GERMINATION, GROWTH AND YIELD RESPONSESOFRELEASED TOMATO (*Solanumlycopersicum*L.) VARIETIES TOSALT STRESS

M. Sc. Thesis

SHAMIL ALO SORA

OCTOBER 2019

JIMMA, ETHIOPIA

Jimma University

College of Agriculture and Veterinary Medicine

Department of Horticulture and Plant Science

Thesis Submission for External Defense Request Form (F-07)

Name of student: Shamil AloSoraID No: RM 1205/10

Program of study: MSc in Horticulture

Title: "GERMINATION, GROWTH AND YIELD RESPONSESOF RELEASED TOMATO (*Solanumlycopersicum*L.) VARIETIES TOSALT STRESS"

I have incorporated the suggestion and modification given during the internal thesis defense and got the approval of my advisors. Hence, I hereby kindly request the department to allow me to submit my thesis for external thesis defense.

Shamil AloSoraSignature _____Date_____

We, the thesis advisors, haveverified that the student has incorporated the suggestions and modifications given during the internal thesis defense and the thesis is ready to be submitted. Hence, we recommend the thesis to be submitted for external defense.

Major advisor: Derbew Belew (Professor) Signature  Date:_____

Co-advisor: EdossaEtissa(PhD) Signature  Date: _____

Decision/Suggestion of Department Graduate Council (DGC)

_____ _____ _____

Chair Person, DGCSignature Date

_____ _____ _____

Chair Person, CGS Signature Date

GERMINATION, GROWTHAND YIELD RESPONSESOF RELEASED TOMATO (*Solanumlycopersicum*L.) VARIETIES TO SALT STRESS

M.Sc. Thesis

Submitted tothe Department of Horticulture and Plant Sciences, Jimma University College of Agriculture and Veterinary Medicine in Partial Fulfillment of the Requirements for Degree of Master of Sciencein Horticulture

By

ShamilAloSora

OCTOBER 2019

JIMMA, ETHIOPIA

JIMMA UNIVERSITY

College of Agriculture and Veterinary Medicine

Department of Horticulture and Plant Science

GERMINATION,GROWTH AND YIELD RESPONSES OF RELEASE D TOMATO (*Solanum lycopersicum* L.) VARIETIES TO SALT STRESS

By

ShamilAloSora

Major Advisor: Derbew Belew (Professor)

Co-advisor: EdossaEtissa (PhD)

DEDICATION

This Thesisis dedicated to my father and my mother who brought me up and taught me the value of education, an opportunity they themselves were unable to have.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my own work and that all sources of materials used for this thesis have been duly acknowledged. This Thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree in horticulture at the Jimma University, college of agriculture and veterinary medicine and is deposited at the University Library to be made available to borrowers under rules of the library. I declare that I and other scholars or institution anywhere for the award of any academic degree does not submit this thesis. Brief quotations from this thesis are allowable without special permission provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the School of Graduate Studies when in his or her judgment the proposed use of the material isfor scholarlyinterest. In all other instances, however, permission must be obtained from the author.

Name: ShamilAloSora

Signature: --------

Place: Jimma University, Jimma Ethiopia.

Date of submission: October 2019

BIOGRAPHICAL SKETCH

The author was born from his father AloSora and his mother SemeraAbdaon January 1, 1983 E.C in Goro district of Bale zone, Oromia Regional State, Ethiopia. He completed his primary School at Mana Primary School from 1990-1998 E.C and attended Secondary and Preparatory School from 1999-2002 E.C. at Goro Secondary and Preparatory School.Hejoined Dilla University in 2003, and graduated with B.Sc. degree in Horticulture in 2005 E.C. After graduation, he joined Ethiopian Institute of Agricultural Research (EIAR) and assigned to work as Horticulture Researcher at Teppi Agricultural Research Center for three years. Then, he joinedJimma University in September 2018 to pursue his graduate study leading to Master of ScienceDegree in Horticulture.

ACKNOWLEDGEMENTS

First of all, I would like to thank my Lord Allah, the almighty who gaveme everything, without the help of whom my plans would not have been achieved. It is my pleasure to express my heartfelt appreciation and special gratitude to my advisors, Professor Derbew Belew, and Dr. EdossaEtissa for their invaluable advice and critical review of the Thesis. I am grateful to the Ethiopian Institute of Agricultural Research for granting me the M.Sc. study and financial support. I am also grateful to Teppi and Melkassa Agricultural Research Centers for their material support for my thesis research project. I wish also to extend my appreciation to the staff and the management of Jimma University for facilitating my course work. The material helps and gentle treatment I received from the staff of horticulture research division of Teppi and Melkassa Agricultural Research Centers is highly appreciated. My sincere thanks also go to Mr. AberaSeboka, Mr. MergaJibat, Mr. GutaAmente, Mr. AbukiyaGetu, Mr. MekonenAdelo, Mr. KedirJemal, MsEtalemGeremew and all field workers of the division are sincerely acknowledged for their help during planting and data collection. Last but by no means least, the moral support and encouragement from my father, mother and brothers deserve a special place in my memories.

ABBREVIATIONS AND ACRONYMS

CSA	Central Statistical Agency
CV	Coefficient of Variation
dSm^{-1}	Decisimen per Meter
ECw	Electrical Conductivity of Water
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
MARC	Melkassa Agricultural Research Center
SNNP	Southern Nations Nationalities and People
TARC	Teppi Agricultural Research Center
TDS	Total Dissolved Salts

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF TABLES IN THE APPENDIX

FIGURE IN THE APPENDIX

GERMINATION, GROWTH AND YIELD RESPONSES OFRELEASED TOMATO (*Solanum lycopersicum* L.) VARIETIES TO SALT STRESS

ABSTRACT

*Tomato (Solanumlycopersicum*L.)*is the major horticultural crop and salinity is one of the major abiotic factors limitingits production and productivity in Ethiopia. High salt level of irrigation water may induce a reduction and delay of germination, growth, physiological activities and yield due to osmotic effect, nutrient imbalance and/or ion toxicity. The present study was conducted toassess germination, growth, physiological and yield responses of14 tomato varieties tosix different salinity levels. Evaluation of the varieties for salt tolerance was carried out in laboratory and greenhouse in 2018/19. Each treatment was replicated three times and arranged in RCBD in factorial arrangement. Germination percentage, germination index and seedling vigor, leaf number, leaf area, plant height, fruit yield, shoot fresh weight, shoot dry weight, root fresh weight, root dry weight, root to shoot ratio and photosynthetic rate were measured. All the traits showed significantdecrease (P<0.0001) with increased salt concentration,for except leaf number and root to shoot ratio. The result clearly revealed that the highest germination percentage (95%) was recorded from the control treatment for variety ARP, whilethe lowest germination percentage (11.67%) was recorded from 5dSm^{-1}for variety Eshet. The highest shoot fresh weight (163.13g/plant), shoot dry matter (32.8g/plant) and leaf area (26.93 cm^2) were recorded for the control treatment and the highest root fresh weight (12.27g/plant), root dry weight (5.53g/plant) and fruit yield (22.71ton/ha) were recorded at 1dSm^{-1}for variety Melka Shola, while the lowest shoot fresh weight (79.9g/plant), shoot dry matter(22.67g/plant),leaf area(17.63 cm^2),root fresh weight (6.12g/plant) and root dry weight (3.8g/plant) were recorded at 5 dSm^{-1} for variety ARP. The lowest yield (16.73qt/ha) was recorded at 5 dSm^{-1} for variety ARP. The highest and the lowest values of photosynthetic rate (0.82µmolCo$_2$m^{-2}s^{-1} and (0.47 µmolCo$_2$m^{-2}s^{-1}respectively) were obtained from the control treatment and the highest salinity level for variety Melka Shola, whereas, corresponding values of (0.84µmolCo$_2$m^{-2}s^{-1} and 0.56µmolCo$_2$m^{-2}s^{-1} were recorded for variety ARP. Results of laboratory analysis showed that, sodium and Na/K significantly increased with increased salinity level. However, potassium, Sulfur and phosphorus showed significant decrease with increasing salinity level. Among the varieties. MelkaShola wasfound to be more salt tolerant.Since the present experiment was conducted for one season and under controlled condition,it deserves further evaluation and verification under field condition in salt affected areas and the effect of salinity on tomato quality also deserves further investigation.*

Keywords:*Irrigation watersalinity, photosynthetic rate, tomato yield.*

1. INTRODUCTION

Tomato (*Solanumlycopersicum* L.) is the major horticultural crop with an estimated global production of 164 million metric tons from 4.73 million ha of land (FAO, 2014). In Ethiopia, current tomato production is estimated at 277,74.538 tons from 5,235.19 hectare of land for the *Meher* (main season) (CSA, 2018) and it is an important food ingredient in daily diet of people in almost all regions of the country. The crop is an important cash-generating crop to small-scale farmers and provides employment in the production and processing industries (Selamawit*et al.,* 2017).

Despite its importance, still the national average yield of tomato for the *Meher* (Main season) in Ethiopia is 5.31 ton/ha (CSA,2018), which is quite incomparable with the average yield of other countries such as China, USA, Turkey, India, Egypt, Italy and Spain with average yield of 22.67, 80.61, 35.81, 18.61, 40.00 and 76.35 ton/ha, respectively (FAOSTAT, 2010). A number of constraints are contributing to lower yield and yield components of tomato under farmer's condition in developing countries like Ethiopia including lack of improved varieties that tolerate different stresses. Among them, salinity is the most contributing stress factors (Kassaye*et al*., 2013).

Soil salinity is one of the most devastating environmental stresses caused by mismanagement of irrigation and aridity, results in major reductions in cultivated land size, crop productivity and quality all over the world (Shahbaz and Ashraf, 2013). In many areas of the world, salinity is one of the principal environmental causes of soil degradation, and consequently, a source of reduction in biomass (Amal*et al*., 2014). Nearly 20% of world's cultivated area and nearly half of the world's irrigated lands are affected by salinity (Mustafa *et al*., 2011). Salt affected soils are also becoming one of the main problems in Ethiopia (Seid and Tessema, 2013). The arid and semi-arid agro-ecologies, which account for nearly 50% of the country's land areas, are regarded as marginal environments for crop production mainly due to soil and water salinity (Asad*et al*., 2018). Ethiopia is ranked seventh in the world in terms of percentage of the total land area affected by salinity. This has threatened the productivity of irrigated lands, which is producing more than 40% of the total food requirement of the country (Mohammed *et al*., 2015).

Low levels of annual rainfall and high daily temperatures have led to high water evaporation rates and consequently contributed to high concentrations of soluble salts in these lowland areas (Sileshi*et al*., 2015). The soil salinity problem in Ethiopia also stemsfrom use of poor quality water coupled with intensive use of soils for irrigation, poor on-farm water management practices and lack of adequate drainage facilities (Gebremeskel*et al*., 2018). Chloride and sulfate salts of sodium and calcium (mainly NaCl and CaSO4) are assumed to be the major soluble salts contributing to the very high salinity level of these soils (Auge*et al*., 2018).

High levels of both Na^+ and Cl^- in plants are inhibitory to a number of metabolic and cellular processes (Ashraf, 2009). Salt stress in soils causes physiological drought to plants, which result in the reduction of osmotic potential of the plant, and excessive toxicity of Na and Cl ions to cells causing the disruption of cell organelles and their metabolism.High uptake of Na and Cl ions also result in nutrient imbalance in plants (Evelin *et al*., 2009). Consequently, it affects plant growth and yield. In addition to this, salinity stress causes reactive oxygen species (ROS) to be produced,inducing oxidative stress in crop plants (Choudhury *et al*., 2016).

To overcome the effects of salt stress, plants produce antioxidants and osmo-protectants to bring about tolerance against oxidative stress and osmotic stress, respectively (Garrido*et al*., 2014). In line with this, great efforts have been devoted to understand the physiological aspects of tolerance to salinity in plants, as a basis for plant breeders to develop salttolerant genotypes (Rashed*et al*., 2016).

As correcting saline conditions in field and greenhouse would be expensive and temporary, selection and breeding for salt tolerance can be a wise solution to minimize salinity effects and improve production efficiency of crops. It has been suggested that great magnitude of genotypic variability in tomato cultivars (*Solanumlycopersicum*L.) was found for salt tolerance at the germination stage (Jogendra *et al.*, 2011). This shows that breeding for tolerant cultivars of tomato is possible under saline conditions. Most of the export crops such as cotton, sugarcane, citrus, banana and vegetables are being produced in the Rift valley of Ethiopia. However, development of large-scale irrigation projects in the Rift valley area in the absence of proper drainage systems for salinity control has resulted in increasing severity and rapid expansion of soil salinity and sodicity problems

leading to complete loss of land for crop cultivation in these areas (Asad *et al*., 2018). Nearly 20 tomato varieties have been released and registered by Ethiopian Agricultural Research System, and many genotypes are under different selection and breeding stages at many Federal and Regional Research centers. However, the reaction of these varieties and genotypes to salt stress was not yet been assessed, except that very few varieties have been tested under low salt concentrations at germination and seedling stages (Personal Communication). Moreover, it has been suggested that more research is needed to identify the variety which will perform better at germination stage and give higher yield under high soil salinity condition (Kassaye*et al*., 2013). Thus, it is essential to screen released tomato varieties under different salinity levels with the following specific objectives.

- To determine the effect of different salinity levels of irrigation water on seed germination, growthand yield of releasedtomato varieties
- To identify potential sources of salt tolerance for future breeding activities

2. LITERATURE REVIEW

2.1. Botany and Ecological Requirement of Tomato

Tomato *(Lycopersiconesculentum*L.*)* belongs to the *Solanaceae*family. The Central and South America are the origin and diversity of the crop. It distributed to Europe and Asia in the early and mid-1960s (Asfaw and Eshetu, 2015). The crop spread *via* traders to Egypt, Sudan, South Africa, West Africa and to the rest. The different varieties of tomato vary in shape, size, and color. They vary from small cherry like to fresh market and processing types (Asfaw and Eshetu, 2015).

Tomato requires warm, clear, dry conditions and altitudes ranging between 700 and 2000 meters above sea level. It needs optimum day temperature of 25-28°C and 15°C optimum night temperature. Tomatoes can be grown on well-drained soils. Loams, sandy loams and silty loams are preferred to light soils under long growing season for high production. Sandy soils are preferable if early harvest is desired. The favorable pH level ranges between5.5 and 7.0 (Asfaw and Eshetu, 2015).

2.2. The Genetic and Physiological Basis of Salt Tolerance

Recently, it has been reported that the positive effect of rootstocks on salt tolerance of grafted cultivars is related to the capacity to maintain ionic homeostasis in leaves by reducing the accumulation of toxic ions and maintaining the acquisition of essential nutrients like K^+ (Albacete *et al.*, 2009). This capacity has been related to an enhanced production and root-to-shoot transport of cytokinins and their effects on sourcesink relations (Perez-Alfocea*et al.*, 2010). Cytokinins help to delay leaf senescence and to maintain shoot growth and fruit yield (Albacete*et al.*, 2009, 2010; Ghanem*et al.*, 2011a).

Root-targeted breeding and biotechnology are being considered as powerful strategies to improve salt tolerance in crop species (Asins*et al.*, 2010; Perez-Alfocea e*t al.*, 2010; Ghanem *et al.*, 2011b). Marker-assisted breeding is a viable approach for enhancing stress tolerance in tomato. To this end chromosomal regions bearing quantitative trait loci have been explored. Although much progress has been made in tomato genetic transformation, success in developing transgenic tomatoes withhigh salt tolerance has been limited (Foolad, 2007). The transgenic plants accumulated high concentration of Na^+ and Cl^-in their leaves (Apse *et al.*, 1999). Overproduction of this vacuolar Na^+/H^+antiport protein

increased the ability of transgenic plants to accumulate the Na^+ in their vacuoles and thus to reduce its toxic effects in cytosol. This was the first single-gene transformation with a highly positive result in obtaining salt-tolerant tomato plants. In another study, transgenic tomato plants expressing the antisense prosystemin gene performed better under saline conditions than the wild type (Orsini*et al.*, 2010). Prostystem in transgenic plants maintained high stomatal conductance under saline conditions while leaf abscisic acid and proline contents in these plants were low indicating that these transgenic plants experienced a less stressful environment.

Similarly, plant biomass of transgenic plants was also higher. Furthermore, a comparative profile of gene expression showed that partial stomatal closure is not mediated by ABA or components of ABA signal transduction pathway (Orsini *et al.*, 2010). A better understanding of the genetic, biochemical, and physiological basis of salt tolerance would increase the success in developing transgenic tomato lines with increased salt tolerance. The identification, cloning, and characterization of genes involved in tolerance may allow plants with multiple transgenes to be produced. Advanced molecular techniques make this goal achievable (Foolad, 2007). Using mutants, the function of specific genes can be studied easily. For example, the TSS1 (tomato salt-hypersensitive) locus was discovered in tomato usingtss1mutant (Borsani*et al.*, 2001).

2.3. Variability among Tomato Genotypes for Salt Response

The plant's response to salinity stress is characterized by the adaptation potential involving morphological and physiological changes, in which many genes and pathways are involved. Plant early responses to salt stress are relatively well defined, and among others include the alteration of cytoplasmic free Ca^{2+} activation of Ca^{2+}, production of secondary signaling molecules such as reactive oxygen species (ROS) and abscisic acid (ABA) for regulation and maintenance of ion homeostasis (Julkowska and Testerink, 2015). Tomato, the largest horticultural crop next to potato in the world, is a self-pollinating diploid species and a model for genetic studies (Lin *et al.*, 2014). While most modern tomato cultivars are sensitive to moderate levels of salinity stress, natural variation in salinity tolerance has been found in wild tomato species, including *S. cheesmaniae, S. chmielewskii, S. habrochaites, S. lycopersicoides, S. pennellii and S. pimpinellifolium* (Li *et al.*, 2011). It has been suggested that great magnitude of genotypic variability in cultivated tomato cultivars (*Solanum lycopersicum* L.) was also found for salt tolerance at

the germination stage (Jogendra *et al.*, 2011). Research into genes responsible for these QTLs have led to the identification of few tomato genes involved in improvement of tomato tolerance to salinity stress, including two tomato HKT1 (High-affinity Potassium Transporter) genes on chromosome 7 (Asins*et al.*, 2013). HKT1-like transporters are involved in Na^+ xylem unloading (Plett*et al.*, 2010; Almeida *et al.*, 2014). The two tomato HKT transporters, HKT1;1 and HKT1;2, are Na^+selective transporters, preventing Na^+ accumulation in aerial parts and indirectly improving K^+ homeostasis. Different studies showed that only HKT1;2 has a significant role in Na^+ homeostasis and salinity tolerance in tomato (Jaime-Perez *et al.*, 2017).

