnóstico do estado nutricional das plantas. Viçosa: UFV, 122p.

Food and Agricultural Organization of the United Nations, Statistics (FAO).(2013). URL: http://faostat.fao.org/site/291/default.aspx .Viewed on 14 January 2015.

Foolad MR (2007). Genome mapping and molecular breeding of tomato. International Journal of Plant Genomics, 2007: 64358.

Foolad, M.R., L.P. Zhang, and P. Subbiah. (2003). Genetics of drought tolerance during seed germination in tomato: inheritance and QTL mapping. Genome Science Journal, 46:536-545.

FukaiS.Pantuwan G., Jong dee b. and Cooper M. (1999). Screening for drought resistance in rainfed lowland rice. Field Crops Research Journal, 64:61-74.

Ghafoor, A., Z. Ahmad, A.S. Qureshi ans M. Bashir. (2002). Genetic relationship in *Vigna mungo* (L.) Hepper and *V. radiate* (L.) R. Wilczek based on Morphological Traits and SDS-PAGE. Euphytica, 123: 367-378.

Ghosh, K.P., A.K.M.A. Islam, M.A.K. Mian and M.M.Hossain. (2010). Variability and character association in F_2 segregating population of different commercial hybrids of tomato (*Solanum lycopersicum* L.). Journal of applied science and management, 14:91-95.

Goncalves, L.S.A., R. Rodrigues, A.T.jr. Amaral, M. Karasawa and C.P. Sudre. (2009). Heirloom tomato gene bank: assessing genetic divergence based on morphological, agronomic and molecular data using a Ward-modified location model. Genetic and Molecular Research Journal, 8(1): 364-374.

Gong, h., X. Zhu, K. chen, s. wang and c. Zhang. (2005). Silicon alleviates oxidative damage of wheat plants in pots under drought. Journal of Plant Sciences, 169:313–321.

Gower JC. (1966). Distance properties of latent root and vector methods used in multivariate analysis. Biometrika Journal, 53: 325–338.

Grierson, D. and A.A. Kader. (1986). Fruit Ripening and Quality. In: The Tomato Crop, Atherton, J.G. and J. Rudich (Eds.). Chapman and Hall, New York, London, pp: 241-280.

Gustavo, R.R., R.P. Guillermo, Z. Roxana and A.P. Liliana. (2006). Evaluation of plant and fruit traits in recombinant inbred lines of tomato obtained from a cross between *Lycopersicon esculentum* and *Lycopersicon pimpinellifolium.* Chilean Journal of Agricultural Research, 33(2): 111-118.

Hanson PM, Sitathani K, Sadashiva AT, Yang RY, *et al*. (2007). Performance of Solanum habrochaites LA1777 introgression line hybrids for marketable tomato fruit yield in Asia. Euphytica, 158: 167-178.

Hayat Q, Hayat S, Irfan, M, Ahmad A. (2010). Effect of exogenous salicylic acid under changing environment: A review. Journal of environmental and experimental botany, 68:14-25.

HCDA. (2010). Horticultural crop production report. Horticultural development authority (HCDA), http://www.hcda.or.ke.

HCDA. (2013). Horticultural crop production report. Horticultural development authority (HCDA), http://www.hcda.or.ke.

HCDA. (2014). Horticulture Data 2011-2013 Validation Report. Horticultural Crops Development Authority, February 2014 pp 65.

Heim, R.R. (2002). A review of twentieth-century drought indices used in the United States. Bull. Am. Meteorol. Soc, 83 (8): 1149 –1165.

Helyes L, Dimény J, Pék Z, Lugasi A. (2006). Effect of maturity stage on content, color and quality of tomato (*Lycopersicon lycopersicum* (L.) Karsten) fruit. International Journal of Horticultural Science, 12:41-44.

Hetherington Am, Woodward Fi. (2003). The role of stomata in sensing and driving environmental change. Nature Journal 424: 901-908.

Huang, X.H., Zhao, Y., Wei, X.H., Li, C.Y., Wang, A., Zhao, Q., Li, W.J., Guo, Y.L., Deng,L.W., Zhu, C.R., Fan, D.L., Lu, Y.Q., Weng, Q.J., Liu, K.Y., Zhou, T.Y., Jing, Y.F., Si, L.Z.,Dong, G.J., Huang, T., Lu, T.T., Feng, Q., Qian, Q., Li, J.Y., Han, B. (2012). Genome-wide association study of flowering time and grain yield traits in a worldwidecollection of rice germplasm. Nature Review Genetics Journal, 44 (1):U32–U53.

Islam BMR, Ivy NA, Rasul MG and Zakaria M. (2010). Characters association and path analysis of exotic tomato (Solanum lycopercicum L.) genotypes. Bangladesh Journal of Plant Breeding and Genetics, 23:13-18.

Jackson R.D., (1982). Canopy temperature and crop water stress. In: Advances in Irrigation. Hillel, D. (Ed.). 1: 43-85. Academic Press, New York.

Johnson AR and Wichern DW (1992) Applied multivariate statistical analysis. (3rd ed), Prentice-Hall, Englewood Cliffs, NJ, pp. 767.

Jolliffe IT (1986) Principal component analysis. Springer-Verlag, Berlin. pp. 522.

