EFFECTS OF DIFFERENT ROOTSTOCKS ON PLANT GROWTH, DEVELOPMENT AND YIELD OF GRAFTED TOMATO (*Lycopersicon esculentum* Mill.)

DARLI WAI SOE

JULY 2017

EFFECTS OF DIFFERENT ROOTSTOCKS ON PLANT GROWTH, DEVELOPMENT AND YIELD OF GRAFTED TOMATO (*Lycopersicon esculentum* Mill.)

DARLI WAI SOE

A Thesis Submitted to the Post-Graduate Committee of the Yezin Agricultural University in Partial Fulfillment of the Requirements for the Degree of Master of Agricultural Science (Horticulture)

Department of Horticulture and Agricultural Biotechnology
Yezin Agricultural University
Nay Pyi Taw, Myanmar

July 2017

The thesis attached hereto, entitled **"Effects of different rootstocks on plant growth, development and yield of grafted tomato (*Lycopersicon esculentum* Mill.)"** was prepared and submitted by Darli Wai Soe under the direction of the chairperson of the candidate supervisory committee and has been approved by all members of that committee and board of examiners as a partial fulfillment of the requirements for the degree of **MASTER OF AGRICULTURAL SCIENCE (HORTICULTURE).**

Dr. Aye Aye Thwe
Chairperson of Supervisory Committee
Associate Professor
Department of Horticulture and
Agricultural Biotechnology
Yezin Agricultural University

Dr. Nyo Nyo
External Examiner
Professor and Head (Retd.)
Department of Horticulture and
Agricultural Biotechnology
Yezin Agricultural University

Daw Zar Zar Win
Member of Supervisory Committee
Assistant Lecturer
Department of Horticulture and
Agricultural Biotechnology
Yezin Agricultural University

Dr. Aye Aye Than
Member of Supervisory Committee
Assistant Lecturer
Department of Soil and Water Science
Yezin Agricultural University

Dr. Khin Thida Myint
Professor and Head
Department of Horticulture and Agricultural Biotechnology
Yezin Agricultural University

Date---------------------------------

This thesis was submitted to the Rector of the Yezin Agricultural University and was accepted as a partial fulfillment of the requirements of the degree of **MASTER OF AGRICULTURAL SCIENCE (HORTICULTURE).**

Dr. Myo Kywe

Rector

Yezin Agricultural University

Nay Pyi Taw

Date -----------------------------

DECLARATION OF ORIGINALITY

This thesis represents the original work of the author, except where otherwise stated. It has not been submitted previously for a degree at any other university.

Darli Wai Soe

Date -----------------------------

DEDICATED TO MY BELOVED PARENTS,

U KYI THEIN AND DAW SAN SAN WAI

ACKNOWLEDGEMENTS

Firstly, I would like to express my special gratitude to Dr. Myo Kywe, Rector, Dr. Soe Soe Thein, Pro-rector (Academic Affair) and Dr. Nang Seng Hom, Pro-rector (Administration), Yezin Agricultural University (YAU) for their kind permission and administrative support in the completion of this study.

I would like to extend my thanks to external examiner, Dr. Nyo Nyo, Professor (Retd.), Department of Horticulture and Agricultural Biotechnology, YAU for her kind support, critical reading and valuable suggestions for this thesis. I wish to extend my sincere thanks to Dr. Khin Thida Myint, Professor and Head, Department of Horticulture and Agricultural Biotechnology, YAU, for her kind suggestions and administrative support during my study program.

I wish to express my deepest gratitude to my supervisor, Dr. Aye Aye Thwe, Associate Professor, Department of Horticulture and Agricultural Biotechnology, YAU, for her skillful supervision, valuable advice, great understanding and inestimable support not only in research work but also in the preparation and critical check of this manuscript.

I acknowledge to my supervisory committee members, Dr. Aye Aye Than, Assistant Lecturer, Department of Soil and Water Science, YAU and Daw Zar Zar Win, Assistant Lecturer, Department of Horticulture and Agricultural Biotechnology, YAU, for their keen interest and constructive criticism in the preparation of this manuscript.

I would like to extend my thanks to Mitsubishi group, for finical support to conduct this research.