2.4. Biotic Approaches for Improving Salt Stress

Development of crop plants tolerant to salt stress is very important to meet the growing food demand. It has been suggested to exploit naturally occurring inter-and intra-specific genetic variability by hybridization of selected salt tolerant genotypes with high yielding genotypes adapted with target environment (Munns*et al.*, 2006). Among various strategies, biotic approach could be adopted to cope with salinity stress. This is because the uptake and assimilation of mineral nutrients including Na^+ and Cl^- are genetically controlled and can be manipulated (Flowers, 2004; Munns, 2005; Munns*et al.*, 2006) and some plants have ability to grow under high saline conditions (Ashraf, 2004; Flowers, 2004).

It is largely believed that the adverse effects of salt stress on plant growth are mainly due to its toxic and osmotic effects, therefore major focus is on selective ion accumulation or exclusion, control of sodium uptake and its distribution within the plant, compartmentation of ions at cellular or at whole plant level (Munns, 2005 and Tester, 2008). Because of the complex nature of salinity tolerance, as well as the difficulties in maintaining long-term growth experiments, trait-based selection criteria have been recommended for screening techniques. Specific traits are less subject to environmental influence than growth rates.

2.5. Screening and Selection Criteria for Salt Tolerance

In recent years, there has been much interest in the development of salt tolerant crop varieties. For this purpose, genetic improvement of salinity tolerance in the cultivated genotypes has been proposed as the most effective strategy to solve salinity problems. As

is well evident from the literature on the existence of inter- and intra-specific genetic variability for salt tolerance, it could be exploited judiciously for screening and breeding for higher salt tolerance. For example, (Jogendra*et al.*, 2011) found a great magnitude of genotypic variability in tomato cultivars (*Lycopersiconesculentum*L.) for salt tolerance at the germination stage. They identified some salt tolerant cultivars with higher root growth and mineral nutrient accumulations. Siddiky*et al.*(2012) found some salt tolerant tomato cultivars at the salinity areas of Bangladesh that maintained their salt tolerance at later growth stages. Seedling pretreatment with NaCl are interesting strategies to be applied when tomato plants have to be grown in saline soils or soils irrigated with saline water (Rashed*et al.*, 2016).

Salinity tolerance for cultivated crops vary depending upon climate, soil conditions and cultural practices. Crops are often less tolerant during germination and seedling stage. The Electric Conductivity threshold for tomatoranges from 0.9 to 2.5 dSm^{-1} (FAO56). This indicates that some tomato varieties are salt tolerant where yield reductions do not decline at up to 2.5 dSm^{-1} while some varieties are salt susceptible as their yield reduction would start to decline at 0.9 dSm^{-1}. Improving salt tolerance of genotypes is often inhibited by the lack of effective evaluation growth stage to identify salt tolerant genotypes (Munns 2002, 2005). For instance, in a number of crop species, salt tolerance is a developmental stage specific phenomenon. Thus, salt tolerance should be evaluated at germination, seedling and adult (reproductive) stages (Ashraf, 2004). In contrast, while evaluating salt tolerance in tomato at the seedling stage and maturity stage, Dasgan*et al.* (2002) suggested the screening at the seedling stage is not only less laborious, less time consuming and less expensive, but also has a high reliability.

Furthermore, screening process under natural field conditions is not feasible due to the high degree of soil heterogeneity (Dasgan *et al.*, 2002). Not all plants respond to salinity in a similar manner, some crops can produce acceptable yields at much higher soil salinity levels than others. This is because some crops are better able to make the needed osmotic adjustments that enable them to extract more water from a saline soil, or they may be more tolerant of some of the toxic effects of salinity.

2.6. Effects of Salinity on Tomato Germination and Growth

2.6.1. Standard germination percentage

The germination of tomato seed was reduced at relatively low salinity. At higher salinity (NaCl), the germination percentage declined drastically. There were differences in the germination percentage between the varieties in salinity (Jogendra*et al.*, 2011). The genotypes which are least affected may be potential source of salinity tolerance for tomato breeding (Amir *et al*., 2011; Hamed*et al*., 2011). The effect of external salinity on seed germination may be partially osmotic or ion toxicity, which can alter physiological processes such as enzyme activities (Croser*et al*., 2001; Essa and Al-Ani 2001).

The salinity notably affects germination in many species but also lengthens the time needed to complete germination. The speed of germination was reduced that, it took more days to complete the germination under salinity (Amir *et al*., 2011). Genotypes that germinate earlier at higher salinity are supposed to be more vigorous and might be used as parents or potential donor in salinity tolerance crop breeding programs (Amir *et al*., 2011; Hamed*et al*., 2011). The stimulation of germination and days required for its completion, depend upon Gibbrelic Acid content in seed. A low level of GA in seed in saline medium was unable to break the mechanical resistance of endosperm against imbibition of water by seed and this leads to the reduction in speed of germination (Groot and Karssen 1992; Groot *et al*., 1988). Delayed germination causes increased irrigation cost and irregular and weak seedling growth in the establishment of crops (Berhanu and Berhane, 2014).Khayatnezhad and Gholamin(2011) reported that, an increased germination index is indicative of decreased phytotoxicity and thus of a more mature germinated seeds.

2.6.2. Tomato leaf number

Salt stress can adversely affect the tomato leaf number. The reason for lower number of leaves at higher salinity is due to the restriction in the movement of water from root to shoot resulting to the reduction in leaf growth (Kassaye*et al*., 2013). Subsequently the salinity stress leads to an ion imbalance causing necrosis and premature death of older leaves (Julkowska and Testerink, 2015).Both the accumulation of specific toxic ions including Na^+ and changes in leaf hormone relations contribute to leaf senescence and hence limit tomato productivity under saline conditions (Ghanem*et al.*, 2008).

2.6.3. Tomato leaf area

During the onset and development of salt stress within a plant, all the major processes such as photosynthesis, protein synthesis, energy, and lipid metabolism are affected. The earliest response is a reduction in the rate of leaf surface expansion, followed by a cessation of expansion as the stress intensifies. Growth resumes when the stress is relieved (Bruria, 2005)**.**The reduction in tomato leaf area under salt stress might be due to the reduction of growth parameters contributing to photosynthetic products (Rubio *et al.,* 2009).

2.6.4. Tomato root and shoot

Shoot was affected drastically in plants grown under salt stress than in control environment (Amir *et al.*, 2011; Hamed *et al.*, 2011; Jogendra *et al.,* 2011).Kamrani *et al.* (2013), Osakabe *et al.* (2014) and Xu *et al.* (2010) reported that salt stress brings about osmotic stress and subsequently ionic toxicity and oxidative stress. Salt stress limits water available to plants, hence, causes osmotic stress, which leads to loss in turgor pressure of the plant especially in the leaves due to decreased water potential, resulting in wilting that affects plant morphology and biomass production. Edris *et al. (*2012) has also reported similar result in that tomato plant shoot fresh weight was highly reduced with increasing NaCl concentration.Salinity reduced fresh and dry weight of plants (Kassaye *et al.*,2013; Dheeba *et al.,* 2015). Deficiency in dry and fresh biomass at higher concentration might be due to poor absorption of water from the growth medium due to physiological drought (Ramezani *et al.*, 2011).

Root senses the effect of soil salinity and influences root-to-shoot signaling to control shoot growth and physiology via hormonal signals, such as cytokines, ABA and auxin IAA, thus coordinating assimilate production and usage in competing sinks (Perez-Alfocea *et al.,* 2010). Salt stress leads to changes in growth, morphology and physiology of the roots that will, in turn, change water and ion uptake and the production of signals (hormones) that can transfer information to the shoot, affecting the whole plant when the roots are growing in a salty medium (Smolik *et al.*, 2011).In spite of the negative effects of salt on roots, the root growth in tomato appears to be less affected whereas, shoot was affected drastically, so that the dry weight ratio was higher in plant grown under salt stress than in control environment. Root/shoot dry weight ratio was increased under higher salt

concentration (Jogendra *et al.*, 2011). The rise in root/shoot dry weight in tomato under salt stress must be accompanied by changes in the allocation of assimilates between root and shoot meaning that, greater proportion of assimilates for root compared with shoot (Amir *et al*., 2011; Hamed *et al*., 2011; Chookhampaeng *et al*.,2007). According to Danait (2018) root dry weight is positively correlated to salinity but, shoot dry weight is negatively correlated to salinity.

2.6.6. Tomato Physiology

High salt concentration in the root zone hinders plants growth and development. To overcome this problem, plants have developed the mechanisms of physiological adaptation, such as development of the root system to acquire water or accumulation of osmoprotectants. Proline is one of well-known osmoprotectants and its accumulation is widely observed in various organisms under salt stress. The amino acid may play a role in protecting membranes and proteins against adverse effects of higher concentrations of inorganic ions and temperature extremes. In tomatoes, proline accounts for only a small fraction of the total concentration of osmotically active solutes (Trovato*et al.*, 2008; Szabados and Savoure, 2009). The mechanism of salt tolerance depends on the capacity for osmotic adjustment, which allows growth to continue under saline conditions. Salt stress leads to changes in growth, morphology and physiology of the roots that will in turn change water and ion uptake and the production of signals (hormones) that can transfer information to the shoot. Then the whole plant is affected when the roots are growing in a salty medium (Smolik*et al.*, 2011).

Stomata conductance and photosynthetic rate play important role in growth and development of any plants. The increasing salinity level decreased the stomata conductance and the reduction is greater at the highest level. The irrigation water with excessive salinity has negative effects on the chlorophyll content of tomato (Zhai*et al.*, 2015). Tomato is moderately tolerant to saline environment. Salt stress also down regulates the physiological and biochemical processes going on in tomato (Rivero*et al.*, 2014; AlHarbi*et al.* 2015; Manan *et al.*, 2016). Reduced water contents lead to the stomatal closure to safeguard further loss of water by transpiration (Manan *et al.*, 2016). In addition to reduced transpiration and stomatal closure, net photosynthesis also reduced under salt stress by the production of ROS, not proper functioning and decrease in chlorophyll contents and rubisco (Zhang *et al.*, 2009; Zribi*et al.*, 2009). Physiological

efficiency of tomato is also adversely affected by saline conditions. High salt concentration also causes an ionic imbalance and osmotic shock to tomato plants (Ciobanu and Sumalan, 2009). As in most mesophytes the amount of Na^+ and Cl^- increased, while that of Ca^{2+} and K^+ decreased in the tomato plants under saline conditions (Turhan*et al.*, 2009). K^+/Na^+ ratio also decreased both in roots and shoots (Li, 2009). Both the accumulation of specific toxic ions including Na^+ and changes in leaf hormone relations contribute to leaf senescence and hence limit tomato productivity under saline conditions (Ghanem*et al.*, 2008). In leaves showing premature senescence due to salinity, ABA increased while IAA strongly decreased with salinization time. Salinity affects photosynthesis by decreasing CO_2 availability because of diffusion limitations (Flexas*et al.*, 2007) and a reduction of the contents of photosynthetic pigments (Ashraf *et al.*,2013).

2.6.7. Tomato yield

As soil salinity increase fruit yield decrease. The fruit yield and increasing salinity have strong negative correlation (Danait, 2018). Soil salinity causes prominent losses of yield in all crops, therefore causing to reduction in crop production (Ashraf, 2009; Cha-um. *et al.*, 2011). Increasing salt stress restricts plant growth and yield around the world (Ali *et al.*, 2014; Mittelstet *et al.*, 2015). Tomato yield negatively affected by the increasing salinity (Shao *et al.*, 2012; Shao *et al.*, 2013; Hou et *al.*, 2014). As reported by (Mestre *et al.*, 2012) blossom end rot is related to high salinity and environmental factors. Irrigation with saline water has been shown to enhance the occurrence of blossom-end rot in tomato, pepper fruits, and eggplants, a nutritional disorder related to Ca^{2+} deficiency. The reduction of stomatal conductance under salt stress conditions result to the lower photosynthetic rate that in turn leads to lower total yield of the crop (Kassaye *et al.*, 2013).

Tomato is considered by some authors to be sensitive to moderately sensitive to salt stress (Foolad, 2007; Ciobanu and Sumalan, 2009) and 50% yield loss occurs at moderate salinity level ($5dSm^{-1}$) (Ciobanu and Sumalan, 2009). Salinity stress has been reported to cause alteration in a variety of morphological attributes and to decrease almost all growth parameters, including shoot and root fresh and dry weights, plant height, total leaf area and yield, and some yield quality attributes (Li, 2009; Tantawy *et al.*, 2009). It has also been reported that both vegetative and fruit growth of tomato decrease markedly under saline conditions (Campos *et al.*, 2006).

Salt stress also causes changes in a range of metabolic processes. For example, protein contents and activities of ascorbate peroxidase and catalase decreased, proline contents increased, and superoxide dismutase activity remained unchanged under saline conditions (Chookhampaeng *et al.*, 2008). In mature tomato fruit, the amount of sucrose and the activity of sucrose phosphate synthase increased while fruit yield decreased under saline conditions (Chookhampaeng *et al.*, 2008). Carbon partitioning and sucrose metabolism in both sink and source organs have been studied in salt-tolerant and salt-sensitive tomato genotypes (Balibrea *et al.*, 2000). Dry weight was reduced to a greater extent in sensitive than in tolerant cultivars.

Physiological efficiency of tomato is also adversely affected by saline conditions. For example, leaf water and osmotic potentials decreased in tomato plants while endogenous ABA concentrations increased under saline conditions (Maggio *et al.*, 2007). Furthermore, considerable decrease in stomatal conductance and evapotranspiration was observed in tomato plants subjected to saline medium (Katerji *et al.*, 2003). The activity of the nitrate reductase decreased under saline conditions and this reduction was ascribed mainly to lower uptake of NO_3 and higher uptake of Cl^- (Flores *et al.*, 2002). Increase in proline content, ascorbic acid, and hydrogen peroxide was reported in tomato under saline regimes by Li (2009).

The activities of other antioxidant enzymes such as catalase, peroxidase, superoxide dismutase, and ascorbate peroxidase were also reported to be increased under saline conditions (Li, 2009). High salt concentration also causes an ionic imbalance and osmotic shock to tomato plants (Ciobanu and Sumalan, 2009). As in most mesophytes the amount of Na^+ and Cl^- increased, while that of Ca^{2+} and K^+ decreased in the tomato plants under saline conditions (Maggio *et al.*, 2007; Li, 2009; Turhan *et al.*, 2009). K^+/Na^+ ratio also decreased both in roots and shoots (Li, 2009). Both the accumulation of specific toxic ions including Na^+ and changes in leaf hormone relations contribute to leaf senescence and hence limit tomato productivity under saline conditions (Ghanem *et al.*, 2008).

2.6.8. Effect of Salinity on Concentrations of Cations

A higher Na^+ concentration in root or shoot increases the osmotic potential and decreases water uptake, while K^+ concentration in root or shoot of tomato plants, changes little under saline environment. Thus, increased concentration of K^+ in plant is consequently advisable

for further breeding program that is based on salinity tolerance (Jogendra *et al*., 2011). The lower value of Na^+/K^+ ratio, indicated more uptake of K^+ from soil/medium byplants and such types of plants are similar to non-salinized plant i.e. salt tolerant (Jogendra*et al*., 2011). At cellular level salinity brings about ionic toxicity by elevated Na^+ and Cl^- levels. Increased concentration of sodium affects the entry of K^+ ions (Flowers *et al*., 2015). Salinity has an antagonistic impact on the uptake of Calcium and Magnesium, which was caused by displacing Ca in membrane of plant root cells (Asik *et al.*, 2009).

In addition, Sadak*et al.* (2015) illustrated that the reduction in Ca and Mg uptake under salt stress conditions may be due to the suppressive impact of Na on Ca and Mg or due to the reduced transport of Ca and Mg cations. According to results of Sadak*et al.* (2015), sodium concentration was higher in plants grown under higher salinity levels. Akram*et al.* (2010) also reported that sodium concentration increases in plants under salt stress and suppresses the potassium concentration. The salt tolerant genotypes transport very small amount of toxic ions (Na^+) to the upper areas like leaf, they store them in their roots that is why the phenomenon of photosynthesis proceeds normally in tolerant genotypes. That is an adaptation mechanisms of tolerant plant species to withstand the adverse conditions that sensitive species substantially lack (Akram *et al.*, 2010).

In addition to this, (Maggio *et al.*, 2007) also found similar observations in tomato. Increase in K^+ concentration in nutrient solution could ameliorate negative effects of salt condition and potassium can alleviate the negative effects of NaCl on vegetative growth and yield (Khalafalla *et al.*,2010).The adverse effects of salt stress on plant growth are mainly due to its toxic and osmotic effects, therefore major focus is on selective ion accumulation or exclusion, control of sodium uptake and its distribution within the plant, compartmentation of ions at cellular or at whole plant level (Munns, 2005) and (Tester, 2008).

3. MATERIALS AND METHODS

3.1. Descriptions of the Study Areas

The study was conducted at Melkassa and Teppi Agricultural Research Centers in 2018/19 in the laboratory and Greenhouse starting from August 2018. The laboratory experiment was conducted at Melkassa Agricultural Research Center. Melkassa is located in the Central Rift Valley of Ethiopia at 8°24′N latitude, 39°21′E longitude, and at an altitude of 1,550 meter above sea level. The Green house experiment was conducted at Teppi Agricultural Research Center during 2018/2019 cropping seasons. Teppi is located in South Western part of Ethiopia in SNNP Regional State at an elevation of 1200 meters above sea level and it is situated at 7° 10،54.5، NLatitude and 35° 25،04.3-28. 2, E Longitude. The average maximum and minimum monthly temperatures in the greenhouse were 22.5 and 28.6ºC, whereas the maximum and minimum relative humidity were 41 and 72.3% respectively, for the experiment season.