Jones, J.B. (2008). Tomato Plant Culture: In the field greenhouse and garden. Taylor and Francis Group, USA. 55.

Kaemer, D., K. Weising, B. Beyermann, T. Börner, J.T. Epplen and G. Kahl. (1995). Oligonucleotide fingerprinting of tomato DNA. Journal of plant breeding, 114:12-17.

Karasawa, M., R. Rodrigues, C.P. Sudre and M.P. Silva. (2005). Cluster analysis in quantifying genetic divergence in tomato accessions. The Journal Horticultura Brasileira, 23: 1000-1005.

Kaya, C., Levant, J., David, H. (2006). Effect of silicon and plant growth and mineral nutrition of maize grown under water stress condition. Journal of Plant Nutrition, 29(8):1469-1480

Kenya Agricultural Research Institute (KARI).(2005). KARI annual report 2005. Nairobi, Kenya.

Kenya Horticulture Competitiveness Project (KHCP) report. (2011). Fruits and Vegetable Retail Tracker June – August 2011 report.

Khachik, F., L. Carvalho, P.S. Bernstein, G.J. Muir, D.Y. Zhao, N.B. Katz, and L. Cohen. (2002). Chemistry, distribution, and metabolism of tomato carotenoids and their impact on human health. International symposium on the role of tomato products and carotenoids in disease prevention. New York Acad. Journal of Medicine Experiment and Biological Medicine, 227(10):845–851.

Khalid, K. A. (2006). Influence of water stress on growth, essential oil and chemical compostion of herbs (Ocimum species). International Journal of Agro-physics, 20:289-296

Kirnak, H., Kaya, C., Tas, I. and Higgs, D. (2001). The influence of water deficit on vegetative growth, physiology, fruit yield and quality in eggplants. Bulgarian Journal of Plant Physiology, 27(3-4), 34-46.

Kjeldahl JZ (1883). A new method for the determination of nitrogen in organic bodies. Journal of Analytical Chemistry 22: 366.

Kozlowski, T.T. (1972). Water Deficit and Plant Growth. Academic Press. London. pp 91-111.

Li L, Zhao Y, McCaig B *et al*. (2004). The tomato homologof coronatine-insensitive is required for the maternal control of seed maturation, jasmonate signaled defense responses, and glandular trichome development. Plant Cell Journal, 16:126.

Lobato, A.K.S., C.F.O. Neto, R.C.L. Costa, B.G.S. Filho, F.J.R. Cruz and H.D. Laughinghouse. (2008). Biochemical and physiological behavior of *Vigna unguiculata* (L.) Walp. Under water stress during the vegetative phase. Asian Journal of Plant Sciences, 7: 44-49.

Maerere AP, Sibuga KP, Mwajombe KK .(2006). Baseline survey report of tomato production in Mvomero district-Morogoro region, Tanzania. Sokoine University of Agriculture Faculty of Agriculture, Morogoro, pp. 1-31.

Maria LLG, Óscar JG, Juan JLG, Paola HC,Carlos EOV. (2014). Quality Parameters and Bioactive Compounds of Red Tomatoes (*Solanum lycopersicum* L.) cv Roma VF at Different Postharvest Conditions. Journal of food research, 3(5):8-18.

Mbaka, J. N., Gitonga, J. K., Gathambari, C. W., Mwangi, B. G., Githuka, P. and Mwangi, M. (2013). Identification of knowledge and Technology gaps in high tunnels Tomato Production in Kirinyaga and Embu counties.

Mburu, M.W.K. (1996). The effect of irrigation, fertilizer nitrogen and planting density on bean (*Phaseolus vulgaris*) yield under different weather conditions, Ph.D. Thesis University of reading, Britain.

Mittler R., Blumwald E. (2010). Genetic engineering for modern agriculture: challenges and perspectives. Annual review on plant biology, 61:443–462. 10.1146/annurev-arplant-042809-112116.

Mohammadi, S. A. and Prasanna, B. M. (2003). Analysis of Genetic Diversity in Crop Plants—Salient Statistical Tools and Considerations. Review and Interpretation. Crop Science Journal, 43: 1235-1248.

Mohanty BK. (2002). Variability, heritability, correlation and path coefficient studies in tomato. Haryana Journal of Horticultural Science, 31 (3 and 4): 230-233.

Mohanty, B.K. (2003). Genetic variability, correlation and path coefficient studies in tomato. In. Journal of Agriculture Research, 37: 68-71.

Molyneux, P. (2004). The use of the stable free radical diphe-nylpicrylhydrazyl (DPPH) for estimating antioxidant activity. Songklanakarin Journal of Science and Technology, 26(2): 211-219.

Morales R, Resende L, Maluf W, Peres L, Bordini I. (2015). Selection of tomato plant families using characters related to water deficit resistance. Horticultura Brasileira 33: 027-033. DOI - http://dx.doi.org/10.1590/S0102-053620150000100005.

Müller K, McDermott JM, Wolfe MS, Limpert E. *(*1996). Analysis of diversity in populations of plant pathogens: the barley powdery mildew pathogen across Europe. European Journal of Plant Pathology, 102*:* 385–395.