I would like to express special thanks to my friends for their cooperation in conducting experiments, sympathetic support, suggestions and sharing my stress in time of need and throughout the study period of master course.

I express great thanks from the bottom of heart to my elder sister, Ma Akari Phyo for her kind encouragement and moral support throughout my life.

Finally, but not the least, although words are not enough to, my greatest and heartfelt thanks to my beloved father, U Kyi Thein for his never-ending love, invaluable guidance, moral and financial support from the beginning of my life.

ABSTRACT

Use of grafted seedlings has become a widespread agricultural practice in many parts of the world. It is an important technique to improve crop production of vegetable crops such as tomato, watermelon, muskmelon etc. This study was undertaken to evaluate the effects of different rootstocks on performance of grafted tomato and to determine the suitable rootstock. In the experiment, local cultivars of eggplant (ခရမ်းပဒေသာ), hot pepper (ရမည်းသင်းမိုးထောင်) and tomato (ကျောက်မဲခေါင်းစိမ်း) were used as rootstocks and commercial tomato cultivar (Platinum 701) was used as scion. Three sets of experiments (two pot experiments and one field experiment) were conducted at the Department of Horticulture and Agricultural Biotechnology, Yezin Agricultural University from 2014 to 2016 using Randomized Complete Block Designs (RCBD) with 4 replications. Results indicated that all tested local types (eggplant, tomato and hot pepper) are feasible to use as rootstock for tomato production since the grafting success rate is over 70%. Leaf emergence rate (Plastochron day^{-1}) was faster and plant height was taller in the grafted plants than non-grafted plants. Increased photosynthesis efficiency with higher chlorophyll content leads to enhanced plant growth and reproductive developments of grafted tomato (0.81 and 58.7) compared with the non-grafted tomato (0.75 and 52.3). Marketable yields were also higher in the grafted tomato (4146.1 g plant^{-1}) than non-grafted tomato (2491.7 g plant^{-1}). Among the plants, grafted plants with rootstock of local eggplant produced the highest marketable fruit yield (5071.4 g plant^{-1}) followed by grafted plant with rootstock of local tomato (3894.3 g plant^{-1}) and local hot pepper (3472.6 g plant^{-1}). However non-grafted plants showed the lowest marketable yield (2491.7 g plant^{-1}) in field production. The results suggested that grafting on suitable rootstock has positive effects on plant growth and fruit yield of tomato and local eggplant rootstock was the most suitable rootstock for the grafted tomato.

Keywords- **tomato, rootstock, scion, growth, development, grafting**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is one of the most economically important vegetable crops and widely cultivated in the world. World production of fresh tomato for 2012 was about 161.8 million tons planted on 4.8 million hectares in 144 countries (FAOSTAT 2012). In 2012, tomato production was valued at 58 billion dollars and tomatoes were the eighth most valuable agricultural product worldwide. In Myanmar, tomato production for 2015 was 1,343,172 MT planted on 110,157 hectares. Tomato is consumed as fresh, cooked or processed into various products such as tomato paste (puree), sauces, juice, canned and dried tomatoes that are economically important processed products (Naika et al. 2005). Tomatoes contribute to a healthy, well-balanced diet. They are rich in vitamins A and C, iron, phosphorus, amino acids, sugars and dietary fibers.

Tomato is susceptible to numerous soil-borne diseases and abiotic stress that cause significant losses in vegetable yield every year (Rivard and Louws 2008). Root knot nematodes caused a 53% - 62% loss of yield in Bangladesh (Ali et al. 1994). European greenhouses have reported yield losses of up to 75% due to corky root rot (Hasna et al. 2009). In Japan, soil-borne diseases can cause loss of as much as 6% of the vegetables production (Oda 1999). Abiotic stresses limit production of many crops. These stresses include temperature, drought, nutrients, and salinity. Estimates of the effect of abiotic stress on global agriculture suggest that up to 70% of crop production is affected by environmental constraints (Cramer et al. 2011).