3.2. Experimental Materials

Table 1. List of released tomato varieties by MARC and Hybrid cultivars used for the study

No.	Variety	Year of Release (E.C.)	Productivity (ton/ha)		Days to Maturity	Responsible/Source Organization/company
			Research field	Farmer field		
1	Melka-salsa	1990	45.0	-	100-110	MARC
2	Melka-shola	1990	43.0	-	100-120	MARC
3	Gelilema	2007	50.0	-	80-92	MARC
4	Chali	1999	43.0	-	80-90	MARC
5	Cochoro	1999	46.3	-	70-80	MARC
6	Eshet	1997	39.4	-	130-140	MARC
7	Fetan	1997	45.4	-	110-120	MARC
8	Metadel	1997	34.5	-	90-140	MARC
9	Bishola	1997	34.0	-	140-150	MARC
10	Miya	1999	47.1	-	75-80	MARC
11	ARP tomato d2	2004	43.5	-	80-90	MARC
12	Galilea	2003	66.6	65.9	70-75	Green Life Plc
13	Awash River	2007	50-75	40-70	75	Mekamba Plc
14	Venis	2007	75	55	75	Markos Plc

Source: MoA (1998-2014)

3.3. Treatments and experimental Design

3.3.1. Experiment set I - Laboratory experiment

The study consisted of six levels of salt concentrations (Awash river water as control, 1, 2, 3, 4 and 5dSm^{-1}) and fourteen released tomato varieties (Melka Salsa, Melka Shola, Gelilema, Chali, Cochoro, Eshet, Fetan, Metadel, Bishola, Miya, ARP tomato d2, Galilea, Awash River and Venis).The total number of treatment combinations was 84 (six different salinity levels in combination with fourteen tomato varieties). Thus the experiment consisted ofa total of 252 experimental units. A Randomized Complete Block Design in factorial arrangement was used and the treatments were replicated three times.

3.3.1.1. Experimental procedures

For the laboratory experiment, 11 tomato varieties (MelkaSalsa, MelkaShola, Gelilema, Challi, Bishola, Cochoro, Fetan, Eshet, Metadel, ARP tomato-d2 and Miya) were obtained from Melkassa Agricultural Research Center and three hybrid lines (Gelilea,Venis and Awash River) were obtained from different seed companies (Green Life Plc, Markos Plc and Mekamba Plc).The varieties were screened for salt tolerance using six levels of salinity treatments at germination stage on petridishes in the laboratory at Melkassa Agricultural Research Center. The electrical conductivity (EC) and total dissolved salts (TDS) of the Awash river water were tested by using the conductivity meter 4310 JENWAY and pocket TDS scan 20 respectively.

Then, the levels of salt solutions were prepared usingNaCl salt (pure 99.5% assay) to get the desired electrical conductivity of the solution (treatment) in separate containers. The amount of NaCl salt added per unit of irrigation water was calculated using formula indicating relationship between the electrical conductivity (dSm^{-1}) and TDS (mg/L) of the solutions as TDS (g/L) = 0.64g x EC, where EC is the desired electrical conductivity of solution(Ali *et al.*,2012). Accordingly, 0.64 gram of NaCl was used per a liter of water to get the electrical conductivity of 1 dSm^{-1} and calculated for all treatments following the same formula.

Tomato seeds were sterilized by soaking in a 5% alcohol solution for 5 minutes. After the treatment, the seeds were washed several times with distilled water to remove the alcohol from the seed surface. Petri dishes were also sterilized with alcohol and thoroughly washed before use with clean water. Petri dishes were layered with filter papers (9 cm diameter) and 40 seeds were put in each Petri dish on the filter paper moistened with the respective treatment solutions in three replications. Five ml of saline treatments were added to each Petri dish containing seeds as described in the previous works (Jogendra *et al.*, 2012). The Petri dishes were covered to prevent the loss of moisture by evaporation and put in the laboratory for 14 days. Seeds that produced full radicle were considered as germinated seeds. The initial and final germination counts were made at 4^{th} and 14^{th} day after treatment application, respectively, and the result was expressed as percentage.

3.3.2. Experiment Set II- Greenhouse Experiment

3.3.2.1. Treatments and Experimental Design

For the Greenhouse experiment, two best varieties (ARP tomato-d2 and Melka Shola) that were selected from the laboratory observationin terms of salt tolerance were used and grown in pots. The experiment consisted of a total number of twelve treatments (six salt levels (tap water as control ($0.15 dSm^{-1}$), 1, 2, 3, 4 and $5 dSm^{-1}$) and two varieties (ARP tomato d-2 and Melka Shola). It was laid out in a 3x6 factorial arranged in Randomized Complete Block Design (RCBD) with three replications and a total of 360 pots. Ten pots were used per plot and arranged by keeping 30cm and 1m spacing between plants and between rows, respectively. The size of each pot was 30 cm in diameter and 35 cm in height. The plot size was $3m^2$ (1.5m x 1.6m) and 7.5m x 30m was the total area occupied by the experiment in the greenhouse.

3.3.2.2. Experimental procedures

The seeds of both varieties were sown on seedling trays and watered using non-saline water for 30 days. Growth media was prepared from forest soil and sand in 3:1 ratio, respectively, filled in pots one month prior to transplanting the seedlings and arranged in the greenhouse. Soil samples were taken from the prepared media. Then, saturated soil paste (soil samples saturated with distilled water) was prepared, the soil water was then extracted and EC and pH of the extract were measured using conductivity meter and pH meter, respectively, before application of the treatments.

After 30 days, seedlings were transplanted to the pots and irrigated uniformly for ten (10) days with non-saline water. Saline solutions were prepared in separate containers to get the desired electrical conductivity and the containers were labeled according to the treatment solution (control, 1,2,3,4 and $5 dSm^{-1}$). Each container was filled with tap water and the treatment solutions were prepared by adding 0.64, 1.28, 1.92, 2.56 and 3.2 grams of NaCl salt per a liter of water for 1,2,3,4 and $5 dSm^{-1}$ respectively. Then, application of saline water treatments started after the seedlings were watered with non-saline water for ten days according to the water requirement of the crop and 16% leaching requirement was applied.

Plant tissue analysis was done at Horticoop Ethiopia (Horticulture) PLC Soil and Plant Analysis Laboratory at DebreZeit after harvesting the crop. The concentration of nutrients (Calcium, Potassium, Sodium, Magnesium, Phosphorus, Sulfur and Na^+/K^+ ratio in the tomato plant tissue) was analyzed after harvest.1N hydrochloric acid (diluted 83.3ml concentrated HCl to 1L deionized H_2O) and 6N hydrochloric acid (diluted 50ml concentrated HCl to 100ml deionized H_2O) were used as reagents. The following procedures were followed for ashing of plant tissue to determine the concentration of Na, K, Mg, Ca, P andS in the plant tissue and overall processes:

1.25g plant tissue sample was weighted into "high form" porcelain crucible. Sample was placed in to furnaceand the temperature was increased gradually until it reached 540^{o}C where samples were ashed for six hours. Samples were then wetted with small amount of deionized water, then 5-10ml of 6N HCL and brought to near dryness on hot plate. Ash was dissolved by adding 10 ml 1N HCl to crucible. Dissolved ash was transferred quantitatively into 100 ml volumetric flasks. Samples were washed down and diluted with deionized water and shake. Finally, aliquot was collected into ICP test tube and the concentration of each nutrient were measured using Mehlich III method.

3.4. Data Collection

3.4.1. Experiment I

In the laboratory experiment germination process was recorded using the procedures described by ISTA (1996) and Kandil*et al.*(2012). Three parameters of germination were recorded:

1. Standard germination percentage: Standard germination count was made at 14th day after treatment application and expressed in percentage using the following equation (ISTA, 1996and Kandil*et al*. ,2012).

$$SG=\frac{\text{Number of normal seedlings}}{\text{Number of total seeds sown}} \text{ x } 100$$

2. Germination index (GI): GI was calculated according to the following equation (Karim *et al.* 1992):

$$GI = \frac{Germination\ Percentage\ in\ eacht\ reatment}{Germination\ Percentage\ in\ control\ treatment} \text{x } 100$$

3.Seedling Vigor Index (SVI): SVI was calculated according to the following equation as described by (Abdul-Baki and Anderson, 1970):

SVI = [(Root length (cm) + shoot length(cm) x Germination %]

4. Speed of germination (SG): Speed of germination was measured by the following formula (ISTA, 1996):

$$SG = \frac{No.of germinated seeds}{Days to first count} + \ldots + \frac{No.of germinated seeds}{Days to final count}$$

3.4.2. Experiment II

3.4.2.1. Growth parameters

The following growth parameters were measured in the greenhouse experiment:

Number of leaves/plant: Five sample plants were selected per each plot at 36 days after the commencement of treatment application and number of leaves on each plant was counted and the average value was used for analysis.

Leaf Area: Leaf area was measured using a Photoelectric Leaf Area Measure GDX-500. Nine leaves per plant were taken from different positions on the plant and the area of each leaf was measured at 36 and 65 days after the commencement of treatment application and the average value was used for analysis.

Plant Height: Five plants were randomly selected from each plot at flowering stage and plant height was measured from the base to the tip of the stem by using pocket meter.

Shoot fresh and dry weight per plant: After harvesting, all the shoots of five randomly selected plants were collected and fresh weight was recorded immediately. Then after, shoots were chopped into very thin pieces and were put into envelop and placed in an oven at 75 °C until a constant weight was obtained and dry mass was measured in gram by using digital balance and finally the average values were used for analysis.

Root fresh and dry weight per plant: After harvesting, all the roots of five randomly selected plants were collected and fresh weight was recorded immediately. Then after, roots were chopped into very thin pieces and were put into envelop and placed in an oven

at 75 °C until a constant weight was obtained. Root dry mass was measured in gram by using digital balance and finally the average values were used for analysis.

Root to shoot ratio: Root to shoot ratio was calculated from the drymatter yield of shoots and roots.

3.4.2.2. Physiological data

Photosynthetic Rate: Photosynthetic rate was measured using Chlorophyll Flourometer at flowering stage. Five green and fully expanded leaves were selected per plot and photosynthetic rate was measured during 10 AM to 5AM time of the day.

3.4.2.3. Tomato fruit yield data

Fruityield (ton/ha): Fruit yield was recorded on plant basis and then converted in tonper hectare.

3.5. Statistical Analysis

Data were subjected to Analysis of variance (ANOVA) and simple correlation analysis was performed using SAS PROC CORR (SAS Institute, 2008) version 9.0. Treatment means were separated by using Duncan's Multiple Range Test at 5% probability level for all the parameters recorded in both laboratory and Green house experiments.

4. RESULTS AND DISCUSSION

4.1. Experiment I(lab experiment)

4.1.1. Standard germination percentage

The effects of salt concentrations, varieties and their interactions on standard germination percentage showed significant difference ($P<0.0001$),(Appendix Table 1). The result revealed that the highest germination percentage (95%) was recorded for the control treatment for variety ARP tomato d-2. On the other hand, the highest salinity level($5dSm^{-1}$NaCl)resulted in the lowest germination percentage (11.67%) forvariety Eshet(Table 3). Increasing salinity levels from 1 to $5dSm^{-1}$NaCl significantly reduced the standard germination percentages compared with the control treatment. At the final germination count, the applied moisture (treatment solution) was totally absorbed by the seeds of all varieties in the control plot.

In contrast, the moisture remained unabsorbed in the treatments with the higher salt concentrations, except for few varieties (ARP tomato-d2, Melka Shola and Gelilea) that showed better water uptake and germination percentage (AppendixFigures 1, 2 and 3). This indicates that, in the higher salt concentrations the seed could not absorb water due to higher osmotic pressure of the solution or the lower water potential of the solution, while there was high water absorption by seeds in the control and lower salt concentrations.Since seed germination is a function of hydrolysis that helps the breakdown of starch to simple sugars and oxidizing of resulting sugarto energy, salt may have effect on hydrolysis (i.e. synthesis of enzyme amylase) and metabolic impairment. The reason why seeds of some varieties absorbed more water and showed higher germination percentage in concentrated salt solution may due to the ability of osmotic adjustment and tolerance to salinity stress.This result was in agreement with the findings ofCroser*et al.*(2001) and Essa and Al-Ani (2001)who reported the effect of external salinity on seed germination may be partially osmotic or ion toxicity, which can alter physiological processes such as enzyme activities.

Among the different varieties treated with different NaCl concentration, ARP tomato-d2, Melka Shola and Gelilea gave higher standard germination percentage (Table 2). Varieties Eshet, Challi, Metadel and Melka Salsa, on the other hand, gave lower standard germination percentage. For any seed to germinate there should be uptake of water by the

process of imbibitionthen a general activation of seed metabolismfollows. The water imbibition is followed by the diffusion of GA to the cytoplasm that is responsible for the production of amylase enzyme used for the breakdown of starch to simple sugars that facilitate germination. But, under higher salt conditions the process was delayed due to osmotic pressure. This result was in line with the findings of (Jogendra*et al.*, 2011) who reported that germination of tomato seeds drastically reduced with increasing salinity level. The genotypes which are least affected may be potential source of salinity tolerance for tomato breeding (Amir *et al.*, 2011; Hamed*et al.*, 2011). Seed germination is usually the most critical stage in seedling establishment, determining successful crop and seed quality (Khaje*et al.*, 2003).

Table 2. Standard germination percentage as affected by the interaction of salinity level and variety

Salt (dSm^{-1})	Varieties													
	Bishola	Fetan	Eshet	Challi	Metad-el	Melka Salsa	Melka Shola	ARP	Gelile-ma	Venis-e	Gelil-ea	Awash River	Cocho-ro	Miya
0	65^{n-q}	85^{b-h}	65^{n-q}	86.67^{a-h}	59.17^{qr}	73.33^{i-n}	94.17^{ab}	95^{a}	69.17^{l-p}	90.83^{a-d}	91.67^{a-c}	73.33^{i-n}	85.83^{a-h}	72.50^{i-n}
1	71.67^{j-o}	72.50^{i-n}	19.17^{za-d}	62.50^{o-r}	28.33^{w-y}	35^{vw}	90^{a-e}	90.83^{a-d}	55^{rs}	79.17^{f-k}	93.33a-c	78.33^{g-l}	78.33^{g-l}	70.83^{l-o}
2	50^{st}	66.67^{m-q}	23.33^{yzab}	17.50^{a-d}	25^{x-za}	25^{x-za}	88.33^{a-f}	87.5^{a-g}	39.17^{uv}	75^{i-m}	87.5^{a-g}	71.67^{j-o}	60^{qr}	47.50^{stu}
3	31.67^{v-y}	45^{tu}	16.67^{a-d}	19.17^{za-d}	22.5^{yza-c}	18.33^{a-d}	87.5^{a-g}	84.17^{c-h}	19.17^{za-d}	73.33^{i-n}	80.83^{e-j}	$64.17^{n-q'}$	45.83^{tu}	45^{tu}
4	23.33^{yzab}	33.33^{v-x}	11.67^{d}	15^{a-d}	15.83^{a-d}	13.33^{cd}	80.83^{e-j}	81.67^{d-i}	15.83^{a-d}	72.5^{i-n}	77.5^{h-k}	$61.67^{p-r'}$	40^{uv}	30^{w-y}
5	27.5^{w-z}	31.67^{v-y}	11.67^{d}	12.5^{d}	15.83^{a-d}	10.83^{d}	67.5^{m-q}	78.33^{g-l}	16.67^{a-d}	39.17^{uv}	70^{l-p}	35.83^{vw}	33.33^{v-x}	29.17^{w-y}
CR	9.98													
CV	8.89													

Means with the same letters with columns and rows are not significantly different at 5% probability level, CV = Coefficient of Variation, CR =Critical range

4.1.2. Germination index (GI)

Significant difference was observed between salinity level, varieties and their interactions ($p<0.0001$) with respect to germination index (Appendix Table 1). The highest germination index was recorded for the control treatment. The highest salinity concentration of $5dSm^{-1}$NaCl resulted in the lowest average germination index (Table 3).Hence, germination index decreased as the salinity level increases from the control to the highest level.This could be probably due to toxic effect of salt ions on seed. This result was in line with the findings of Khayatnezhad and Gholamin(2011) who reported that, an increased germination index is indicative of decreased phytotoxicity and thus of a more mature germinated seeds.

The highervalues of germination indices (107, 101.8 and 100%) wererecorded in the control treatment and $1dSm^{-1}$for most of the varieties. In contrast, the highest salinity level ($5dSm^{-1}$NaCl)resulted in the lowest germination index (14.3%) for variety Challi. Among the different varieties treatedwith different NaCl levels, ARP tomato-d2, Melka Shola,Gelilea and Awash River gave highest germination index VarietiesEshet, Challi and Melka Salsa on the other hand,had lower germination index. This indicated that Eshet, Challi and Melka Salsa were the most affected varieties due to the toxic effects of salinity as compared to the other varieties.

Table 3 Germination index (%) as affected by the interaction of salinity leveland variety

Salt (dSm^{-1})	Varieties													
	Bisho-la	Fetan	Eshet	Challi	Metadel	Melka Salsa	Melka Shola	ARP	Gelil-ema	Veni-se	Gelil-ea	Awash River	Coch-oro	Miy-a
0	100^{a-c}	100^{a-c}	100^{a-c}	100^{a-c}	100^{a-c}	100^{a-c}	100^{a-c}	100^{a-c}	100^{a-c}	100^{a-c}	100^{a-c}	100^{a-c}	100^{a-c}	100^{a-c}
1	96.8^{a-e}	85.2^{d-i}	29.5^{v-zabc}	72.2^{k-m}	48^{p-t}	47.9^{p-t}	95.6^{a-e}	95.5^{a-e}	79.9^{h-k}	87.2^{c-i}	101.8^{ab}	107^{a}	91.6^{b-h}	97.7^{a-d}
2	77.2^{i-l}	78.5^{i-k}	36.8^{s-z}	$20.3^{bcd'}$	42.6^{q-u}	$34.2^{u-zab'}$	93.7^{b-f}	92^{b-h}	56.7^{n-p}	82.6^{f-k}	95.6^{a-e}	97.8^{a-d}	70.3^{k-m}	65.8^{l-n}
3	48.5^{p-t}	53^{o-r}	$25.8^{yza-d'}$	$22^{bcd'}$	37.8^{s-y}	$24.9^{za-d'}$	92.9^{b-f}	88.7^{c-i}	$27.8^{x-zabc'}$	80.9^{g-k}	88.3^{c-i}	87.8^{c-i}	53.7^{o-q}	62.2^{m-o}
4	$36.1^{t-za'}$	39.4^{s-v}	$18.1^{cd'}$	$17.2^{cd'}$	$26.8^{x-zabcd'}$	$18.3^{cd'}$	85.8^{d-i}	86^{d-i}	$22.8^{bcd'}$	79.9^{h-k}	84.8^{e-i}	84.4^{e-j}	46.9^{p-t}	41.3^{r-v}
5	42.4^{q-u}	37.2^{s-y}	$18.4^{cd'}$	$14.3^{d'}$	$26.6^{x-zabcd'}$	$14.9^{d'}$	71.7^{k-m}	82.4^{f-k}	24.2^{za-d}	42.9^{q-u}	76.4^{i-l}	49.3^{p-s}	38.8^{s-x}	40.1^{s-v}
CR	13.41													
CV	9.69													

Means with the same letters with columns and rows are not significantly different at 5% probability level, CV = Coefficient of Variation, CR =Critical range

4.1.3. Seedling vigor index

Significant difference was observed between salinity level, varieties and their interactions ($p<0.0001$) forseedling vigor index (Appendix Table 1). The highestseedling vigor index was recorded in the control treatment,while the highest salinity level ($5dSm^{-1}$NaCl)resulted in the lowest value (Table 5). Hence, seedling vigor index decreased as the salinity level increased from the control to the highest. This could be probably due to osmotic and toxic effect of salt ions on seedling growth. This result was in line with the findings of Zaheer (2017), indicating thatseedling vigor index decreased with increasing NaCl level.Increased seedling vigor index is an indicative of increased uniformity and good performance of the seedlings. Highest values of seedling vigor index, 1225.5, 1231.17 and1211.58 wereresulted from the control treatment for varieties Gelilea, ARP tomato d-2 and Melka Shola, respectively.