Mwirigi PN, Kahangi EM, Nyende AB, EG. Mamati. (2009). Morphological variability within the Kenyan yam (*Dioscorea spp.).* Journal of Applied Biosciences; 16:894–901.

Neera, J., Sharma, parveen, kumar, M.S. Kadian, S.K, Luthra. (2011). Performance of potato (Solanum tuberosum L) clones under stress CIP south west and central Asia Region. Indian Journal of Agricultural Sciences, 81(9):825-9.

Newton, A.C., Akar, T., Baresel, J.P., Bebeli, P.J., Bettencourt, E., Bladenopoulos, K.V.,Czembor, J.H., Fasoula, D.A., Katsiotis, A., Koutis, K., Koutsika-Sotiriou, M., Kovacs,G., Larsson, H., de Carvalho, M.A.A.P., Rubiales, D., Russell, J., Dos Santos, T.M.M.,Patto, M.C.V. (2010). Cereal landraces for sustainable agriculture. A Review of Agronomy and Sustainainable Development Journal, 30 (2), 237–269.

Nonami H. (1998). Plant water relations and control of cell elongation at low water potentials. Journal of Plant Research, 111: 373-382.

Nuruddin M.M., Madramootoo C.A. and Dodds G.T. (2003). Effects of water stress at different growth stages on greenhouse tomato yield and quality. Journal of Horticultural Sciences, 38, 1389-1393.

Nuruddin, M. M. (2001). Effects of water stress on tomato at different growth stages, Thesis msc., Mc Gili university, Macdonald campus, Montreal, Canada.

Oh, M.M., Carey, E.E., Rajashekar, C.B. (2009). Environmental stresses induce health-promoting phytochemicals in lettuce. Journal of Plant Physiology and Biochemistry, 47:578–583.

Olmstead RG, Bohs L, Migid HA, Santiago-Valentin E, *et al*. (2008). A molecular phylogeny of the Solanaceae. Journal of Taxonomy, 57: 1159-1181.

Osei, M. K.,Akromah,R.,Shilh,S.L, Green,S.K. (2010). Evaluation of some tomato Germplasm for resistance to Tomato Yellow leaf curls Virus disease (TYLCV) in Ghana. Aspects Applied Biology Journal, 96:315-323.

Osei, M.K., Bonsu, K.O., Agyeman, A., Choi, H.S. (2014). Genetic diversity of tomato germplasm in Ghana using morphological characters. Journal of Plant Nutrition and Soil Science, 3(3), 220–231.

Payne RW, Murray DA, Harding SA, Baird DB and Soutar DM. (2011). An introduction to GenStat for Windows (14th Edition). VSN International, Hemel Hempstead, UK.

Peralta IE, Spooner DM. (2007). History, origin and early cultivation of tomato (Solanaceae). In: Razdan MK, Mattoo AK (eds) Genetic Improvement of Solanaceous Crops, volume 2, Tomato Science Publishers.

Perez de la Vega M. (1993). Biochemical characterization of population. In: MD. Hayward NO. Bosemark, and I. Romagosa (eds.). Plant Breeding Principles and ProspectsChampman and Hall, London, 184-200.

Perrier X and Jacquemud-Collet JP .(2006). DARwin software. http://darwin.cirad.fr/darwin.

Perry, M.C. and M.S. McIntosh. (1991). Geographical patterns of variation in the USDA soybean germplasm collection: In. Morphological traits. Journal of Crop Science, 31: 1350-1355.

Ramadasan, A., K.V. Kasturi Bai & S. Shivashankar. (1993). Selection of coconut seedlings through physiological and biochemical criteria. In: Advances in Coconut Research Development (M.K.Nair *et al.* editions.), pp. 201-207. New Delhi.

Republic of Kenya, (2008): Review and Analysis of Existing Drought Risk Reduction Draft 2008; Republic of Kenya, Nairobi.

Rick CM (1976). Tomato *Lycopersicon esculentum* (Solanaceae). In: Evolution of Crop Plants (Simmonds NW, ed.). Longman, London, 268-273.

Rick, C.M. and M. Holle. (1990). Andean *Lycopersicon esculentum* var. *cerasiformie*: Genetic variation and its evolutionary significance. Journal of Economic Botany, 44:69-78.

Rivera CM, Rouphael Y, Cardarelli M, and Colla G. (2007). A simple and accurate equation for estimating individual leaf area of eggplant from linear measurements. European Journal of Horticulture Science, 72: 228–230.

Robertson, L.D. and J.A. Labate. (2007). Genetic resources of tomato (lycopersicum esculentum Mill) and wild relatives. In: Genetic Improvement of Solanaceous Crops Vol. 2. Tomato. (Eds.): M.K. Razdan and A.K. Mattoo. Science publishers, new hampshire, pp. 25-75.

Rodriguez, M., Canales, E. and Borras-Hidalgo, O. (2005). Molecular aspects of abiotic stress in plants‘. Biotecnologia Aplicada Journal, 22:1-10.

Rodriguez-Amaya, D. B., & Kimura, M. (2004). HarvestPlus handbook for carotenoids analysis (first edition). Washington, DC and Cali: IFPRI and CIAT (Chapter 2), 58 pp.