There are different ways to prevent soil-borne diseases such as crop rotation, breeding programs, soil fumigant (Rivero et al. 2003; Yetisir and Sari 2003). Difficulties in chemical control of these diseases, absence of crop rotation and sexual barrier between tomato and its wild relatives indicate that the only short-term practical solution of the problem. However, developing new cultivars resistant to diseases is time-consuming and enhances the chances of the resistant cultivars becoming susceptible to new races of pathogens.

Vegetable production by grafting on resistant rootstocks has become a common practice to control soilborne pathogens, especially for the cultivation of cucumber, melon, watermelon, tomato, pepper and eggplant in greenhouses in Japan, Korea, China and some other Asian and European countries (Lee 1994; King et al.

2008). Grafting vegetables is becoming popular; not only to control soilborne diseases but also to create a higher tolerance to abiotic soil stresses (Rivero et al. 2003). Grafting may enhance tolerance to abiotic stresses, increase yield, and result in more efficient water and nutrient use; extend harvest periods, and improve fruit yield and quality (Oda 2002; Lee and Oda 2003; Rivero et al. 2003; Hang et al. 2005). Grafting technology is a reliable alternative method for commercial tomato production where soilborne diseases, nematodes, flooding and various physiological disorders are prevailing (Win 2003).

Proper selection of rootstock is the key factor for higher fruit yield and quality of scion. Rootstocks are selected for their ability to resist infection by certain soilborne pathogens or their ability to increase vigor and fruit yield, and the expected level of vigor, relative to scion. The use of rootstocks offers many potential benefits, such as resistance to a wide range of pathogens in the soil, resistance to abiotic stress, and increased yield and fruit quality. However, grafted plants with weak rootstocks elicited lower yields than vigorous rootstock. The use of *Solanum torvum*as rootstock was reported to confer resistance to Verticillium wilt, Fusarium wilt, bacterial wilt and root knot nematode (King et al. 2008).

Tomato can be grown throughout the whole Myanmar where a shift from large scale agribusiness to smaller scale, localized growing can be seen and a large scale traditional hydroponics system is still being used today at Lake Inle. A serious problem of tomato cultivation in lowland area of Myanmar is a decrease in yield due to soilborne diseases, high rainfall and heat stress. Myanmar tomato production was limited by poor fruit set and lower fruit yield caused by high rainfall intensity in rainy season and heat stress in summer. Myanmar tomato farmers are facing problems due to the climate change which leads to outbreak of pests and diseases, physiological disorder, flooding, drought and heat stress. Grafting on the rootstocks with desirable traits is one of the problem solving methods to overcome these production problems of tomato. However, limited information on commercially available rootstock varieties and their combinations with popular scions is currently a major barrier to the wider application of grafting in commercial tomato production in Myanmar.

Therefore, the experiment was carried out with the following objectives:

(1) To evaluate the effects of different rootstocks on the growth and development of grafted tomato.

(2) To determine fruit yield of grafted tomatoes by using different rootstocks.

CHAPTER II
LITERATURE REVIEW

2.1 Effect of Grafting on Plant Behavior

2.1.1 Fruit yield

Eggplant grafted onto tomato rootstock showed improved yields as a result of increased fruit size and number compared to non-grafted controls (Passam et al. 2005). Grafting is associated with noticeable in tomato fruit yield as a result of increased fruit size (Augustin et al. 2002; Pogonyi et al. 2005). In oriental melons, fresh fruit weight increases of 25~55% have been reported as compared to own-rooted plants. Up to 54% increase in marketable yield was obtained with Kagemusia and 51% with Helper rootstocks in tomato (Chung and Lee 2007). The use of rootstocks to improve fruit yield is already a common practice for successful production of Cucurbitaceae (cucumbers, squash, and melon) at the open-ground cultivation during the cold seasons in Japan and Korea, when low soil temperatures may seriously affect the performance of seedlings or may even kill them (Lee 1994). Lee (1994) found an increase in yield which was attributed to the vigor of the rootstock and the higher uptake of water and nutrients.