In contrast, the highest salinity level ($5dSm^{-1}$NaCl)resulted in the lowest seedling vigor index (61.5) for variety Melka Salsa(Table 4). Similarly, varieties Eshet, Challi, Melka Salsa and Metadel showed lower values ofseedling vigor index. This indicated that varieties Eshet, Challi, Melka Salsa and Metadel were the more affected due tohigher salinity level as compared to the other varieties.Platten *et al.* (2013) also reported that plant vigor is one of the major determinants of salt tolerance in plants.Similar report by Kumar *et al.* (2013) also showed that growth vigor is such a mechanism which can avoid the toxic effects of salinity and vigor is an avoidance mechanism rather than tolerance mechanism which works as far as the productivity is concerned.

Table 4Seedling vigor index as affected by the interaction of salinity level and variety

Salt (dS m^{-1})	Varieties													
	Bisho-la	Fetan	Eshet	Challi	Metadel	Melka Salsa	Melka Shola	ARP	Gelil-ema	Venise	Gelilea	Awash River	Cochoro	Miya
0	751.25 $^{m-o}$	975.5^{e-h}	637.1^{pq}	948.7^{f-i}	547.75 $^{q-s}$	724.3^{n-p}	1211.58^{ab}	1231.17 ^{a}	792.92 $^{k-n}$	1141.67 ^{abc}	1225.5^{a}	863.83^{h-m}	1000.75^{e-g}	846^{i-m}
1	789.83^{k-n}	769.58 $^{l-n}$	164.92 $^{za-h}$	613.92^{p-r}	247.5^{x-z}	320.83 $^{u-x}$	1074.67^{c-e}	1110.08 ^{bcd}	573^{qr}	912^{f-j}	1178.17 ^{abc}	816.83^{j-n}	856^{i-m}	752.58 $^{m-o}$
2	579.83^{q-r}	758.42 $^{l-o}$	248^{x-z}	192.92^{y-za-g}	229.67 $^{x-zabc}$	248.5^{x-z}	897.5^{g-k}	924.83^{f-j}	462.75 st	931.83^{f-i}	1019.42 ^{def}	841.42^{i-m}	754.5^{m-o}	514.83 $^{r-t}$
3	306.67^{x-y}	412.5^{t-v}	120.33 $^{b-h}$	161.25^{z-a-h}	172.67 $^{za-h}$	117.83 $^{c-h}$	871.58^{h-l}	888.5^{h-k}	166.33 $^{za-h}$	707.92^{n-p}	901.5^{g-k}	551.92^{q-s}	428^{tu}	413.67 $^{t-v}$
4	209.17^{x-za-e}	276^{x-z}	75.42h	108.83^{d-h}	114^{c-h}	82^{f-h}	638.33^{p-q}	766.5^{l-o}	126.5^{b-h}	656^{o-q}	814.75^{j-n}	515.58^{r-t}	321.25^{u-x}	243.33 $^{x-za}$
5	195.83^{y-za-f}	234.83 $^{x-zab}$	67.67^{h}	77.17^{gh}	101.58 $^{e-h}$	61.5^{h}	418.25^{t-v}	619.17^{p-r}	129.17 $^{a-h}$	314.67^{v-x}	622.17^{p-r}	255.33^{x-z}	248^{x-z}	218.08 $^{x-za-d}$
CR	124.1													
CV	10.71													

Means with the same letters with columns and rows are not significantly different at 5% probability level, CV = Coefficient of Variation, CR =Critical range

4.1.4. Speed of germination

Significant difference was observed between salinity level, varieties and their interactions ($p<0.0001$) with respect to speed of germination (Appendix Table 1). The result clearly revealed that highest number of speed of germination (10 and 9.91) was recorded in the 1 $dSm^{-1}$and control treatments respectively for the variety ARP tomato d-2. On the other hand, highest salinity concentration($5dSm^{-1}$) NaCl resulted in the lowest speed of germination (0.29 and 0.22) for varieties Melka Salsa and Eshet respectively (Table 5). The highest salinity concentration of $5dSm^{-1}$ NaCl recorded the lowest averages of this trait. This result concluded that, increasing salinity levels from 1 to $5dSm^{-1}$ NaCl significantly reduced speed of germination compared with the control treatment.The result also indicated that, salinity highly affected speed of germination of different tomato varieties and lengthened the time needed to complete germination. The speed of germination was reduced, meaning that it took more days to complete the germination under salinity as compared with the control treatment for all of the evaluated tomato varieties. This result is in agreement with the result that reported by (Amir *et al.*, 2011).

The seedlings that were grown under high salinity level ($5dSm^{-1}$) showed lower speed of germination compared to others. Since higher salinity limited water absorption, it prevents the activation and early completion of germination process, as a result, speed of germination declined with increased salinity concentration. This result accords with the results reported by (Groot and Karssen 1992; Groot *et al.*, 1988) that the stimulation of germination and days required for its completion depend upon Gibbrelic Acid content in seed. A low level of GA in seed in saline medium was unable to break the mechanical resistance of endosperm against imbibitions of water by seed and this leads to the reduction in speed of germination. Since the higher salt concentration limited the water absorption, it slows down the germination speed. Delayed germination causes increased irrigation cost, irregular and weak seedling growth in the establishment of crops (Berhanu and Berhane, 2014). Amir *et al.* (2011) and Hamed *et al.* (2011) also reported that genotypes that germinate earlier at higher salinity concentrations are supposed to be more vigorous and might be used as parents or potential donors in salinity tolerance crop breeding programs.

Table 5.Speed of germination as affected by the interaction of salinity level and variety

Salt (dS m^{-1})	Varieties													
	Bisho-la	Fetan	Eshet	Challi	Metad el	Melka Salsa	Melka Shola	ARP	Gelil-ema	Venise	Gelilea	Awash River	Cochoro	Miya
0	$4.56^{i\text{-}v}$	$6.71^{d\text{-}j}$	$4.47^{k\text{-}v}$	$4.84^{h\text{-}t}$	$4.80^{h\text{-}t}$	$5.54^{f\text{-}q}$	9.64^{ab}	9.91^{a}	$5.26^{g\text{-}r}$	$6.38^{e\text{-}k}$	9.48^{ab}	$6.71^{d\text{-}j}$	$7.57^{b\text{-}f}$	$5.6^{f\text{-}p}$
1	$4.49^{i\text{-}v}$	$5.77^{f\text{-}o}$	$0.66^{b\text{-}e'}$	$6.74^{d\text{-}i}$	$2.59^{u\text{-}zabcd'}$	$2.62^{u\text{-}zabcd}$	$8.60^{a\text{-}d}$	10^{a}	$3.35^{q\text{-}y}$	$2.88^{s\text{-}zab'}$	$8.53^{a\text{-}e}$	$7.10^{c\text{-}g}$	$6.60^{d\text{-}j}$	$6.56^{d\text{-}k}$
2	$3.46^{q\text{-}w}$	$6.19^{f\text{-}m}$	$1.03^{za\text{-}e'}$	$0.55^{c\text{-}e'}$	$1.25^{yza\text{-}e}$	$1.25^{yza\text{-}e}$	$6.81^{d\text{-}h}$	$8.53^{a\text{-}e}$	$2.90^{s\text{-}zab'}$	$6.68^{d\text{-}j}$	$5.28^{g\text{-}r}$	$6.83^{d\text{-}h}$	$5.49^{f\text{-}q}$	$2.64^{t\text{-}zabcd'}$
3	$1.52^{xyza\text{-}e'}$	$3.98^{m\text{-}v}$	$0.46^{c\text{-}e'}$	$0.85^{za\text{-}e}$	$1.03^{za\text{-}e}$	$0.57^{c\text{-}e'}$	$7.62^{b\text{-}f}$	$5.52^{f\text{-}q}$	$0.75^{a\text{-}e'}$	$2.71^{t\text{-}zabc}$	$6.09^{f\text{-}n}$	$3.87^{o\text{-}w}$	$3.93^{n\text{-}w}$	$3.65^{o\text{-}w}$
4	$1.28^{yza\text{-}e'}$	$2.40^{w\text{-}zabcde'}$	$0.38^{de'}$	$0.58^{c\text{-}e'}$	$0.48^{c\text{-}e'}$	$0.37^{de'}$	$6.59^{d\text{-}k}$	$6.28^{f\text{-}l}$	$0.42^{c\text{-}e'}$	$3.02^{s\text{-}za'}$	9.16^{abc}	$4.13^{l\text{-}v}$	$1.93^{xyza\text{-}e'}$	$1.31^{yza\text{-}e'}$
5	$1.40^{yza\text{-}e'}$	$2.10^{w\text{-}zabcde'}$	$0.22^{e'}$	$0.68^{b\text{-}e'}$	$0.67^{b\text{-}e'}$	$0.29^{de'}$	$5.045^{g\text{-}s}$	$3.19^{r\text{-}z}$	$0.61^{c\text{-}e'}$	$0.98^{za\text{-}e'}$	$4.37^{k\text{-}v}$	$2.06^{w\text{-}za\text{-}e'}$	$1.57^{xyza\text{-}e'}$	$1.28^{yza\text{-}e'}$
CR	2.33													
CV	28													

Means with the same letters with columns and rows are not significantly different at 5% probability level, CV = Coefficient of Variation, CR =Critical range

4.2. Experiment II (Greenhouse Experiment)

4.2.1. Leaf number

There was no significant difference between salinity treatments (P<0.2313), nor between varieties (P<0.9085) and their interaction (P<0.8503) for leaf number per plant (Appendix Table 2). In general, leaf number decreased with increasing salinity level. The reason for lower number of leaves at higher salinity could be restriction in the movement of water from root to shoot, resulting in reduction in leaf growth (Kassaye *et al.*, 2013). From the experiment, different visual symptoms such as wilting, yellowing of leaves, chlorosis of green parts, leaf tip burning, and necrosis of leaves, and scorching of the oldest leaves were observed after being treated with the salinized irrigation water and the symptoms were higher at higher salinity concentrations as compared to the control. Similar result has been reported by Julkowska and Testerink, (2015), indicating that salinity stress leads to an ion imbalance causing necrosis and premature death of older leaves.

4.2.2. Leaf Area

Both salinity level and variety and their interaction (p<0.0001) significantly affected leaf area of tomato plants (Appendix Table 2). The highest leaf area (26.93 cm^2), was recorded for the control treatment with variety Melka Shola, whereas the lowest value (17.63 cm^2) was recorded at 5$dSm^{-1}$for the variety ARP tomato d-2. Variety Melka Shola showed higher leaf area values as compared to ARP for all the salinity treatments (Figure 1). The reason in leaf area reduction under salinity stress could be as a result of physiological dryness and due to other growth parameters related to photosynthetic products. In line with this, Rubio *et al.* (2009) reported that the reduction in tomato leaf area under salt stress might be due to the reduction of growth parameters contributing to photosynthetic products. Bruria (2005) also reported that the earliest response to salt stress is a reduction in the rate of leaf surface expansion, followed by a cessation of expansion as the stress intensifies.

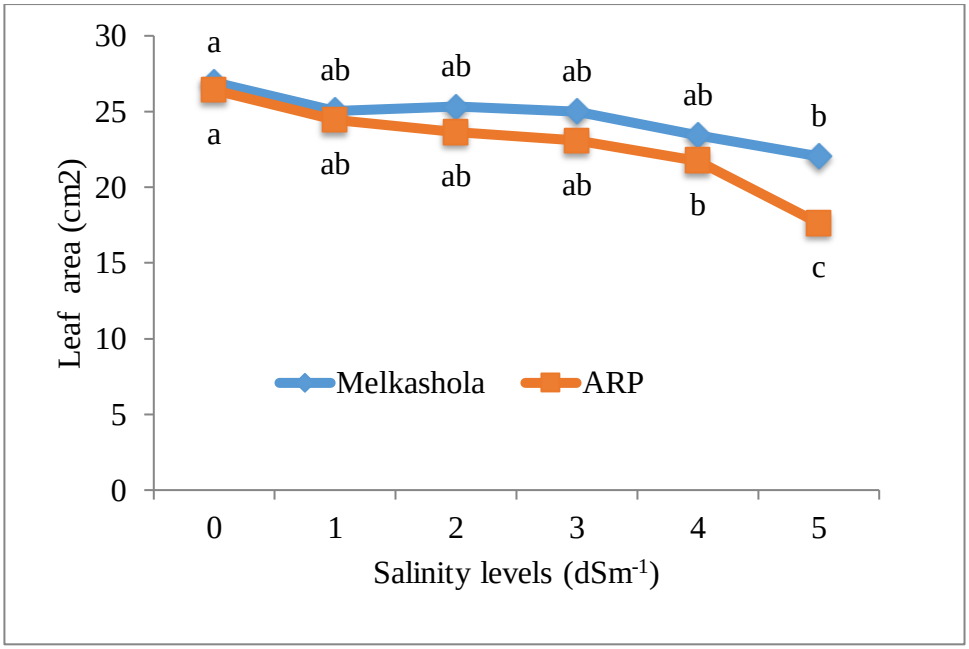

Figure 1 Leaf area of tomato as affected by the interaction of salinity level and variety

4.2.3. Plant height

Plant height was significantly affected by main factors (salinity level and variety) and their interaction ($P<0.0001$) (Appendix Table 2). The tallest (127cm) and the shortest (93.33cm) tomato plants were observed in the control treatment and at highest salinity levels, respectively, for variety Melka Shola, whereas, the corresponding values 151.11cm and 98.89cm were for variety ARP tomato d-2 (Figure 2). The reduction in plant height with increasing salinity level may be due to toxic effect of NaCl, unbalanced nutrient uptake by the plants and probably reduced plant water potential due to exosmosis. The difference in plant height among the varieties may indicate that varieties responded differently to the different level of salt, which might be attributed to their difference in genetic makeup. Edris *et al. (*2012) have also reported similar result indicating that tomato plant height was highly reduced with increasing NaCl concentration.

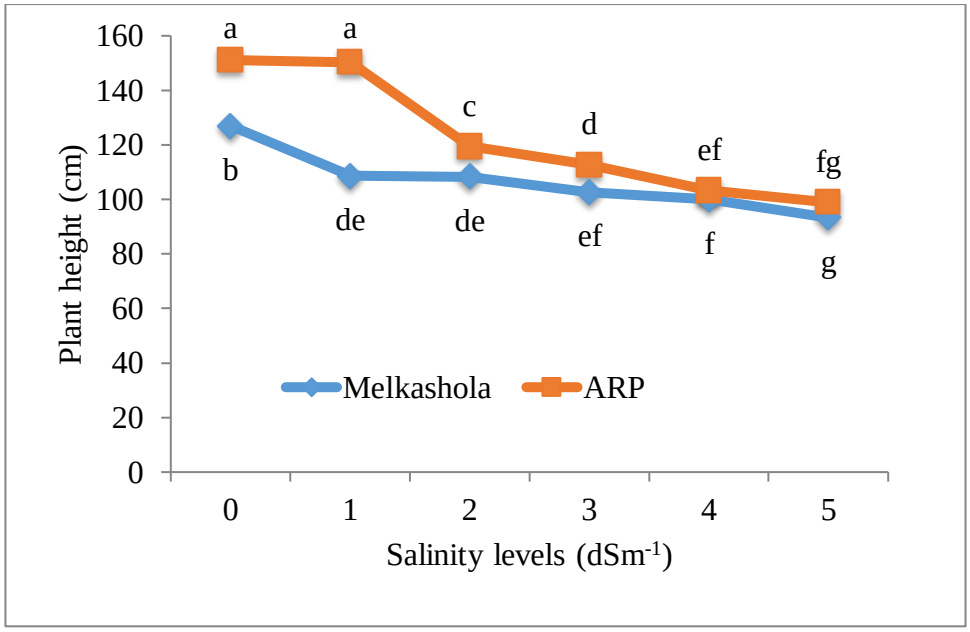

Figure 2 Plant height of tomato as affected by the interaction of salinity and variety

4.2.4. Shoot fresh weight per plant

Significant difference was observed between salinity level, varieties and their interactions ($p<0.0001$) for shoot fresh weight (Appendix Table 2). The highest shoot fresh weight was recorded for the control treatment and $1dSm^{-1}$(163.13g/plant) and 162.33g/plant) respectively, for variety MelkaShola and at $1dSm^{-1}$ and $2dSm^{-1}$with respective values of(153.07 g/plant and 159.67g/plant) for variety ARP tomato d-2 (Figure 3). The highest salinity concentration of $5dSm^{-1}$NaCl resulted in the lowest average shoot fresh weight (79.9g/plant) of variety ARP. Thus, shoot fresh weight significantly decreased as the salinity level increased from the control to the highest.This is due to the exosmosis of water and plasmolysis of plant cells as a result of hypertonic solution of the treatments. In addition to this, under high salt concentration plants undertake stomatal closer due to water stress to safeguard the loss of water through transpiration. This may result in the reduction of photosynthetic rate and assimilate production. In another way, high salt concentration may result in the lower hydrolysis of enzymes responsible for different metabolic activities of the plant.

The result also indicated that tomato varieties responded differently to different salt levels, where variety Melka Shola had higher shoot fresh weight as compared to ARP tomato d-2. This could be probably due to the better potential of Melka Shola to selective ion accumulation or exclusion and ion compartmentalization. This result was in agreement

with the report of Munns (2005) and Tester (2008) that the adverse effects of salt stress on plant growth are mainly due to its toxic and osmotic effects, therefore major focus is on selective ion accumulation or exclusion, control of sodium uptake and its distribution within the plant, compartmentation of ions at cellular or at whole plant level. Amir *et al.* (2011); Hamed *et al.* (2011) and Jogendra *et al.* (2011), also reportedthat shoot was affected drastically in plants grown under salt stress than in control environment. The decrease in shoot fresh weight with increases in salt concentration was in line with the results reported by Kamrani*et al.*(2013) and Osakabe *et al.* (2014); Xu *et al.* (2010) indicating that salt stress brings about osmotic stress and subsequently ionic toxicity and oxidative stress.