Rudich.J, D. Kalmar, C. Greizenberg and S. Harel. (1977). Low water tensions in defined growth stages of processing tomato plants and their effect on yield and quality. Journal of Horticultural Sciences, 52: 391-399.

Schofield, R. K., and A. W. Taylor. (1955). The measurement of soil pH. Soil Science Society of America Journal, 19:164-167.

Schreiner, M.; Beyene, B.; Krumbein, A.; Stützel, H. (2009). Ontogenetic changes of 2-propenyl and 3-Lndolylmethyl glucosinolates in *Brassica carinata* leaves as affected by water supply. Journal of Agriculture and Food Chemistry. *57*, 7259–7263.

Sexton, P. and J. Carrol. (2002). Comparison of SPAD chlorophyll meter readings vs. petiole nitrate concentration in sugarbeet. Journal of Plant Nutrition, 25(9): 1975-1986.

Shaheen, Muhammad R Choudhary M Ayyub,aMuhammad Amjada and Ejaz A Waraichb. (2015). Morpho-physiological evaluation of tomato genotypes under high temperature stress conditions wileyonlinelibrary.com) DOI 10.1002/jsfa.7388.

Shannon, C. E. and W. Weaver. (1949). The Mathematical Theory of Communication. University of Illinois press, Urbana, Illinois. 144pp.

Shao H. B; Chu L. Y; Jaleel C. A; Zhao C. X. (2008). Water-deficit stress-induced anatomical changes in higher plants. Comptes Rendus Biologies, 331: 215-225.

Shao, H.B, Chu, L.Y, Jaleel, C.A., Manivannan, P., Panneerselvam, R. Shao, M.A. (2009). Understanding water deficit stress-induced changes in the basic metabolism of higher plants-biotechnologically and sustainably improving agriculture and the eco-environment in arid regions of the globe. Critical Reviews in Biotechnology Journal, 29: 131-151.

Shushay Chernet, Derbew Belew, Fetien Abay. (2014). Genetic diversity studies for quantitative traits of tomato (*Solanum lycopersicon* L.) genotypes in Western Tigray, Northern Ethiopia. Journal of Plant Breeding and Crop Science, 6(9):105-11.

Sibomana, C. I., J. N. Aguyoh, and A. M. Opiyo. (2004). "Influence of soil moisture levels and packaging on postharvest qualities of tomato. www.academicjournals.org/journal/AJAR/article-full.../AFD771351798.

Sibomana.I. C, J.N. Aguyoh and A.M. Opiyo. (2013). Water stress affects growth and yield of container grown tomato (*lycopersicon esculentum mill*) plants. Global Journal of Biochemistry and Biotechnology, Volume, 2 (4):461- 466.

Siddique M.R; Hamid A; Islam MS. (2001). Drought stress effects on water relations of wheat. Botanical Bulletin of Academia Sinica, 41: 35-39.

Siderius, W. (1976). Environment and characteristics of nitisols at Kabete national agricultural laboratories, Nairobi. Ministry of agriculture and livestock development.

Simpson, E. H. (1949). Measurement of Diversity. Nature Journal, 163: 688.

Singh, D. R., Kumar, K. and Birah, A. (2014a). Eco-friendly management modules for bacterial wilt (*Ralstonia solanacearum*) of tomato for protected cultivation in a tropical island ecosystem. Biological Agriculture and Horticulture: An International Journal for Sustainable Production Systems,

Singh, D., Yadav, D. K., Sinha, S. and Choudhary, G. (2014b). Effects of temperature, cultivars, injury of root and inoculum load of *Ralstonia solanacearum* to cause bacterial wilt of tomato. Journal of Phytopathology and Plant Protection, 47(13): 1574-1583

Singh, P.K., B. Singh and P. Sadhukar. (2006). Genetic variability and character association analysis in tomato. Indian Journal of Plant Genetic Resource, 19:196-199.

Sionit, N. & P.J. Kramer. (1977). Effect of water stress during different stages of growth of soy beans. Agronomy Journal, 69**:** 274-277.

Sivaprasad, K. (2008). Genetic variability and correlation studies in biparental mating populations of tomato (*Solanum lycopersicon* (Mill.) Wested). M.Sc. diss. Univ. Agricultural Sciences, Dharwad-580005, India.

Smirnoff, M. (1993). The role of active oxygen in the response of plants to water deficit and desiccation. New Phytologist Journal, 125: 27–58.

Smith M. (2000). The application of climatic data for planning and management of sustainable rainfed and irrigated crop production. Agricultural Journal for Meteorology, 103: 99-108.

Sofo, A., Tuzio, A.C., Dichio, B., Xiloyannis, C. (2005). Influence of water deficit and rewatering on the components of the ascorbate-glutathione cycle in four interspecific Prunus hybrids. Journal of Plant Science, 169:403–412.

Steel RGD and Torrie JH. (1980). Principles and procedures of statistics, a biometrical approach. (2nd Edition) New York: McGraw-Hill, 633 p.

Subhash C. (2010). Plant physiology. New age international (P) publishers, Delhi, India. Page 618.