2.1.2 Fruit quality

Fruit quality was affected due to the rootstock–scion interaction. This could induce the overgrowth and undergrowth of the scion, leading to important changes in water and nutrient flow uptake. The solutes associated with fruit quality are translocated in the scion through the xylem, whereas quality traits, e.g. fruit shape, skin color, skin or rind smoothness, flesh texture and color and soluble solids concentration are influenced by the rootstock (Nicoletto et al. 2012). Brix value (Total Soluble Solid, TSS) in the tomato is mainly sugars (fructose). Flavour is generally related to the relative concentrations of sugars and acids in the fruit, mainly fructose and citric acid. The best, most flavors some combination is a high sugar and high acid content. Flores et al. (2010) found that fruit from ‘Kyndia’, an indeterminate commercial cultivar, grafted onto ‘UC82B’, a determinate processing tomato known to have high soluble solid content, had higher TSS as compared to fruit harvested from self-grafted tomato plants.

The fruit size of watermelons grafted to rootstock having vigorous root systems is often significantly increased compared to the fruit from intact plants. It is also known that other quality characteristics, such as fruit shape and skin color, rind thickness, and soluble solids concentrations are influenced by rootstock (Cushman and Huan 2008).

2.2 Usage of Different Rootstocks

Rootstocks can improve resistance to diseases of the root system and they can impart tolerance to abiotic stress. Rootstocks can also restrict or enhance the uptake of specific nutrients, having higher ability to take up nutrients and others restricting specific transport. Santa-Cruz et al. (2002) suggested that grafting might be a valid technique for tomato under saline conditions. Grafting with tolerant rootstock is also effective at overcoming abiotic stresses such as salinity (Rivero et al. 2003; Estan et al. 2005; Cuartero et al. 2006), thermal stress (Abdelmageed et al. 2004), and excessive soil moisture (Black et al. 2003).

Rootstocks offer a potential solution to reduce the negative effects of high salt concentration and avoid damage by salinity (Venema et al. 2008). Estañ et al. (2005) demonstrated that grafting onto appropriate rootstock could reduce ionic stress. Grafting provides an alternative way to confer salt tolerance on the scion through the rootstock. Depending on the rootstock genotype, grafted plants may grow under conditions of heavy metal contamination by minimizing transport of heavy metals (Cu, B, Cr, Cd) into the fruit or leaves, using a mechanism of restricted uptake (Estañ et al. 2005; Arao et al. 2008; Savvas et al. 2009; Savvas et al. 2011).

The use of wild eggplant genotypes for rootstock in tomato production has also been well-documented (Matsuzoe et al. 1993). Wild eggplant rootstocks are resistant to bacterial wilt as well as root-knot nematodes. Similarly, grafting eggplant onto wild Solanum rootstock showed significant yield increases as compared to self-grafted controls (Ibrahim et al. 2001; Rahman et al. 2002). According to Rivard and Louws (2006), grafting with a disease resistant and highly vigorous rootstock is an important component in an integrated approach to manage soil borne disease and improve yields. The use of *Solanum torvum* as rootstock was reported to confer resistance to *Verticillium* wilt, Fusarium wilt, bacterial wilt and root knot nematode (King et al. 2008). Wild eggplant rootstock for tomatoes has allowed plants to cope with hot-wet seasons, including flooding, water logging and high temperature (Black et al. 2003; King et al. 2010). Rivero et al. (2003) grafted tomato onto a heat tolerant rootstock (*L. esculentum* cv. ‘RX-335’), and demonstrated resistance to high temperatures which resulted in superior plant biomass in grafted plants compared to non-grafted plants.

Grafting onto resistant rootstocks has the potential to address concerns about chemical use while increasing production efficiency (McAvoy et al. 2012). Currently, interest in breeding for improved rootstock is increasing rapidly in the private sector due to cost effectiveness and expanded diseases resistance (King et al. 2010).

2.3 Grafting Method

Selecting the most appropriate grafting technique must take considerations for the rootstock, plant maturity, quantity of plants to graft, environmental control and healing structure. There are three main grafting techniques used in tomato: splice grafting, slide grafting and cleft grafting.