Salt stress limits water available to plants, hence, causes osmotic stress, which leads to loss in turgor pressure of the plant especially in the leaves due to decreased water potential,resulting in wilting that affects plant morphology and biomass production.Edris *et al. (*2012) has also reported similar result in that tomato plant shoot fresh weight was highly reduced with increasing NaCl concentration.The similarresults reported by Dheeba *et al.* (2015) who showed that salinity reduced fresh and dry weight of plants. Deficiency in dry and fresh biomass at higher concentration might be due to poor absorption of water from the growth medium due to physiological drought (Ramezani *et al.*, 2011).

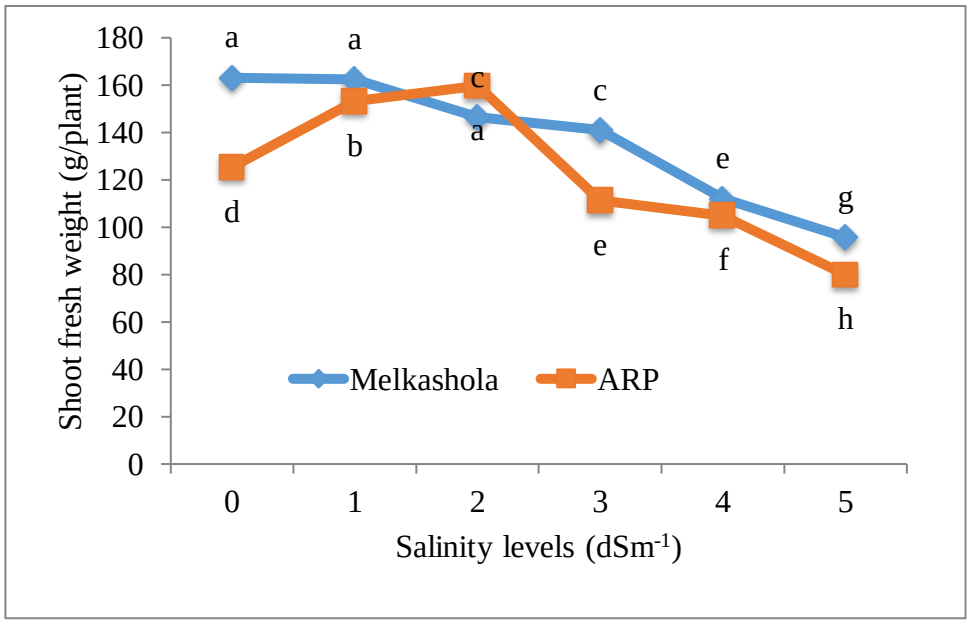

Figure 3Shoot fresh weight of tomato as affected by the interaction of salinity level and variety

4.2.5. Shoot dry weight per plant

Significant difference was observed due to the main factors (salinity level and variety) and their interaction ($p<0.0001$) for shoot dry matter yield (Appendix Table 2). The highest average shoot dry matter yield (32.8 g/plant) was recorded for the control treatment with variety MelkaShola, whereas the lowest value (22.67 g/plant) was recorded for 5dSm^{-1}with variety ARP tomato d-2 (Figure 4). The reduction in shoot dry matter yield under higher salinity level could probably be due to physiological dryness of the plants as a result of exosmosis and decline in plant water potential. The reduction in shoot dry matter with increasing salinity levels may also be due to reduced number of branches and leaves, leaf size and stem diameter of tomato plants. It was observed that,variety MelkaShola was better than ARP tomato-d2 in salt tolerance in terms of shoot dry matter production and, thus,salinity threshold level. Kassaye*et al.* (2013) have also found that shoot fresh and dry weight decreased as salinity level increases from control to the highest concentration.

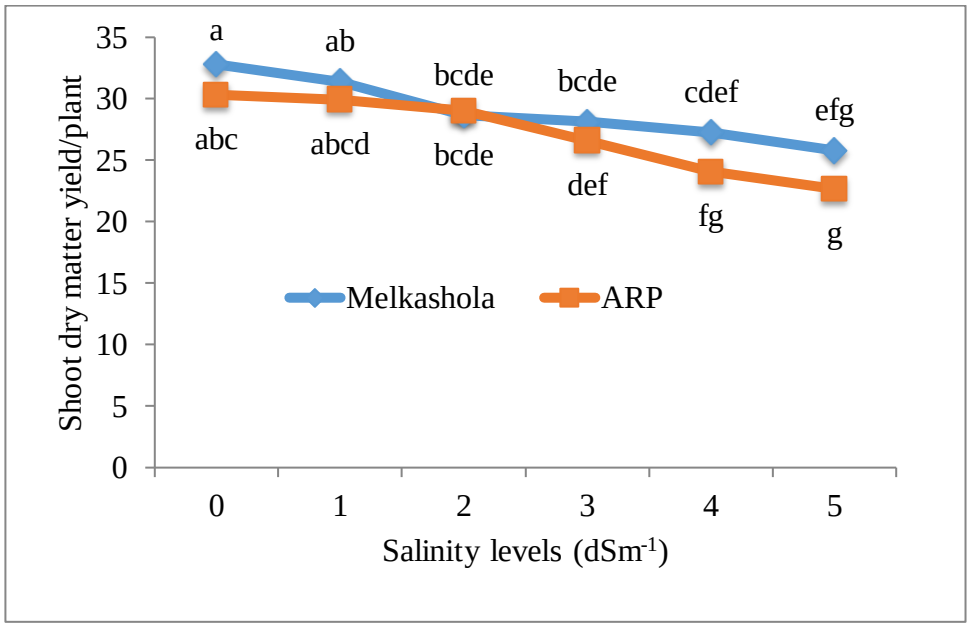

Figure 4Shoot dry matter of tomato as affected by the interaction of salinity level and variety

4.2.6. Root fresh weight

Root fresh weight was significantly affected by both salinity level and varietyas well as by their interaction ($p<0.0001$) (Appendix Table 2). The highest average root fresh weight (12.27g/plant), was recorded for 1dSm^{-1}with variety MelkaShola, whereas the lowest

value (6.12g/plant) was recorded at 5dSm^{-1}for variety ARP tomato d-2 (Figure 5). Since plant roots play a great role in plant growth and development, restriction in root growth may affect the whole processes when the plant grows under stress condition.Perez-Alfocea*et al.* (2010) also reported thatthe importance of root in hormonal regulation of source–sink relations during the osmotic phase of salinity stress in tomato. They also reported that root senses the effect of soil salinity and influences root-to-shoot signaling to control shoot growth and physiology via hormonal signals, such as cytokines, ABA and auxin IAA, thus coordinating assimilate production and usage in competing sinks. Smolik*et al.*(2011) also found that salt stress leads to changes in growth, morphology and physiology of the roots that will, in turn, change water and ion uptake and the production of signals (hormones) that can transfer information to the shoot,affecting the whole plant when the roots are growing in a salty medium.

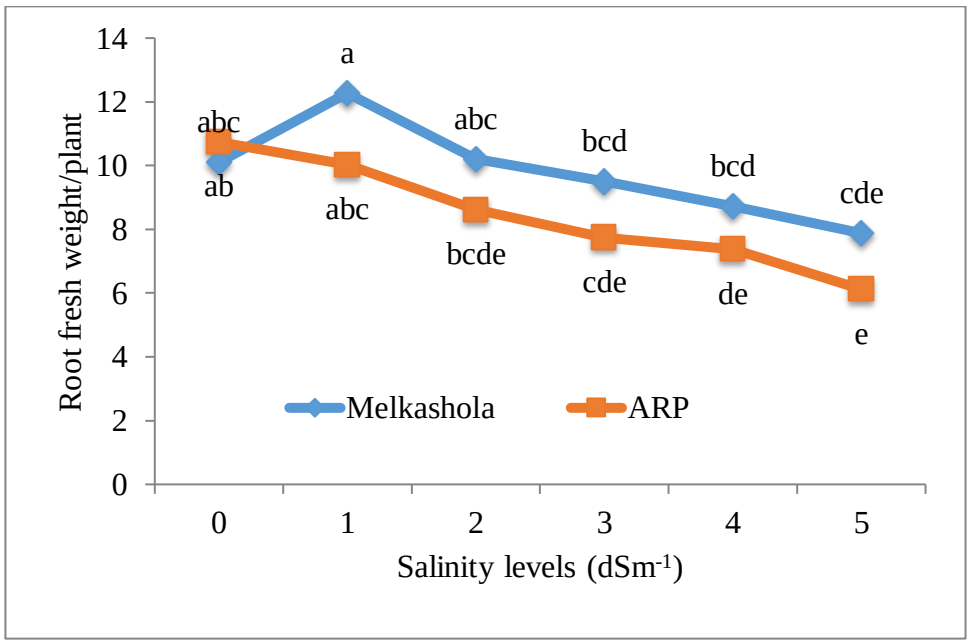

Figure 5Root fresh weight of tomato as affected by the interaction of salinity level and variety

4.2.7. Root dry weight

Root dry weight showed significant difference for both the main factors (salinity level and variety) and their interaction t (P<0.0001) (Appendix Table 2). The highest average root dry weight (5.53g/plant), was recorded at 1dSm^{-1}for the variety MelkaShola, whereas the lowest root fresh weight (3.8 g/plant) was recorded at 5dSm^{-1}for variety ARP tomato d-2(Figure 6). Both varieties showed decreasing root dry matter along with increasing

salinity concentrations. However, variety Melka Shola had better dry matter accumulation under higher salinity stress as compared to ARP tomato d-2. The reduction in root dry and fresh weights under higher salinity levels could be probably due to the adverse effects of salinity on tomato root development like root length, number and diameter as result of exosmosis and lower water potential in the roots. Kassaye*et al.* (2013) also found that root fresh and dry weight decreased as salinity level increases from control to the highest.Furthermore, they reported that tomato plant root was more affected as compared to the shoot part. However, less reduction in root growth as compared to the shoot partin the present study might be due to higher salt concentration which reduces water potential of the plant which results in the preferential allocation of biomass to roots.

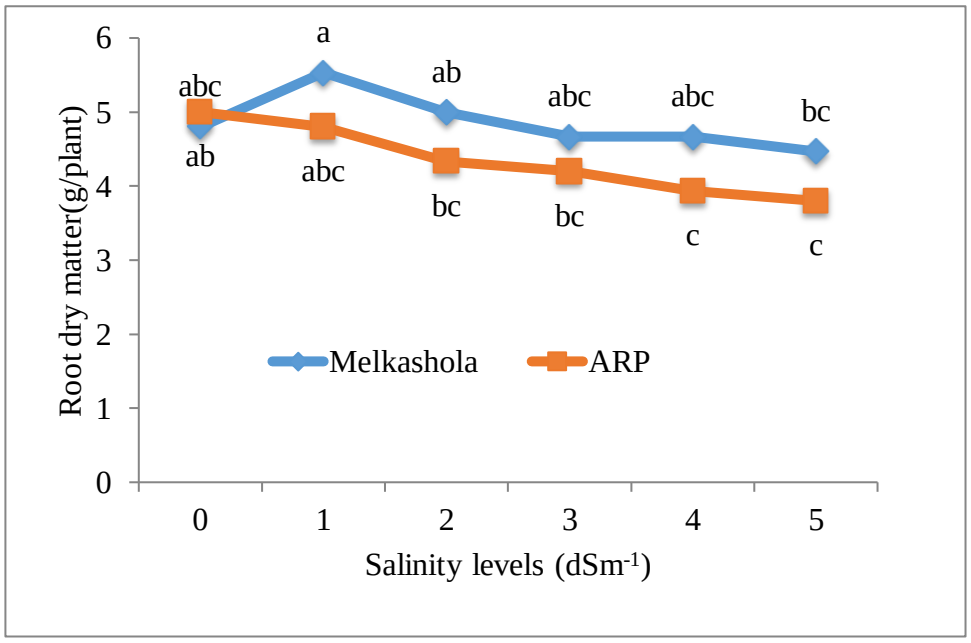

Figure 6Root dry weight of tomato as affected by the interaction of salinity leveland variety

4.2.8. Root to shoot ratio

Root to shoot ratio was not affected by salinity (P<0.8032), variety (P<0.3049) and their interaction (P<0.5482) (Appendix Table 2). However, lower root to shoot ratio was recorded for the lowest salt concentration. It was observed that, root to shoot ratio increased with increasing salt concentrations, indicating that, tomato root was less affected by the salinity stress than did the shoot part, although there was no significant difference between the treatments (Table 6). This might be due to the preferential allocation of assimilates to root due to osmotic stress. This result was in line with the findings of

Jogendra *et al.* (2011) who reported that the root growth in tomato appears to be less affected, whereas, shoot was affected drastically, so that, the dry weight ratio was higher in plant grown under salt stress than in control environment. The root/shoot dry weight ratio increased under higher salt concentration and the rise in root/shoot dry weight in tomato under salt stress must be accompanied by changes in the allocation of assimilates between root and shoot, i.e., greater proportion of assimilates for root compared with shoot(Chookhampaeng *et al.*, 2007; Amir *et al.*, 2011; Hamed *et al.*, 2011). Danait (2018) has also reported that, root dry weight is positively correlated but, shoot dry weight is negatively correlated to salinity. In contrast, Akram et al. (2010), reported that the salt tolerant genotypes transport very small amount of toxic ions (Na^+) to the upper areas like leaf, they store them in their roots, so that the phenomenon of photosynthesis proceeds normally in tolerant genotypes. That is an adaptation mechanisms of tolerant plant species to withstand the adverse conditions that sensitive species substantially lack.

4.2.9. Photosynthetic rate

The rate of photosynthesis was significantly ($P<0.0001$) affected by salinity level, variety and their interaction (Appendix Table 2). The highest and the lowest photosynthetic rates (0.82 $\mu molm^{-2}s^{-1}$ and 0.47 $\mu molm^{-2}s^{-1}$) of tomato leaves were recorded for the control treatment and highest salinity level respectively for variety Melka Shola, whereas the respective values of 0.84 $\mu molm^{-2}s^{-1}$ and 0.56 $\mu molm^{-2}s^{-1}$ were for variety ARP tomato d-2 (Figure 7). It was observed that increasing salinity level from 1 to $5dSm^{-1}$NaCl significantly reduced photosynthetic rate of tomato compared with the control treatment for both varieties.

Unlike for the other parameters, variety ARP exhibited higher photosynthetic rate as compared to Melka Shola. In general, the decrease in photosynthetic rate with increasing salinity might be due to stomatal closure of the plant in response to salt stress and due to its effects on leaf gas exchange, particularly CO_2. This result was in agreement with the findings of Kassaye *et al.* (2013), who reported that stomatal conductance determines photosynthetic rate, which plays important role in growth and development of any plant, and increasing salinity level decreased stomatal conductance and the reduction was greater at the highest level. Such reduction of stomatal conductance under salt stress conditions may result in lower photosynthetic rate that, in turn, leads to lower total yield of the crop. In line with this Zhai *et al.* (2015) have also reported that irrigation water with excessive

salinity has negative effects on the chlorophyll content of tomato, which directly influence photosynthetic rate of the plant.Photosynthetic rate was positively significantly ($p<0.001$) correlated with shoot fresh weight, shoot dry matter, plant height, and leaf area. However, it was negatively highly correlated to Na ion concentration in plant tissue (Appendix Table 4).

Salt stress also down regulates the physiological and biochemical processes going on in tomato (Rivero *et al.*, 2014; AlHarbi *et al.*, 2015; Manan *et al.*, 2016). Reduced plant water contents or water potential due to salt stress lead to stomatal closure to safeguard further loss of water by transpiration (Manan *et al.*, 2016). In addition to reduced transpiration due to stomatal closure, net photosynthesis may also be reduced under salt stress by the production of ROS and decrease in chlorophyll contents and rubisco activity (Zhang *et al.*, 2009; Zribi *et al.*, 2009). ROS decrease net photosynthesis, chlorophyll content and rubisco activity by increasing the osmotic stress causing, oxidative damage due to lack of dissipation of excessive excitation of energy resulting in loss of chlorophyll leading to decreased rubisco activity that finally cause reduction in photosynthesis. Physiological efficiency of tomato is also adversely affected by saline conditions, as salinity affects photosynthesis by decreasing CO_2 availability because of diffusion limitations (Flexas *et al.*, 2007) and a reduction in the contents of photosynthetic pigments (Ashraf *et al.*,2013).

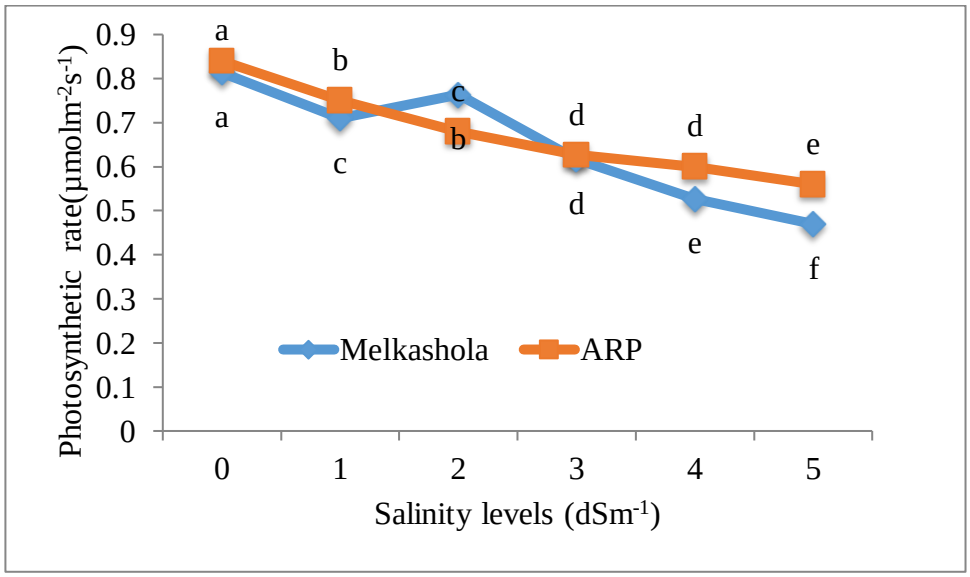

Figure 7 Photosynthetic rate of tomato as affected by the interaction of salinity level and variety

4.2.10. Fruit yield

Difference between salinity level, variety and their interaction weresignificant (P<0.0001) for tomato yield (Appendix Table 2). Highest yields of 21.48, 22.71 and 21.59 ton/ha) were recorded for thecontrol and at1 and 2dSm^{-1} for variety Melka Shola with the corresponding yields of 21.34, 21.78 and 19.65 ton/ha for variety ARP tomato d-2, respectively. The minimum yield (16.73 ton/ha) was recorded at 5dSm^{-1}NaCl levelfor variety ARP tomato d-2 (Figure 8). In general, it was observed that increased concentrations of NaCl significantly reduced tomato yield compared with the lower salt levels.The result indicated thatthe highest salinity concentration of NaCl highly affected yield of tomato for both varieties. However, variety Melka Shola showed better relative tolerance as compared to ARP tomato d-2.