Susic, Z., N. Pavlovic, D. Cvikic and T. Sretenovic-Rajiicic. (2012). Studies of correlation between yield and fruit characteristics of (*Lycopersicon esculentum* Mill.) hybrids and their parental genotypes. Acta of Horticulture, 579:163-166.

Szabó, B.; Lakatos, Á.; Koszegi, T.; Botz, L. (2008). Investigation of abiogenic stress-induced alterations in the level of secondary metabolites in poppy plants (*Papaver somniferum* L.). Acta Biologica Hungarica. *59*, 425–438.

Tahat, M.M.and Kamaruzaman S. (2010). Ralstonia solanacearum: The bacterial wilt causal agent. Asian Journal of Plant Sciences, 9:385-393.

Terzopoulos, P.J. and P.J. Bebeli. (2008). DNA and morphological diversity of selected Greek tomato (Solanum lycopersicum L.) landraces. Journal of Horticultural Sciences, 116: 354-361.

Terzopoulos, P.J., P.J. Bebeli. (2007). Genetic diversity of tomato (*Lycopersicon esculentum* Mill.) landraces using morphological and ISSR data. 18th EUCARPIA Genetic Resources Section Meeting 23-26 May, Piestany, Slovak Republic.

Terzopoulos, P.J., S.A. Walters and P.J. Bebeli. (2009). Evaluation of Greek tomato landrace populations for heterogeneity of horticultural traits. European Journal of Horticultural Sciences, 74: 24-29.

Torrecillas A, Alarcón Jj, Domingo R, Planes J, Sánchez-Blanco Mj. (1996). Strategies for drought resistance in leaves of two almond cultivars. Journal of Plant Science, 118: 135-143.

Torrecillas A;Guillaume C; Alarcón JJ Ruiz-sánchez MC. (1995). Water relations of two tomato species under water stress and recovery. Plant Science Journal, 105: 169-176.

Turan MA, Elkarim AH A , Taban N, and Taban S. (2009). Effect of salt stress on growth, stomatal resistance, proline and chlorophyll concentrations in maize plant. African Journal of Agriculture Research, 4 (9): 893 – 897.

Turner NC. (1986). Crop water deficits: a decade of progress. Journal of Advances in Agronomy, 39:1-51.

Upadhyaya HD, Reddy KN, Gowda CLL and Singh S. (2007). Phenotypic diversity in the pigeon pea (*Cajanus cajan)* core collection. Journal of Genetic Resources and Crop Evolution 54: 1167-1184

Valls JFM. (2007). Characterization of Plant Genetic Resources. In: NASS LL (Ed.) Plant genetic resources. Brasilia: Embrapa Genetic Resources and Biotechnology, Page 281-305.

Van der Vossen, H.A.M. & Nono-Womdim, R. & Messiaen, C.-M. (2004). *Lycopersicon esculentum* Mill. In: Grubben, G.J.H. & Denton, O.A. (Editors). PROTA 2: Vegetables/Légumes. [CD-Rom]. PROTA, Wageningen, Netherlands. variation and its evolutionary significance. Economic Botany Journal, 1990; 44:69-78.

Veit-Köhler U, Krumbein A, Kosegarten H. (1999). Effect of different water supply on plant growth and fruit quality of *Lycopersicon esculentum* . Journal of Plant Nutrition and Soil Science, 162:583–588.

Vijitha and Mahendran (2010). Effect of moisture stress at different growth stages of tomato plant (*lycopersicon esculentum* mill.) on yield and quality of fruits. Journal of Science of University of Kelaniya 5 (2010): 1-11.

Vikram, V. B., Ramesh, M. N., & Prapulla, S. G. (2005). Thermal degradation kinetics of nutrients in orange juice heated by electromagnetic and conventional methods. Journal of Food Engineering, 69, 31-40.

Waiganjo, M. M., Wabule, N. M., Nyongesa, D., Kibaki, J. M., Onyango, I., Wepukhulu, S. B. and Muthaka, N. M. (2006). Tomato Production in Kirinyaga District Kenya, a Baseline Survey Report. KARI/IPM CRSP, Nairobi, Kenya 1-43.

Wamache A. (2005). Vegetable seeds handbook. Regina seeds Seminis. Printed by Bizone ltd. Nairobi Kenya.

Wang F, Kang S, Du T, Li F, Qiu R. (2011). Determination of comprehensive quality index for tomato and its response to different irrigation treatments. Agricultural Water Management Journal, 98:1228- 1238.

Wang, Q., J. Chen and Y. Li, (2004). Non destructive and rapid estimation of leaf chlorophyll and nitrogen status of peace lily using a chlorophyll meter. Journal of Plant Nutrition, 27: 557-569.

Warnkce D and Brown JR. (1998). Potassium and basic cations. In. J. R. Brown (ed.). Recommended chemical soil test procedures for the north central region, N.C. Reg. Res. Pub. 221 (Revised). (Mo. Agric. Exp. Stn. SB 1001).

Wiersinga, R., De Jager, A., Nabiswa, A., Kiragu, B. (2008). High segment report: 4 Final– Wageningen UR E-depot. http:/edepot.wur.nl/13874 Wageningen University NL, Accessed 10th June 2015.

Wiley EO (1981) Phylogenetics: The theory and practice of phylogenetics and systematic. John Wiley, New York, pp. 456.