Splice grafting is also known as slant-cut grafting, tube grafting or top grafting (Oda 1999; Rivard and Louws 2006; Oda 2007; Sakata et al. 2007). This technique allows plant material to be grafted at a younger age with seedlings grafted when the stem is 1.5-2 mm in diameter and plants have developed 2-4 true leaves (Rivard and Louws 2006; Kubota et al. 2008). Rootstock and scion are grafted at 45º angles and held together with a grafting clip. The rootstock is cut at a 45º or greater angle below the cotyledons to prevent adventitious shoot formation from the rootstock (Bausher 2011). Steeper angled cuts maximize surface area resulting in greater pressure between scion and rootstock, more contact between vascular bundles, and thus higher survival. Splice grafting is the most commonly used technique for producing large numbers of grafted plants, as it is possible to graft plants 2-3 times faster and at a younger age than other methods (Oda 1999; Oda 2007; Rivard et al. 2010). When grafting large quantities of plants, grafting when plants are smaller in size maximizes space usage in healing chambers and greenhouses thereby reducing costs (Oda 2007; Kubota et al. 2008). Nearly all commercial tomato grafting and most eggplant grafting operations are done using the splice grafting technique (Oda 1999; Oda 2007; Rivard et al. 2010). However, splice grafting can have low survival rates if the healing environment is not optimal. Obtaining high survival with this technique requires that the graft union be secured by a grafting clip and healed in a high humidity environment such as a healing chamber (Sakata et al. 2007).

The major advantage of side grafting is that this method is more forgiving of differing stem diameters than top grafting. The disadvantage of side grafting is that it is more time-consuming to complete an individual graft and requires more materials and labor intensive than splice grafting. Plants are ready to graft approximately 17–21 days after sowing. Larger seedlings are generally used for side grafting because it is easier to make the necessary incisions on a larger stem. With a larger seedling, there is also more surface area for the tissue from the separate plants to connect.

In tomato, “cleft grafting” has high success (Oda 1995), but this method is labor intensive. Prior to grafting, Oda (2007) recommended that exposing the scion and rootstock plants to sunlight and with holding water for 2 to 3 days prior to grafting to avoid spindly growth which can decrease graft success. During the grafting process, environmental conditions that increase transpiration rate such as direct light and wind should be avoided (Rivard and Louws 2006; Oda 2007). Plants must be handled quickly during the grafting procedure, since desiccation at the cut graft surface could be fatal.

Many grafting automatic robots were developed outside of Japan and Korea in the early 2000s. There are two types of robots: fully automated and semi automated. Semi automated machine was the first model that can graft both cucurbits and tomato. This machine was widely marketed in Asia and North America. This machine takes 650 - 900 grafts per hour at 95% or better success rate and needs 2-3 workers to assist the machine. Fully automated machine was introduced in Japanese market in 2009. This machine takes 800 grafts per hour at 95% or greater success rate and need one worker to assist the operation.

2.4 Advantages of Tomato Grafting

Grafting is one of the techniques to solve some of the aforementioned problems existed in tomato. Tomato growers adopted grafting as a way to manage root diseases and increase fruit production. Although in the beginning, tomato grafting was adopted to limit the effects of Fusarium wilt (Lee 1994); the reasons for grafting have increased dramatically over the years. The use of grafted plants under excessively high temperatures may offer an advantage over non-grafted plants in terms of resistance against thermal shock. Moreover, many researchers reported that an interaction between rootstocks and scions exists resulting in high vigor of the root system and greater water and mineral uptake leading to increased yield and fruit enhancement (Leoni et al. 1990; Lee 1994; Oda 1995; Bersi 2002; Ioannou and Hadjiparaskevas 2002; Marsic and Osvald 2004).

Grafting has been used widely in the production of tomatoes, in order to diminish damage by soil pathogens (Lee 1994) and, more recently, grafts have been used to induce resistance against low (Venema et al. 2008) and high temperatures (Rivero et al. 2003; Abdelmageed and Gruda 2009), against iron chlorosis in calcareous soils, to enhance nutrient uptake (Ruiz and Romero 1999), to increase synthesis of endogenous hormones (Proebsting et al. 1992) and to optimize water use (Cohen et al. 2002). Grafting tomatoes can improve production, overall crop health and vigor, reduce or eliminate the need for pesticide use, lengthen harvest duration, and significantly increase net income.