At the salinity level of 5dSm^{-1} yield of tomato varieties decreased by almost 50% as compared to the control treatments. This could be probably attributed to reduced fruit number, fruit size and reduced dry matter accumulation in the fruits, which have direct contribution to lower fruit yields. This result was in agreement with the report of (Ciobanu and Sumalan, 2009) that 50% tomato yield loss was occurred at moderate salinity level (5dSm^{-1}). In addition to this, the reduction of tomato yield under saline conditions may be due to the harmful impact of salt stress on the tomato growth, lowering of plant water potential, disturbance in mineral uptake and enhancement of plant respiration. This result was in line with the findings ofDanait(2018) who reported that fruit yield and increasing salinity have strong negative correlations. Shao *et al.*(2012; 2013 andHou *et al.*(2014) have also reported that tomato yield was negatively affected by increasing salinity levels, as increasing irrigation water salinity levels resulted in a significant reduction in fruit yield.

Furthermore, it has been reported that high saline soil decreased the number of fruits/plant (Khursheda *et al.*, 2015). Babu *et al.* (2012) have also reported that, NaCl stress resulted in decreased rate of fruit growth. The reduction of stomatal conductance under salt stress conditions may result in lower photosynthetic rate that, in turn, leads to lower total yield of the crop and the effects of reactive oxygen species under higher salinity may also the reason for reduced yield. In line with this Zhai *et al.* (2015) have also reported that irrigation water with excessive salinity has negative effects on the chlorophyll content of tomato, which directly influence photosynthetic rate of the plant.

High salt concentration in the irrigation water may also affect the physiological and biochemical process in tomato such as enzymatic activities, reduced water potential and oxidative damage due to increased ROS. In line with this, Rivero *et al.* (2014; AlHarbi *et al.* (2015) and Manan *et al.* (2016) reported that salt stress also down regulates the physiological and biochemical processes going on in tomato and reduced plant water contents or water potential due to salt stress lead to stomatal closure to safeguard further loss of water by transpiration. Zhang *et al.* (2009) and Zribi *et al.* (2009) also reported that in addition to reduced transpiration due to stomatal closure, net photosynthesis may also be reduced under salt stress by the production of ROS and decrease in chlorophyll contents and rubisco activity. ROS decrease net photosynthesis, chlorophyll content and rubisco activity by increasing the osmotic stress causing, oxidative damage due to lack of dissipation of excessive excitation of energy resulting in loss of chlorophyll leading to decreased rubisco activity that finally cause reduction in photosynthesis.

Campos *et al.* (2006) also reported that both vegetative and fruit growth of tomato decrease markedly under saline conditions.That may be due to changes in a range of metabolic processes caused by salt stress. For example, protein contents and activities of ascorbate peroxidase and catalase decreased under saline conditions (Chookhampaeng *et al.*, 2008). High salt concentration also causes an ionic imbalance and osmotic shock to tomato plants (Ciobanu and Sumalan, 2009). Both the accumulation of specific toxic ions including Na^+ and changes in leaf hormone relations contribute to leaf senescence and hence limit tomato productivity under saline conditions (Ghanem *et al.*, 2008).

Flexas *et al*. (2007) reported that physiological efficiency of tomato is also adversely affected by saline conditions, as salinity affects photosynthesis by decreasing CO_2 availability because of diffusion limitations.Similarly, Maggio *et al.* (2007), reported that physiological efficiency of tomato is adversely affected by saline conditions. For example, leaf water and osmotic potentials decreased in tomato plants while endogenous ABA concentrations increased under saline conditions. Simple correlation coefficients revealed that tomato yield exhibited significant positive correlation with growth characters such as leaf number, root fresh weight, shoot dry matter, root dry matter, photosynthetic rate and shoot fresh weight ($P<0.0226$, $P<0.0070$, $P<0.0023$, $P<0.0278$, $P<0.0024$, $P<0.0022$), respectively) (Appendix Table 4). The positive and significant correlation coefficients(r-values) between yield and growth parameters indicate that yield was greatly influenced by these growth parameters under salt stress conditions. However, yield was negatively

highly associated with Na ion,indicating that tomato yield significantly decreased with increasing salinity stress. Most of the growth parameters were positively correlated to each other. However, root to shoot ratio was negatively correlated with all parameters, except leaf number, root fresh weight and root dry matter.

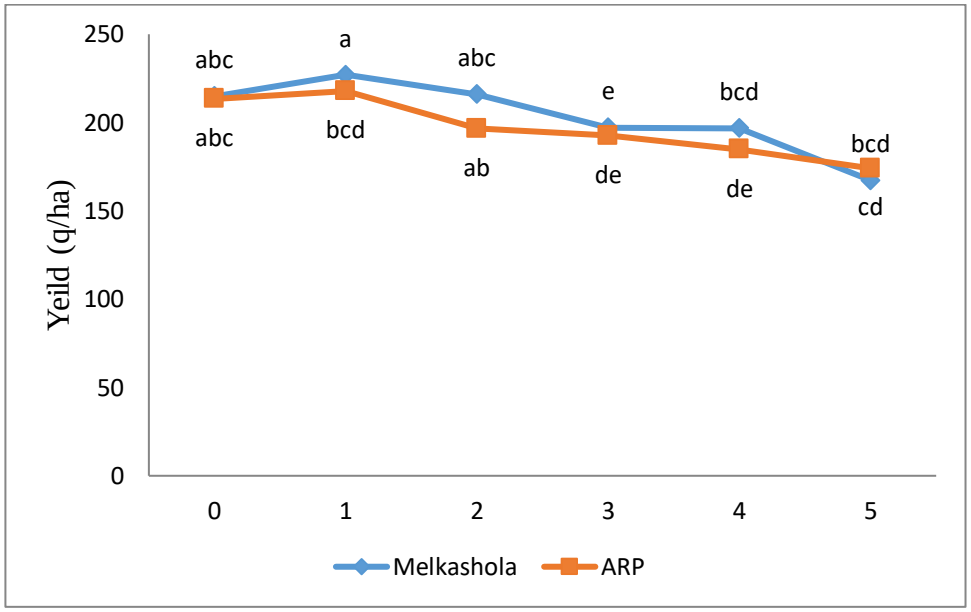

Figure 8Yield of tomato as affected by the interaction of salinity leveland variety

4.2.11 Effect of salinity levels on concentrations of plant nutrients

Significant difference was observed for the interaction of variety with salinity level for ($P<0.0001$)for Na^+/K^+ ratio, Potassium, sodium and sulfur concentrations in tomato plant tissue. However, there was no significant difference between the treatments for Ca($P<0.4381$), Mg ($P<0.7475$) and P ($P<0.9225$)concentrations (Appendix Table 3). This indicates that Ca, Mg and phosphorus were not affected by NaCl concentrations. This could be probably due to the reason that these nutrients were sufficiently taken up by the varieties without being replaced by Na^+. Though there was no significant difference for these nutrients, they showed a decreasing trend as salinity level increased.

Table 6. The main effects of salinity and variety on plant tissue concentration of Calcium, Magnesium and phosphorus on leaf number and Root to shoot ratio of tomato

Salt level (dSm^{-1})	Leaf number per plant	Root to shoot ratio	Calcium	Magnesium	Phosphorus
Control	10.17	0.16	3.30	0.77	0.20
1	11.23	0.17	3.43	0.79	0.17
2	10.34	0.16	3.36	0.83	0.17
3	9.87	0.16	3.43	0.77	0.20
4	9.57	0.17	3.48	0.75	0.17
5	9.47	0.17	3.69	0.81	0.18
Mean	10.10	0.16	3.44	0.78	0.18
CV	12.76	11.22	11.20	10.29	19.80
CR	NS	NS	NS	NS	NS
Variety					
Melka Shola	10.13	0.17	3.58^{a}	0.79	0.19
ARP tomato	10.08	0.16	3.31^{b}	0.78	0.17
Mean	10.10	0.16	3.44	0.78	0.18
CV	12.65	10.80	10.87	9.95	18.80
CR	NS	NS	0.25	NS	NS

CV= Co efficient of variation, CR =Critical range, NS =Non-significant

The concentration K^+ in tomato plant tissue showed significant decrease at $5dSm^{-1}$ salinity levelfor variety ARP.In contrast, K concentration was not significantly affected by increasing salt level for variety Melka Shola (Figure 9).However, the decreasing trend in concentration of potassium (K) at higher salinity levelwas observed for both varieties. Disorder in translocation and distribution of minerals specially K^+ might be the reason for the decreased uptake of K^+at the highest salinity level due to substitution of K with Na at its usual binding sites. The difference between varieties for K concentration imply, difference in osmotic adjustment and thus, can be used as selection criteria for salt stress tolerance.

In line with this, Khalafalla *et al.* (2010),has reported that increase in K^+ concentration in nutrient solution could ameliorate negative effects of salt condition and potassium can alleviate the negative effects of NaCl on vegetative growth and yield.Akram *et al.* (2010) also have reported that salt tolerant genotypes transport very small amount of toxic ions (Na^+) to the upper areas like leaf, they store them in their roots that is why the phenomenon of photosynthesis proceeds normally in tolerant genotypes. That is an adaptation mechanisms of tolerant plant species to withstand the adverse conditions that sensitive species substantially lack. In addition to this, (Maggio *et al.*, 2007) also found

similar observations in tomato.The correlation analysis showed that, K^+ indicated significant negative association with Na^+(Appendix Table 4).This result was in agreement with the findings of Flowers *et al*. (2015) that increased concentration of sodium affects the entry of K^+ ions. Akram *et al.* (2010) also has reported that sodium concentration increases in plants under salt stress and suppresses the potassium concentration.

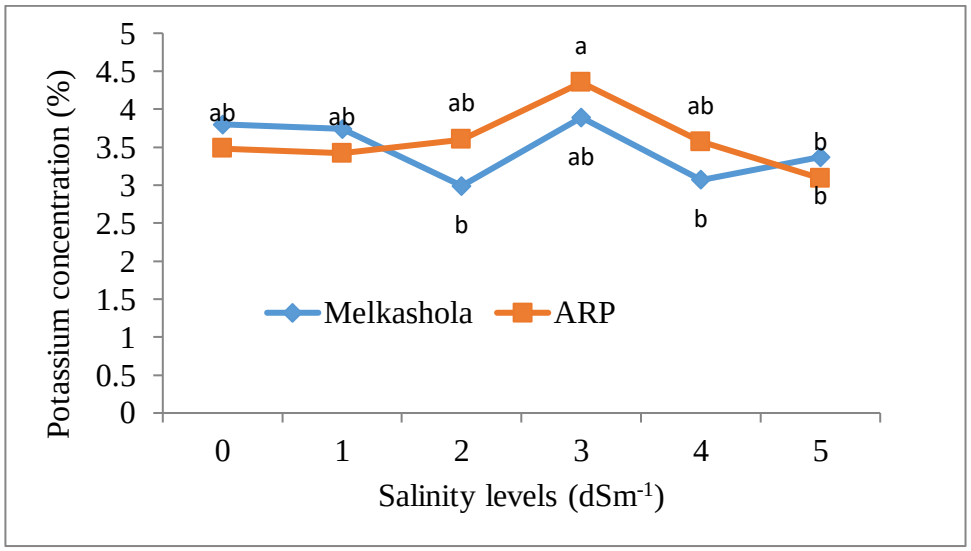

Figure 9Potassium concentration as affected by the interaction of salinity leveland variety

Increasing irrigation water salinity level resulted in a significant increase of Na concentration of tomato plant tissue and the increase reached the highest (0.56%) value at 5 dSm^{-1} compared with the control (0.16%) specifically for variety ARP (Figure 10). In the present study, both tomato varieties showed an increase in Na^+ while decreased tissue K^+ contents. However, variety Melka Shola exhibited the minimum concentration of Na^+. On the other hand, ARP tomato-2 showed elevated Na^+ contents as compared to Melka Shola. This difference between the varieties for sodium and potassium content may be due to their genetic difference in ion uptake for osmotic adjustment. In line with this,Flowers, (2004); Munns, (2005) and Munns *et al.* (2006) reported that salt tolerance is genetically controlled and the ability of plants to overcome the effects of salt depends on selective ion accumulation or exclusion or osmotic adjustment. Akram *et al.* (2010) also have reported that salt tolerant genotypes transport very small amount of toxic ions (Na^+) to the upper areas like leaf.

Variety Melka Shola exhibited such potential and better accumulation of K as compared to the variety ARP tomato-d2. Akram *et al.* (2010) also reported that sodium concentration increases in plants under salt stress and suppresses the concentration of potassium.

Flowers *et al.* (2015) also reported that, at cellular level salinity brings about ionic toxicity by elevated Na^+ and Cl^- levels. According to results of Sadak *et al.* (2015), sodium concentration was higher in plants grown under higher salinity levels.

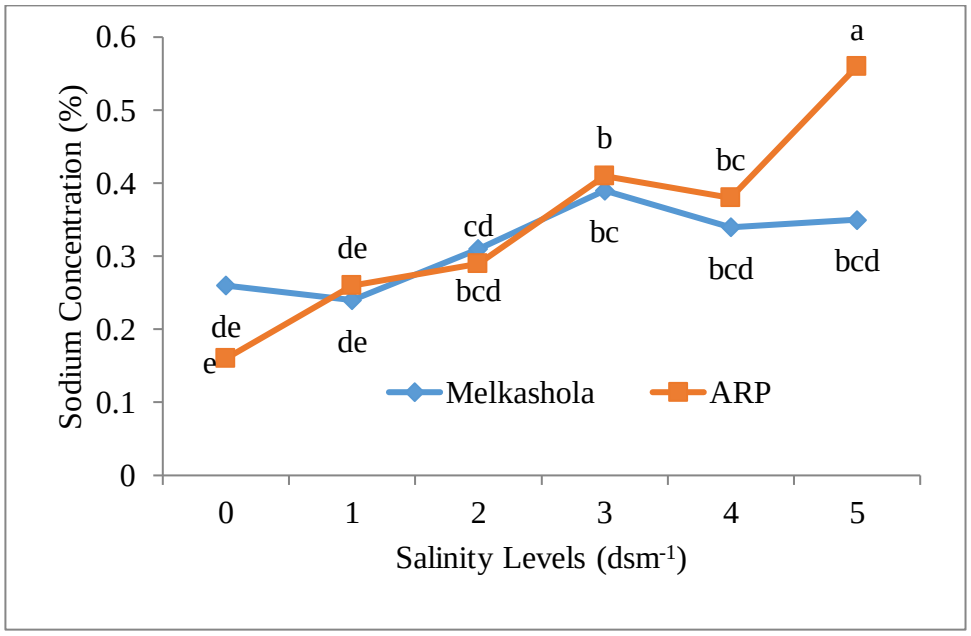

Figure 10Sodium concentrations as affected by the interaction of salinity leveland variety

Maximum reduction of sulfur content in tomato plant tissue was noted at 5 dSm^{-1} salinity level. On the other hand, maximum values were recorded forthe lower salinity level as shown in (Figure 11). The results showed that salinity had significant effect on concentration of sulfur in the tomato plant tissue. Increased salinity concentrations significantly affected the uptake of K, S and Na/K ratio. The result of laboratory analysis of tomato plant tissue indicated that Phosphorus and Sulfur were deficient because the recorded values of these nutrients were below the sufficiency ranges reported by Hochmuth *et al.* (2018).

However, Sodium concentration was higher. This indicates that Na^+ affected the proper uptake of S and P nutrients. This result was in agreement with that of Asik *et al.* (2009) who reported that salinity has an antagonistic impact on the uptake of nutrients. In addition, Sadak *et al.* (2015) illustrated that the reduction in Ca and Mg uptake under salt stress conditions may be due to the suppressive impact of Na and K on Ca and Mg or due to the reduced transport of Ca and Mg cations.In the present study, it was observed that sulfur had significant negative association with Na^+.

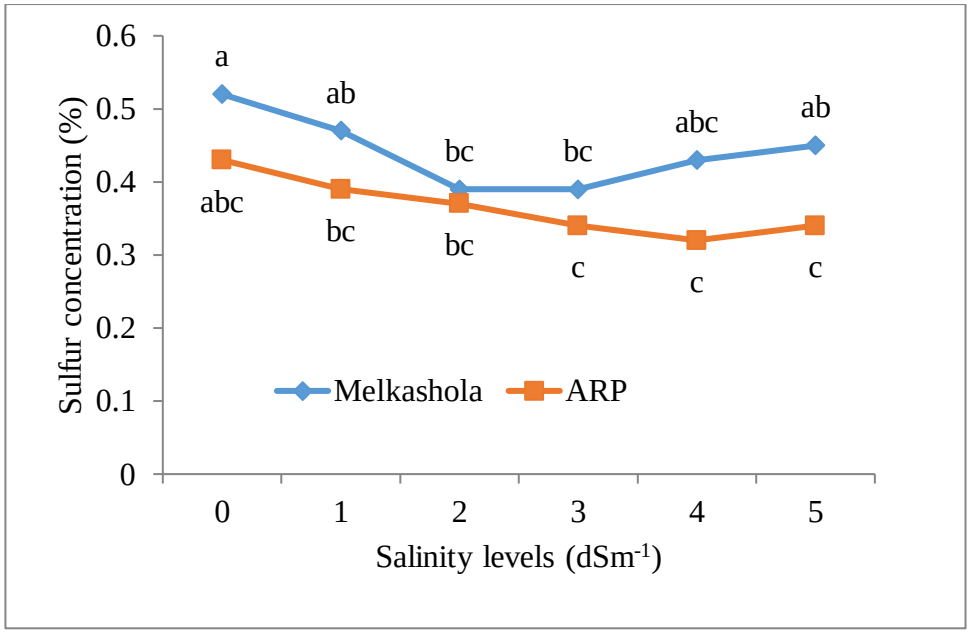

Figure 11Sulfur concentrations as affected by the interaction of salinity leveland variety

The highest averageNa^+/K^+ ratio in tomato plant tissue was recorded for the highest salt concentration of variety ARP tomato d-2. The control treatment exhibited the lowest averageNa^+/K^+ ratio in tomato plant tissue. It was observed that increasing salinity level significantly increased Na^+/K^+ ratio in the plant tissue as compared with the control treatment (Figure 12). Hence, the highest Na^+/K^+ ratio (0.184) was recorded for 5dSm $^{-1}$while the lowest value (0.047) was for the control treatment. Better nutrient uptake under saline condition may help the plant to counteract the nutrient imbalance occurring under saline environment. This finding was in line with the result of Jogendra *et al.*(2011), who reported that the lower value of Na^+/K^+ ratio, indicated more uptake of K^+ from soil/medium by plants and such types of plants are similar to non-salinized plant, i.e. salt tolerant.