Wilhite, D.A.; and M.H. Glantz. (1985). Understanding the Drought Phenomenon: The Role of Definitions. Water International Journal, 10(3):111–120.

Williams CE and Clair DA. (1993). Phenetic relationships and levels of variability detected by restriction fragment length polymorphism and random amplified polymorphic DNA analysis of cultivated and wild accessions of *Lycopersicon esculentum.* The Genome Journal, 36: 619-630.

Xiao, X.; Yang, F. ; Zhang, S.; Korpelainen, H.; Li, C. (2009). Physiological and proteomic responses of two contrasting *Populus cathayana* populations to drought stress. Journal of Plant Physiology, *136*, 150–168.43.

Xu, S., An, L., Feng, H., Wang, Z., Li, X. (2002). The seasonal effects of water stress on Ammopiptanthus monolilusin a desert en-vironment. Journal of Arid Environment, 51(3): 437–447.

Xu,Z.,Zhou,G.,andShimizu,H.(2010). Plant responses to drought and re-watering. Journal of Plant Signal and Behavior, 5:649–654.doi:10.4161/psb.5.6.11398.

Yada B, Tukamuhabwa P, Ajao A and Mwanga RO. (2010). Morphological characterization of Ugandan sweetpotato germplasm. Journal of Crop Science, 50: 2364-2371.

Yamasaki, S., L. C. Dillenburg. (1999). Measurements of leaf relative water content in *Araucaria angustifolia*. Brazilian Journal of Plant Physiology, 11(2), 69–75.

Yan, W., Rutger, J.N., Bryant, R.J., Bockelman, H.E., Fjellstrom, R.G., Chen, M.H., Tai,T.H., McClung, A.M. (2007). Development and Evaluation of a Core Subset of theUSDA Rice Germplasm Collection. Journal of Crop Science, 47 (2), 869–878.

Yang, R.C., S. Jana and J.M. Clarke. (1991). Phenotypic diversity and association of some potentially drought-related characters in durum wheat. Journal of Crop Science, 31: 1484-1491.

Yi, S.S., S.A. Jatoi, T. Fujimura, S. Yamanaka and K.N. Watanabe. (2008). Potential loss of unique genetic diversity in tomato landraces by genetic colonization of modern cultivars at a non-center of origin. Plant Breeding Journal, 127: 189- 196.

Yu, X., Du, X, Song, L. (2007). Effect of water stress on the growth and ecophysiology of seedlings of Rhus typhina. Scientica Silvge Sinicae, 43(11):57-61.

APPENDICES

Appendix 1: Weather conditions at Kabete field station between May 2014 and May 2015 cropping season

	Temperature (^{o}C)		Rainfall(mm)	Relative humidity (%)
Month	Mean Max	Mean Min	Total	Mean
May	23.5	14.8	72.8	55.1
June	23.3	14.1	101.5	64.4
July	21.6	12.5	10.0	61.0
August	N/A	12.4	28.9	54.3
September	22.3	12.2	23.9	52.0
October	N/A	14.5	136.2	51.7
November	N/A	14.4	95.5	58.6
December	N/A	13.8	88.6	55.2
January	25.7	12.8	27.7	41.1
February	N/A	13.6	50.8	40.8
March	14.2	N/A	30.1	40.4
April	N/A	15.3	323.9	55.5
May	N/A	14.0	298.3	63.6

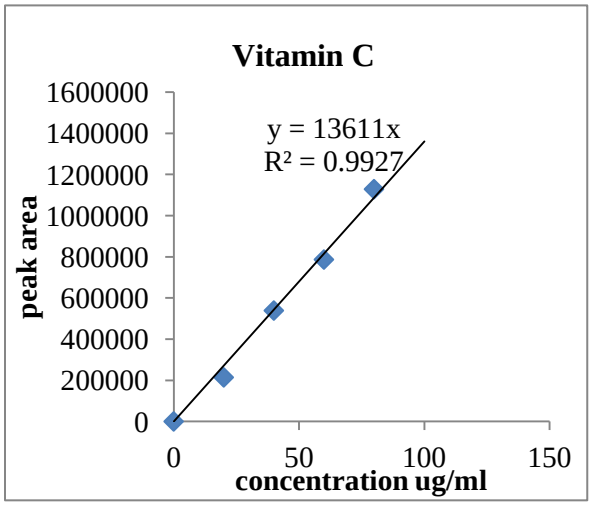
Appendix 2: Chemical characteristics of sampled greenhouse soil

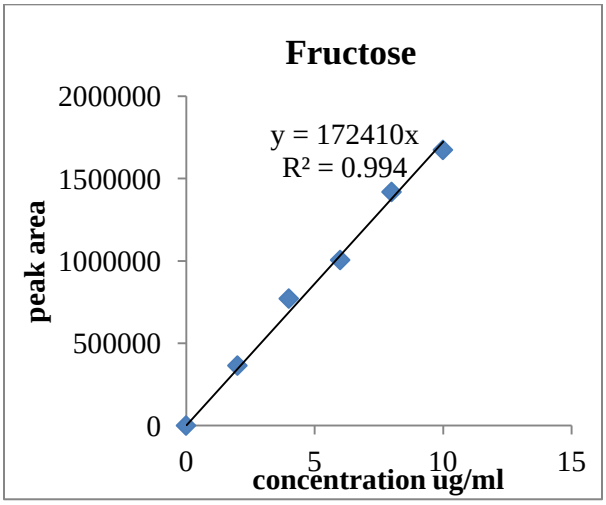
Fertility results	Value	Class
Soil pH	6.2	Slight acid
Total Nitrogen%	0.3	Adequate
Total organic Carbon%	2.9	Adequate
Phosphorus ppm	45.0	Adequate
Potassium me%	1.8	High
Calcium me%	6.3	Adequate
Magnesium me%	7.1	High
Manganese me%	0.7	Adequate
Copper ppm	3.3	Adequate
Iron ppm	69.2	Adequate
Zinc ppm	26.7	Adequate
Sodium me%	0.2	Adequate

Appendix 3: Chemical characteristics of sampled field soil

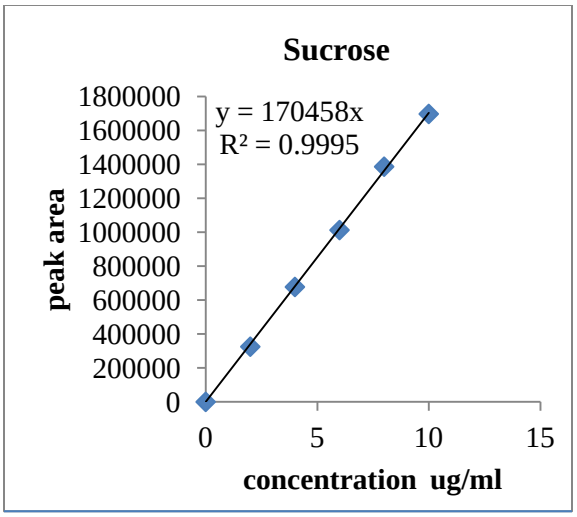
Fertility results	Value	Class
Soil pH	5.7	Medium acid
Total Nitrogen%	0.2	Adequate
Total organic Carbon%	2.2	Moderate
Phosphorus ppm	55.0	Adequate
Potassium me%	1.1	Adequate
Calcium me%	5.1	Adequate
Magnesium me%	5.7	High
Manganese me%	0.6	Adequate
Copper ppm	3.4	Adequate
Iron ppm	60.0	Adequate
Zinc ppm	25.9	Adequate
Sodium me%	0.2	Adequate

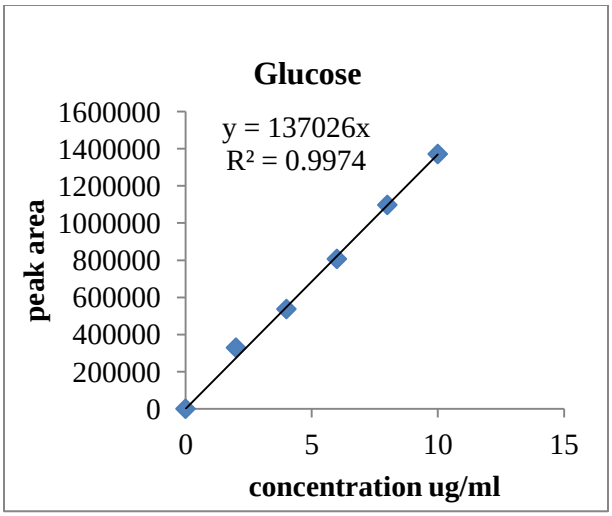
Appendix 4: Standard curves for Vitamin C and Fructose



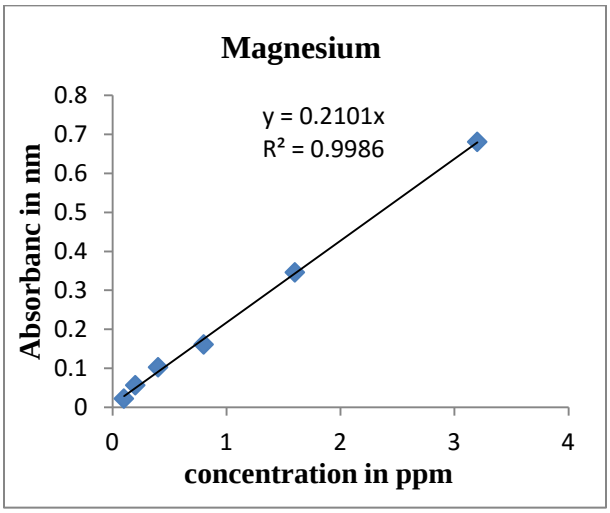


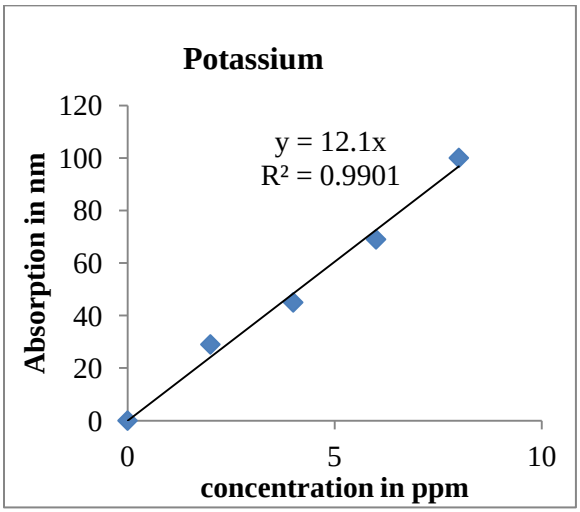
Appendix 5: Standard curves for sucrose and glucose