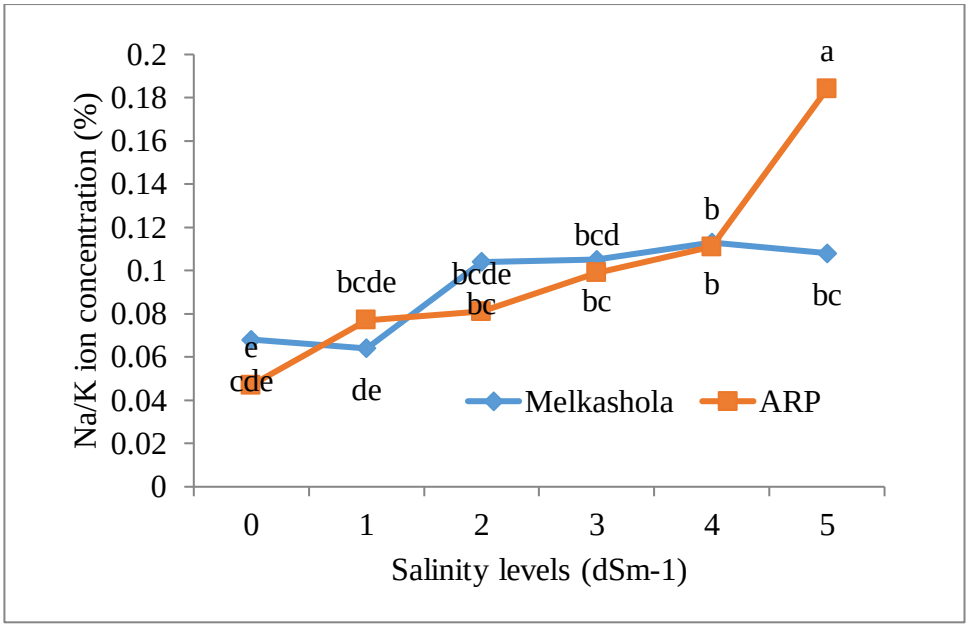

Figure 12Sodium/Potassium ratio concentrations as affected by the interaction of salinity level and variety

5. CONCLUSION AND RECOMMENDATION

Salinity is one of the major abiotic factors limiting production and productivity of tomato in Ethiopia. An experiment was conducted to assess germination, growth, physiological and yield responses of tomato varieties to different salinity levels. Salinity induced in the form of NaCl solution had a pronounced effect on tomato varieties resulting in a considerable decrease in germination percentage, germination speed, germination index and seedling vigor index.

With increase in salt concentration, all, the germination parameters were significantly redu -ced and the reductions were higher at $5dSm^{-1}$. NaCl stress substantially affected the growth, physiological and yield attributes of tomato inboth varieties. The tomato varieties were more affected at lower salinity concentrations at early than at later growth stages. The comparison within varieties indicated that Melka Shola was tolerant as compared to ARP tomato-d2. It can be concluded that the main effects of salt on tomato varieties were due to the osmotic effect, ion toxicity (specifically Na^+) and nutrient imbalance due to increased uptake of Na^+ that resulted in reduction of Sulfur and Phosphorus uptake by plants. In addition to Sulfur and Phosphorus, Potassium also indicated significant reduction with the increased salinity level. However, both varieties showed sufficient K^+ uptake under salinity stress.

In conclusion, variety Melka Shola showed better tolerance as compared to ARP tomato d-2. Therefore, Melka Shola could be recommended for salt affected areas for farmers and other tomato producers in salinity affected areas for productionand should be considered as potential planting material that is useful to breeders of salt tolerant cultivars.However, since the experiment was conducted for one year and under controlled conditions, on farm verification of the varieties in salt affected areas should be done in order to draw sound conclusions and recommendation and the effect of salinity on tomato quality also deserves further study.

.

6. REFERENCES

Abdul-Baki. AA and JD. Anderson. 1970. Viability and leaching of sugars from germinating barley. *Crops Science*.**10(1)**: 31 – 34.

Akram. M, MY. Ashraf, R. Ahmad, EA. Waraich, J. Iqbal and M. Mohsan. 2010. Screening for salt tolerance in maize (*Zea mays* L.) hybrids at an early seedling stage. *Pakistan Journal of Botany*.**42**: 141-154.

Albacete, A., Martınez-Andujar, C., Ghanem, M. E., Acosta, M., Sanchez Bravo, J., Asins, M. J., Cuartero, J., Lutts, S., Dodd, I. C., and Perez-Alfocea, F. 2009. Rootstock-mediated changes in xylem ionic and hormonal status are correlated with delayed leaf senescence and increased leafarea and crop productivity in salinised tomato. *Plant Cell Environment*.**32**: 928–938.

Al-Harbi AR, AM Al-Omran, MM Alenazi and MA Wahb-Allah. 2015. Salinity and deficit irrigation influence tomato growth, yield and water use efficiency at different developmental stages. *International Journal of Agriculture and Biology*.**17**:241-250.

Ali N S, K. Mo and M. Kim. 2012. A case study on the relationship between conductivity and dissolved solids to evaluate the potential for reuse of reclaimed industrial wastewater KSCE *Journal of Civil Engineering.* **16:** 708–713.

Ali S, CT Charles and RB Glick. 2014. Amelioration of high salinity stress damage by plant growth promoting bacterial entophytes that contain ACC demines. *Plant Physiology and Biochemistry*.**80**: 160-167.

Almeida, P.M.F., de Boer, G.J. and de Boer, A.H. 2014. Assessment of natural variation in the first pore domain of the tomato HKT1;2 transporter and characterization of mutated versions of SlHKT1;2 expressed in Xenopuslaevis oocytes and via complementation of the salt sensitive athkt1;1 mutant. *Frontiers of Plant Science*. **5:** 600.

Amir N, A. Muhammad, AP. Muhammad AP and A. Irfan. 2011. Effect of halo priming on germination and seedling vigor of tomato. *African Journal of Agricultural Research*. **6 (15)**:3551–3559.

Apse, M. P., Aharon, G. S, Snedden, W. A., and Blumwald, E. 1999. Salt tolerance conferred by overexpression of a vaculolar Na/H antiport in Arabidopsis. *Science***285**: 1256–1258.

Asad. SQ, E. E. Tesfaye and M. Melese. 2018. Prospects of alternative copping systems for salt affected soils in Ethiopia. *Journal of Soil Science and Environmental Management*. **9(7)**: 98-107.

Asfaw, Z and D. Eshetu. 2015. Production and Management of Major Vegetable Crops in Ethiopia. Addis Ababa, Ethiopia.

Ashraf M. 2009. Biotechnological approach of improving plant salt tolerance using antioxidants as markers. *Biotechnology Advances*. **27**: 84–93

Ashraf M., R.H. Athar, C. J.P. Harris and R.T. Kwon. 2008. Some prospective strategies for improving crop salt tolerance. *Advance in Agronomy*.**97**: 45-110.

Ashraf, M. and Athar H.R. 2009. Strategies for Crop Improvement Against Salinity and Drought Stress: An Overview. pp 1-10. In: M. Ashraf, M.Ozturk, H.R. Athar (Eds). Salinity and Water Stress, Improving Crop Efficiency. *Springer Science and Business Media B.V.*

Ashraf, M. and Harris, P.J.C. 2013. Photosynthesis under stressful environments: An overview. *Photosynthetica*.**51**: 163–190.

Asins, M. J., Boların, M. C., Perez-Alfocea, F., Estan, M. T., Martınez-Andujar, C., Albacete, A., Villalta, I., Bernet, G. P., Dodd, I. C., and Carbonell, E. A. 2010. Genetic analysis of physiological components of salt tolerance conferred by *Solanum* rootstocks. *Theor. Appl. Genet.**121***: 105–115.

Asins, M.J., Villalta, I., Aly, M.M. 2013. Two closely linked tomato HKT coding genes are positional candidates for the major tomato QTL involved in Na^+/K^+ homeostasis. *Plant, Cell and Environment*. **36(6):** 1171–1191.

Auge KD, TM. Assefa, WH. Woldeyohannes and. BT. Asfaw. 2018. Potassium dynamics under enset (*Ensete ventricosom cheesman)* farming systems of Sidama zone, Southern Ethiopia. *Journal of Soil Science and Environmental Management.* **9(4)**:47-58.

Babu MA, D. Singh, M. Gothandam. 2012. The effect of salinity on growth, hormones and mineral element in leaf and fruit tomato cultivar PKM1. *Journal of Animal & Plant Science.***22(1)**:159-164.

Balibrea, M. E., Dell Amico, J., Boların, M. C., and Perez-Alfocea, F. 2000. Carbon partitioning and sucrose metabolism in tomato plants growing under salinity. *Physiol. Plant.***110**: 503–511.

Borsani, O., Cuartero, J., Fernandez, J. A., Valpuesta, V., and Botella, M. A. 2001. Identification of two loci in tomato reveals distinct mechanisms for salt tolerance. *Plant Cell1*. **3**: 873–887.

Bruria Heuer. 2005. Photosynthetic Carbon Metabolism of Crops under Salt Stress. Institute of Soils, Water and Environmental Sciences, Agricultural Research Organization, Volcani Center.

Campos, C. A. B., Fernandes, P. D., Gheyi, H. R., Blanco, F. F., Goncalves, C.B., and Campos, S. A. F. 2006. Yield and fruit quality of industrial tomato under saline irrigation. *Sci. Agric.* **63**: 146–152.

Carmo-Silva AE, MA Gore, P Andrade-Sanchez, AN French, DJ Hunsaker and ME Salvucci. 2012. Decreased CO_2 availability and inactivation of Rubisco limit photosynthesis in cotton plants under heat and drought stress in the field. *Environmental and Experimental Botany*. **83**: 1-11.

Central Statistical Agency (CSA). 2013. Report on area and production of major crops. Statistical bulletin.

Central Statistical Agency (CSA). 2018. Report On Area and Production of Major Crops. Volume I. Addis Ababa. Statistical Bulletin 586.

Cha-um S, Pokasombat Y and Kirdmanee C. 2011. Remediation of salt-affected soil by gypsum and farmyard manure − Importance for the production of Jasmine rice. *Australian Journal of Crop Science*.**5**: 458-465.

Chookhampaeng S, W. Pattanagul and P.Theerakulpist. 2007. Screening some tomato commercial cultivars from Thailand for salinity. *Asian Journal Plant Science*. **6(5)**:788–794.

Chookhampaeng, S., Pattanagul, W., and Thee rakulpisut, P. 2008. Effects of salinity on growth, activity of antioxidant enzymes and sucrose content in tomato (*Lycopersicon esculentum* Mill.) at the reproductive stage. *Sci. Asia*.**34**: 69–75.

Chookhampaeng, S., W. Pattanagul and P. Theerakulpisut. 2008. Effects of salinity on growth, activity of antioxidant enzymes and sucrose content in tomato (*Lycopersicon esculentum*Mill.) at the reproductive stage. *Science Asia*.**34**: 69–75.

Choudhury, F.K., Rivero, R.M., Blumwald, E. and Mittler, R., 2017. Reactive oxygen species, abiotic stress and stress combination. *The Plant Journal*.**90(5)**: 856-867.

Ciobanu, I. and Sumalan, R. 2009. The effects of the salinity stress on the growing rates and physiological characteristics to the *Lycopersicon esculentum species*. *Bull UASVM Hortic*.**66**: 616–620

Ciobanu, I.P. and R. Sumalan. 2009. The effects of the salinity stress on the growing rates and physiological characteristics to the *Lycopersicum esculentum* specie. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. *Horticulture*. **66(2)**: 616-620.

Croser C, S. Renault, J.Franklin and J. Zwiazk. 2001. The effect of salinity on the emergence and seedling growth of piceamariana, PiceaGlanca and Pinusbarksiana. *Environ Pollution* .**115**: 6–16.

Danait. H. 2018**.** Impact of surface and ground water salinity on soil and plant productivity in the central rift valley region around Lake Ziway. *Academia Journal of Environmental Science*. **6(3)**: 067-084.

Essa. AT and DH. Al-Ani. 2001. Effect of salt stress on the performance of six soybean genotypes. *Pakistan Journal Biological Science.* **4**:175–177.

FAO. 2014. United Nation Food and Agriculture Organization Statistics Division. Crop Production data. Rome, Italy.

FAOSTAT. 2010. United Nations Food and Agriculture Organization. Rome, Italy.

Flexas, J., A. Diaz-Espejo, J. Galmés, R. Kaldenhoff, H. Medrano and M. Ribas-Carbo.2007 Rapid variations of mesophyll conductance in response to changes in CO2 concentration around leaves. *Plant Cell Environment.* **30(5)**: 1284–1298.

Flores, F., El Yahaoui, F., de Billerbeck, G., Romojaro, F., Latche, A., Bouzayen, M., Pech, J. C., and Ambid, C. 2002. Role of ethylene in the biosynthetic pathway of aliphatic ester aroma volatiles in Charentais cantaloupe melons. *J. Exp. Bot.***53**: 201–206

Flowers TJ, R Munns and TD Colmer. 2015. Sodium chloride toxicity and the cellular basis of salt tolerance in halophytes. *Annals of botany*. **115**: 419-431.

Garrido Y, JA Tudela, A Marín, T Mestre, V Martínez and MI Gil. 2014. Physiological, phytochemical and structural changes of multi-leaf lettuce caused by salt stress. *Journal of the Science of Food and Agriculture*. **94**: 1592-1599.

Gebremeskel G, Gebremicael TG, Kifle M, Meresa E, Gebremedhin T and Girmay A .2018. Salinization pattern and its spatial distribution in the irrigated agriculture of Northern Ethiopia: An integrated approach of quantitative and spatial analysis. *Agricultural Water Management.***206**:147-157.

Ghanem, M. E., A. Albacete, C. Mart´ ınez-Andujar, M. Acosta. R. Romero- Aranda, I. Dodd, S. Lutts, and F. Perez-Alfocea. 2008. Hormonal changes ´ during the salt-stress induced leaf senescence in tomato (*Solanumlycopersicum*L.). *Journal of Experimental Botany*. **59**: 3039–3050.

Ghanem, M. E., Albacete, A., Martınez-And ujar, C., Acosta. M., RomeroAranda, R., Dodd, I., Lutts, S., and Perez-Alfocea, F. 2008. Hormonal changes during the salt-stress induced leaf senescence in tomato (*Solanum lycopersicum* L.). *J.Exp. Bot*.**59**: 3039–3050

Ghanem, M. E., Albacete, A., Smigocki, A. C., Frebort, I., Pospisilova, H., Martınez-Andujar, C., Acosta, M., Sanchez-Bravo, J., Lutts, S., Dodd, I. C., and Perez-Alfocea, F. 2011a. Root-synthesised cytokinins improve shoot growth and fruit yield in salinised tomato (*Solanum lycopersicum* L.) *Plants.J. Exp. Bot*.**62**: 125–140.

Ghanem, M., Hichri, I., Smigocki, A. C., Albacete, A., Fauconnier, M. L., Diatloff, E., Martinez-Andujar, C., Lutts, S., Dodd, I. C., and Perez-Alfocea, F. 2011b. Root-targeted biotechnology to mediate hormonal signalling and improve crop stress tolerance. *Plant Cell Rep.***30**: 807–823.

Groot SPC, B. Kieliszewska-Rokicka, E. Vermeer and CM. Karssen CM. 1988. Giberellin induced hybrolysis of endosperm cell walls in giberellin deficient tomato seeds prior to radicle protrusion. *Planta*. **174**:500–504.

Groot SPC, CM. Karssen. 1992. Dormancy and germination of abcissic acid deficient tomato seeds. *Plant Physiology*. **99**:952–958.
Hamed K, N. Hossein F. Mohammad and VJ. Safieh. 2011. How salinity affect germination and emergence of tomato lines. *Journal of Biological and Environmental Science.* **5 (15)**:159–163.

Hasanuzzaman M, K. Nahar, M. Fujita. 2013. Plant response to salt stress and role of exogenous protectants to mitigate salt-induced damages. Ecophysiology and Responses of Plant Under salt stress (Ed.) P. Ahmad P MM. Azooz , MNV. *Prasad. Springer*. 510.

Hochmuth G., D. Maynard, C.Vavrina, E.Hanlon and E. Simonne. 2018. Plant tissue analysis and interpretation for vegetable crops in Florida. University of Florida.

Hou M, X. Shao, Y.Zhai. 2014. Effects of Different Regulatory Methods on Improvement of Greenhouse Saline Soils, Tomato Quality, and Yield. *Scientific World Journal.* **2014**: 953675.

International Seed Testing Association (ISTA). 1996. International Rules for Seed Testing. *Seed Science and Technology.***21**: 25-254.

Jaime-Perez, N., Pineda, B., Garcıa-Sogo, B., Atares, A., Athman, A., Byrt, C.S., Olıas, R., Asins, M.J., Gilliham, M. and Moreno, V. 2017. The sodium transporter encoded by the HKT1;2 gene modulates sodium/ potassium homeostasis in tomato shoots under salinity. *Plant, Cell and Environment*. **40 (5):** 658–671.

Jamil M, D Bae Lee, K Yong Jung, M Ashraf, SC Lee and Y ShikRha. 2006. *Journal Centeral European Agriculture.* **2:** 273-282.

Jogendra. S., E. V. Divakar Sastry and Vijayata Singh. 2011. Effect of salinity on tomato (*Lycopersicon esculentum* Mill.) during seed germination stage. *Physiol Mol Biol Plants***18(1):**45–50.

Julkowska, M.M. and Testerink, C. 2015. Tuning plant signaling and growth to survive salt. *Trends Plant Science*. **20(9):** 586–594.

Kamrani, M.H., Khoshvaghti, H. and Hosseinniya, H. 2013. Effects of Salinity and Hydroponic Growth Media on Growth Parameters in Tomato (*Lycopersicon esculentum* Mill.). *International Journal of Agronomy and Plant Production*.**4**: 2694-2698.

Kandil AA, AE Sherief and SRH. Ahmed. 2012. Germination and seedling growth of some chickpea cultivars (*Cicer arietinum* L) under salinity stress. *Journal of Basic and Applied Science.***8**: 561-571.