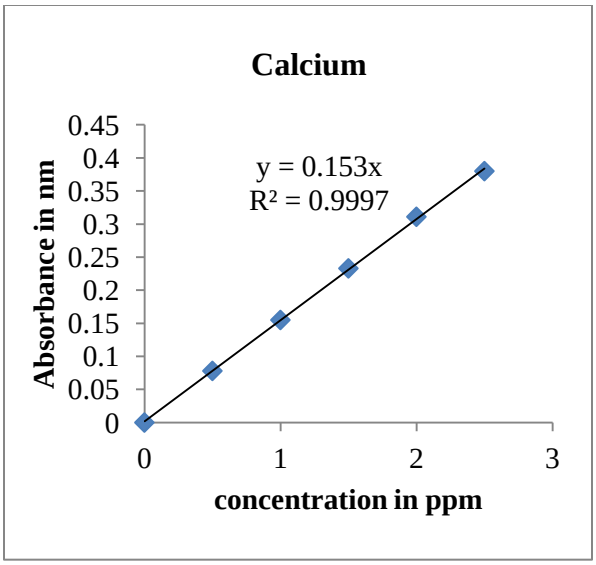


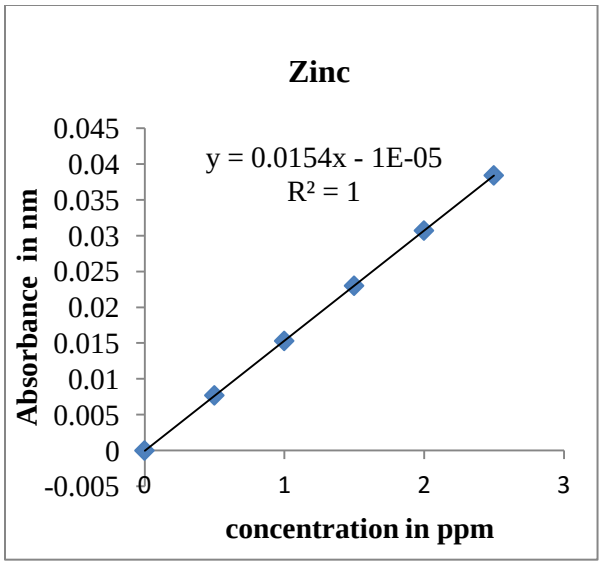
Appendix 6: Standard curves for magnesium and potassium



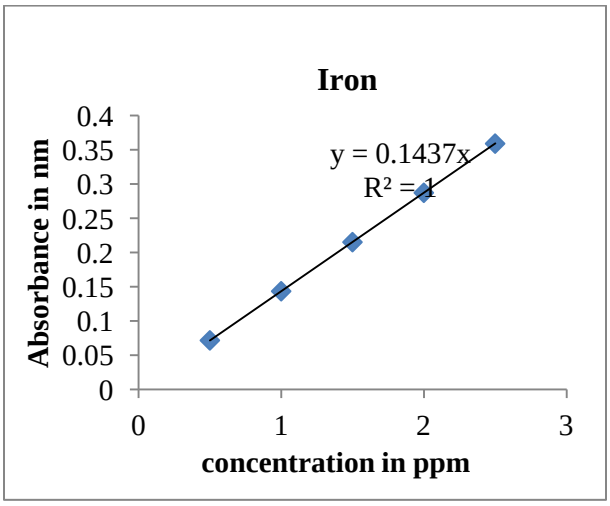


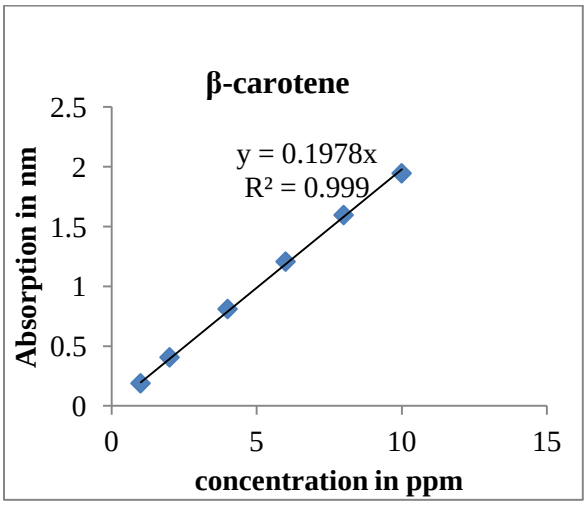
Appendix 7: Standard curves for calcium and zinc





Appendix 8: Standard curves for Iron standard curve and β-carotene





Appendix 9: Standard curve for phenolics.