Karim MA, Utsunomiya N, Shigenaga S. 1992. Effect of sodium chloride on germination and growth of hexaploid triticale at early seedling stage. *Japanese Journal of Crop Science*. **61**: 279-284.

Kassaye. T., A. Debela and G. Lemessa. 2013. Evaluating Seedling Establishment of Tomato (*Lycopersiconesculentum* L.) Varieties as Influenced by NaCl Stress. *International Journal of Current Agricultural Science.* **3(1)**:10-14.

Katerji, N., van Hoorn, J. W., Hamdy, A., and Mastrorilli, M. 2003. Salinity effect on crop development and yield, analysis of salt tolerance according to several classification methods. *Agric. Water Manage*.**62**: 37–66.

Khajanchi, L., R.L. Meena. 2008. Diagnosis of soil and water for salinity. In Conjunctive Use of Canal and Groundwater; Intech Graphics: Karnal, India.57–66.

Khajehosseini M., AA Powell and IJ Bingham. 2003.Seed *Sciences Technology.* **31**: 715-725.

Khayatnezhad M and Gholamin R. 2011.Effects of salt stress levels on five maizes (*Zea mays* L.) cultivars at germination stage. *African Journal Biotechnology*.**10**:12909-12915.

Khursheda Parvin, Kamal Uddin Ahamed, Mohammad Mahbub Islam and Md. Nazmul Haque. 2015. Response of Tomato Plant Under Salt Stress: Role of Exogenous Calcium. *Journal of Plant Sciences*. **10 (6)**: 222-233.

Kumar, K, M. Kumar, S R. Kim, H. Ryu and Y G. Cho. 2013. Insights in to genomics of salt stress response in rice.**6** (1):27.

Levitt, J. 1980. Responses of Plants to Environmental Stresses, second ed. Academic Press, New York.

Li, J., Liu, L., Bai, Y., Zhang, P., Finkers, R., Du, Y., Visser, R.G.F. and van Heusden, A.W. 2011. Seedling salt tolerance in tomato. *Euphytica*.**178 (3):** 403–414.

Li, Y. 2009. Physiological responses of tomato seedlings (*Lycopersicon esculentum L.*) to salt stress. *Modern Applied Science.* **3**: 171–176.

Li, Y. 2009. Physiological responses of tomato seedlings (*Lycopersicon esculentum*) to salt stress. *Modern Appl. Sci*.**3**: 171–176.

Lin, T., Zhu, G., Zhang, J. 2014. Genomic analyses provide insights into the history of tomato breeding. *Nature Genetics*. **46(11):** 1220–1226.

Maggio A, G Raimondi, A Martino and S De Pascale. 2007. Salt stress response in tomato beyond the salinity tolerance threshold. *Environmental and Experimental Botany*.**59**: 276-282.

Maggio, A., Raimondi, G., Martino, A., and De Pascale, S. 2007. Salt stress response in tomato beyond the saline tolerance threshold. *Environ. Exp. Bot.***59**: 276–282.

Manan A, CM Ayyub, MA Pervez and R Ahmad. 2016. Methyl jasmonate brings about resistance against salinity stressed tomato plants by altering biochemical and physiological processes. *Pakistan Journal of Agriculture Sciences*.**53**: 35-41.

Mestre, T.C., Garcia-Sanchez, F., Rubio, F., Martinez, V. and Rivero, R.M. 2012. Glutathione homeostasis as an important and novel factor controlling blossom-end rot development in calcium-deficient tomato fruits. *Journal of plant physiology*.**169(17)**: 1719-1727.

Mittelstet AR, DE Storm and AL Stoecker. 2015. Using SWAT and empirical relationship to simulate crop yields and salinity levels in the North Fork River Basin. *International Journal of Agricultural and Biological Engineering*. **8**: 1-15.

MOA. 1998-2014. Crop Variety Registry. Animal and Plant Health Regulatory Directorate. Issue No 3-17. AA. Ethiopia.

Mohammed HA, Khader BA, Abdullah NM and Nashwan A. 2015. GIS Based Assessment of Land Suitability for Industrial Crops (Cotton, Sesame and Groundnut) in the Abyan Delta. Yemen. *American Journal of Experimental Agriculture*. **8(6)**:

Munns R and M Tester. 2008. Mechanisms of salinity tolerance. *Annual Reviews of Plant Biology*.**59**: 651-681.

Nasri N., Kaddour R., Rabhi M., Plassard C. and Lachaâl M. 2011. Effect of Salinity on Germination, Phytase Activity and Phytate Content in Lettuce Seedling. *Acta Physiologiae Plantarum*. **33**: 935-942.

Neocleous, D. and Vasilakakis, M. 2007. Effects of NaCl stress on red raspberry (Rubusidaeus L. 'Autumn Bliss'). *Scientia Horticulturae*. **112**:282–289.

Orsini F, M Alnayef, S Bona, A Maggio and G Gianquinto. 2012. Low stomatal density and reduced transpiration facilitate strawberry adaptation to salinity. *Environmental and Experimental Botany*. **81**: 1-10.

Osakabe Y, K Osakabe, K. Shinozaki and L-SP Tran. 2014. Response of plants to water stress. *Frontiers in plant science*. **5**: 86.

Parida AK. and AB. Das. 2005. Salt tolerance and salinity effects on plant: *a review. Ecotoxical Environ Safety*. **60**:324–349.

Platten J D, J A. Egdane and A M. Ismail.2013. Salinity tolerance, Na^+ exclusion and allele mining of *HKT1;5* in Oryza sativa and O. glabberima: Many sources, many genes, many mechanisms. *BMC Plant Biology*,13:32.

Plett, D., Safwat, G., Gilliham, M., Skrumsager Moller, I., Roy, S., Shirley, N., Jacobs, A., Johnson, A. and Tester, M. 2010. Improved salinity tolerance of rice through cell type-specific expression of AtHKT1;1. *PLoS ONE*. **5(9):** 12571.

Rashed MRU, MR. Roy, SK. Paul and MM. Haque .2016. *In vitro* Screening of Salt Tolerent Genotypes in Tomato (*Solanum lycopersicum* L.). *Journal of Horticulture*. **3**: 186.

Rivero RM, TC Mestre, RO Mittler, F Rubio, FR Garcia-Sanchez and V Martinez. 2014. The combined effect of salinity and heat reveals a specific physiological, biochemical and molecular response in tomato plants. *Plant, Cell and Environment*.**37**: 1059-1073.

Rubio JS, Garcia F, Rubio F and Martinez V. 2009. Yield, blossom end rot incidence and fruit quality in pepper plants under moderate salinity area affected by K^+ and Ca^{2+} fertilization. *Scientia Horticulture*. 79-87.

Saure MC. 2001. Blossom-end rot of tomato (Lycopersicon esculentum Mill.) a calcium- or a stress related disorder. *Scientia Horticulturae.* **90**: 193–208.

Seid M, T. Genanaw. 2013. Evaluation of soil and water salinity for irrigation in North-eastern Ethiopia: Case study of Fursa small scale irrigation system in Awash River Basin, *AfricanJournal of Environmental Science and Technology*. **7(5)**: 167.

Selamawit K., J. Geleto, Y. Alemu, G. Wondimu, M. Hinsermu and T. Binalfew. 2017. Yield Stability and Quality Performance of Processing Tomato (*Lycopersicon esculentum* Mill) Varieties in the Central Rift Valley of Ethiopia.*International Journal of Research in Agriculture and Forestry*. **4**: 11-15.

Shannon, M.C. C.M. Grieve. **1998**. Tolerance of vegetable crops to salinity. *ScitiaHorticulturae. **78***: 5–38.

Shao X, M. Hou and J. Chen. 2013. Effects of EM-calcium spray on Ca uptake, blossom-end rot incidence and yield of greenhouse tomatoes (*Lycopersicon esculentum* L.). *Research on Crops.* **14**: 1159–1166.

Shao XH, Hou MM, Chen LH, Chang TT and Wang WN. 2012. Evaluation of Subsurface Drainage Design Based on Projection Pursuit. *Energy Procedia.* **16**: 747–752.

Siddiky M.A., P.K. Sardar, M.M. Hossain, M.S. Khan and M. Khabir Uddin. 2012.Screening of Different Tomato Varietiesin Saline Areas of Bangladesh. *International Journal of Agricultural Research. Innovation and Technology*. **2 (1)**: 13-18.

Sileshi A, Kibebew K and Amanuel Z. 2015. Temporal and Spatial variations in of salt-affected soils using GIS and Remote Sensing at Dubti/Tendaho state farm. *Ph.D. Dissertation thesis, Haramaya University, Ethiopia.*

Smolik M., P. Kram, M. Krupa-Małkiewicz, B. Smolik and K. Malinowska. 2011. Response of tomato genotypes to salinity stress assessed at the seedlings stage, *Electronic Journal of Polish Agricultural Universities*. **14(4)**:17.

Steppuhn H .2013. Sustainable Production of Crops Grown in Saline Root Zones, The *Canadian Society for Bioengineering*.**13**(19): 4-5.

Szabados L., S. Armould. 2009. Proline: a multifunctional amino acid. *Trends in Plant Science.* **15(2)**: 89-97.

Tal, M. 1984. Physiological genetics of salt resistance in higher plants. In: Staples, R.C., Toenniessen, G.H. (Eds.), Salinity Tolerance in Plants. *Wiley-Interscience, New York*. 301–320.

Tantawy, A. S., Abdel-Mawgoud, A. M. R., El-Nemr, M. A., and Chamoun, Y. G. 2009. Alleviation of salinity effects on tomato plants by application of amino acids and growth regulators. *European Journal of Science Research*.**30**: 484–494.

Taylor MD, SJ. Locascio, MR. Alligood. 2004. Blossom-end rot incidence of tomato as affected by irrigation quantity, calcium source, and reduced potassium. *HortScience*. **39 (5)**:1110–1115.

Turhan A, V. Seniz and H. Kuscu. 2009. Genotypic variation in the response of tomato to salinity, African *Journal of Biotechnology*. **8(6):**1062-1068.

Turhan, A., Seniz, V., and Kusc¸u, H. 2009. Genotypic variation in the response of tomato to salinity. *African Journal of Biotechnology*. **8**: 1062–1068.

Xu Z, G. Zhou and H. Shimizu. 2010. Plant responses to drought and dewatering. *Plant signaling and behavior*. **5**: 649-654.

Yokafi B, L. Tuna, B. Burun, H. Altunlu, F. Altan, C. Kaya. 2008. Responses of the Tomato (Lycopersicon esculentum Mill.) Plant to Exposure to Different Salt Forms and Rates. *Turkish Journal of Agriculture and Forestry*. **32**: 319-329.

Zaheer A, Sumera A, Abdulraziq B, Shaber A,Fazal M, Nazeer A, Manzoor A, Shahbaz K and Shah F.2017. Effect of halopriming on seed germination and seedling vigor of solanaceous vegetables. *Journal of natural science research*.7:9.

Zhai Y., Q. Yang and M. Hou. 2015. The Effects of Saline Water Drip Irrigation on Tomato Yield, Quality, and Blossom-End Rot Incidence. A 3a Case Study in the South of China. PLoS ONE **10(11)**: e0142204.

Zhang H, YK. Ye, SH. Wang, JP. Luo, J. Tang and DF. M. 2009. Hydrogen sulfide counteracts chlorophyll loss in sweet potato seedling leaves and alleviates oxidative damage against osmotic stress. *Plant Growth Regulation*.**58**: 243-250.

Zribi L, G Fatma, R Fatma, R Salwa, N Hassan and RM Nejib. 2009. Application of chlorophyll fluorescence for the diagnosis of salt stress in tomato "*Solanum lycopersicum L*. (variety Rio Grande)". *Scientia Horticulturae*. **120**:367- 372.

7. APPENDICES

Appendix Table 1 Analyses of variance for germination parameters as influenced by salinity levels and variety

Source of Variation	Degree of Freedom	Mean Square			
		Germination %	Seedling Vigor Index	Germination Index	Speed Germination Index
Block	2	110.5903	8620.91	27.1956	1.133803
Treatment	83	2280.9727***	359965.82***	2712.0668***	24.080964***
Salt	5	11648.0159***	2608091.55***	19840.463***	136.420154***
Variety	13	8610.6227***	1154918.54***	7058.5724***	81.802015***
Salt*Variety	65	294.5009***	28042.52***	525.1967***	3.895278***
Error	166	22.7138	3508.42	40.9447	1.240645
R-Square		0.98	0.98	0.97	0.90
Mean		53.59	552.54	65.97	3.95

Appendix Table 2 Analyses of variance for growth parameters as influenced by salinity levels and variety

Sources of Variation	DF	Mean Square									
		LN	LA	RFWt	SDM	RDM	PH	SFWt	RSDMR	YLD	PR
Block	2	2.186	1.632	0.832	6.061	0.186	43.314	3.048	0.0005	93.220	0.003
Treatment	11	1.431^{NS}	18.637^{***}	8.573^{***}	26.325^{***}	0.713^{***}	1104.186^{***}	2443.693^{***}	0.0003^{NS}	1025.429^{***}	0.040^{***}
Salt	5	2.494^{NS}	32.134^{***}	14.088^{***}	48.681^{***}	0.901^{***}	1652.318^{***}	4514.238^{***}	0.0002^{NS}	1716.256^{***}	0.082^{***}
Variety	1	0.023^{NS}	29.449^{***}	16.187^{***}	32.680^{***}	2.351^{***}	2292.814^{***}	1874.890^{***}	0.0005^{NS}	397.604^{***}	0.006^{***}
Salt*Variety	5	0.650^{NS}	2.977^{***}	1.535^{***}	2.698^{***}	0.196^{***}	318.328^{***}	486.909^{***}	0.0003^{NS}	460.166^{***}	0.006^{***}
Error	22	1.665	4.705	1.868	3.768	0.265	10.812	13.364	0.0003	155.822	0.0005
R-Square		0.350	0.667	0.700	0.784	0.584	0.980	0.989	0.614	0.769	0.974
Mean		10.100	23.725	9.108	28.058	4.600	114.629	129.572	0.164	199.841	0.663

DF= Degree of Freedom, LF= Leaf Number, LA= Leaf Area, RFWt= Root Fresh Weight, SDM= Shoot Dry Matter, RDM= Root Dry Matter, PH= Plant Height, SFWt= Shoot Fresh Weight, RSDMR= Root to Shoot dry matter Ratio, YLD= Yield, PR = Photosynthetic Rate

Appendix Table 3 Analyses of variance for cations concentrations as influenced by salinity levels and variety

Source of Variation	Degree of Freedom	Mean Square						
		Calcium	Potassium	Magnesium	Sodium	Phosphorus	Sulfur	Na^+/K^+
Salt	5	0.108^{***}	0.661^{***}	0.006^{NS}	0.053^{***}	0.001^{NS}	0.010^{***}	0.006^{***}
Variety	1	0.633^{NS}	0.106^{***}	0.002^{NS}	0.007^{***}	0.002^{NS}	0.055^{***}	0.000^{***}
Block	2	0.124	0.670	0.003	0.035	0.001	0.007	0.006
Treatment	11	0.168^{NS}	0.455^{***}	0.005^{NS}	0.032^{***}	0.001^{NS}	0.010^{***}	0.004^{***}
Salt*Variety	5	0.136^{NS}	0.319^{***}	0.004^{NS}	0.016^{***}	0.0005^{NS}	0.002^{***}	0.002^{***}
Error	22	0.149	0.242	0.006	0.0037	0.001	0.0033	0.0004
R-Square		0.39	0.542	0.29	0.837	0.27	0.641	0.849
Mean		3.447	3.532	0.785	0.331	0.182	0.403	0.097

Appendix Table 4 Correlation of yield, growth parameters and plant nutrients

	LA	YLD	RFWT	SDM	RDM	PH	PR	SFWT	RSR	Ca	K	Mg	Na	P	S	Na^+/K^+
LN	0.27^{ns}	0.38*	0.41*	0.31^{ns}	0.29^{ns}	0.33*	0.35*	0.38*	0.05^{ns}	0.31^{ns}	-0.11^{ns}	0.60***	-0.15^{ns}	-0.40*	0.27^{ns}	-0.08^{ns}
LA		0.30^{ns}	0.57*	0.58*	0.48*	0.42*	0.60***	0.65***	-0.01^{ns}	-0.01^{ns}	0.05^{ns}	0.10^{ns}	-0.44*	0.23^{ns}	0.31^{ns}	-0.44*
YLD			0.44*	0.49*	0.37*	0.32^{ns}	0.49*	0.49*	-0.01^{ns}	0.17^{ns}	-0.16	0.54*	-0.50*	-0.26^{ns}	0.44*	-0.36*
RFWT				0.68***	0.77***	0.41*	0.57***	0.66***	0.23^{ns}	-0.13^{ns}	0.02^{ns}	0.15^{ns}	-0.62***	-0.06^{ns}	0.47*	-0.54*
SDM					0.62***	0.53**	0.66***	0.77***	-0.30^{ns}	-0.21^{ns}	0.08^{ns}	0.07^{ns}	-0.72***	0.08^{ns}	0.56*	-0.65***
RDM						0.24^{ns}	0.44*	0.48*	0.56*	-0.02^{ns}	-0.10	0.08^{ns}	-0.48*	-0.05^{ns}	0.45*	-0.37*
PH							0.78***	0.47*	-0.26^{ns}	-0.33*	0.12^{ns}	-0.03^{ns}	-0.59***	-0.02^{ns}	0.18^{ns}	-0.57***
PR								0.69***	-0.15^{ns}	-0.24^{ns}	0.05^{ns}	0.06^{ns}	-0.56***	0.09^{ns}	0.25^{ns}	-0.50**
SFWT									-0.21^{ns}	-0.22^{ns}	0.17^{ns}	0.10^{ns}	-0.57***	0.13^{ns}	0.34*	-0.58***
RSR										0.31^{ns}	-0.10	0.60***	-0.15^{ns}	-0.40*	0.27^{ns}	-0.08^{ns}
CA											0.05^{ns}	0.10^{ns}	-0.45**	0.23^{ns}	0.31^{ns}	-0.44**
K												0.54***	-0.50**	-0.26^{ns}	0.44**	-0.36*
MG													-0.62***	-0.06^{ns}	0.47**	-0.54***
NA														0.11^{ns}	-0.46**	0.92***
P															0.17^{ns}	-0.12^{ns}
S																-0.42*

Na^+/K^+

LA= leaf area, YLD= fruit yield, RFWT= root fresh weight, SDM= shoot dry matter, RDM= root dry matter, PH= plant height, PR= photosynthetic rate, SFWT= shoot fresh weight, RSR= root to shoot ratio.

Appendix Figure 1Performance of varieties at the vegetative stages in the greenhouse