2.5 Control Management of Soilborne Disease

Grafting has become popular more recently in Mediterranean tomato growing regions, where it has been adopted as a major component of an integrated program to manage soilborne pathogens (Bletsos 2005; Besri 2007). Grafting has been an important method in Asian tomato production to manage bacterial wilt incidence in solanaceous crops. Grafting vegetable crops have been used extensively in greenhouse and tunnel productions as a way to decrease reliance on chemical fumigants (Oda 1999).

The use of grafted tomato for commercial production in Asia is important because soil-borne disease pressure is high (Rivard and Louws 2006). By grafting tomatoes, New Zealand producers were able to reduce the level of corky root rot, caused by *Pyrenochaeta lycopersici*. In Morocco, grafting is used commercially to control root-knot nematodes and other soil-borne diseases in over 2000 ha of greenhouse tomato, melon, and watermelon (Bersi 2002). Grafting with resistant rootstock has been successful against root-knot nematodes (*Meloidogyne incognita*) for cucumbers in Greece (Giannakou and Karpouzas 2003).

2.6 Incompatibility

Grafting compatibility is the ability of two plants (scion and rootstock) to grow successfully and reproduce as a single plant after they are joined. The normal growth of a grafted plant may be interrupted at any stage of development due to incompatibility between scion and rootstock. Graft incompatibility could be directly related to undergrowth or overgrowth of the scion relative to the rootstock (Lee 1994). Physiological incompatibility can result from a failure of recognition of the cells of scion by the cells of rootstock, a failure of response between the cut surface of rootstocks and the scion, or the effect of growth substances or toxins (Andrews and Marquez 1993). The rootstock is the portion of the plant that controls the uptake, synthesis, and translocation of water and minerals from the soil and the scion must be able to transport and use what the rootstock delivers (Lee and Oda 2003). A low or incorrect callus formation between the rootstock and scion could lead to defoliation, reduction of scion growth and low survival of grafted plants (Oda et al. 2005; Johkan et al. 2009). Thus, the vascular connection in the rootstock–scion interface may determine water and nutrient translocation, affecting other physiological traits.

The perfect combination of stock and scion results in a successful plant that can respond to both abiotic and biotic stress in a given environment without decreasing yield or fruit quality. Grafting vegetable scions onto a rootstock of its own species is common because intraspecific compatibility is often very high (Black et al. 2003; Rivard and Louws 2008). Intraspecific grafting has been shown to increase resistance to various environmental pressures such as flood, drought, cold, heat and pathogen stress, however in some cases the transferred tolerance is not strong enough, or a certain desired environmental tolerance does not yet exist within the rootstock germplasm of that species (Venema et al. 2008).

2.7 Factors Influencing on Grafting Success

The success or failure of grafting depends on various factors including taxonomy, environment, availability of oxygen and water, physiological stage of rootstock/scion, herbicide toxicity, the skill of the grafter, mechanical damage of the graft union, and graft incompatibility (Andrews and Marquez 1993). Many other factors influence grafting success, including post-grafting environmental conditions, plant vigor, carbohydrate content, and the proper match of vascular bundles (Bisognin et al. 2005).

Proper acclimatization is critical for grafted plants to survive. Acclimatization involves healing and hardening for field survival (Lee and Oda 2003). Maintenance of proper moisture content before and after grafting is critical for the production of uniform grafted seedlings. Acclimatization may be achieved simply by enclosing the rootstock and scion in a black plastic bag (to avoid heat build-up) until the union is formed. Growers usually achieve acclimatization by use of plastic film coverings. Successful grafting requires high relative humidity and optimal temperatures during the healing period to reduce transpiration of the scion until rootstock and scion vascular tissue are healed together and water transport is restored. The grafted plants are placed on a healing chamber and the trays are sealed with a single layer of semi-transparent high density polyethylene film (0.01 mm or thinner) to reduce the moisture loss and kept sealed for 5–7 days without additional irrigation in commercial nurseries. Partial shading may be needed during the daytime to avoid excessive heat build-up.

2.8 Contamination during Grafting

The grafting process also presents inherent risks, particularly in the transmission of mechanically transmissible plant pathogens. The razor blade used to cut the rootstock or scion was first contaminated by making a single cut on tomato plants infected with either Tomato spotted wilt virus *(TSWV) or* Tomato mosaic virus *(ToMV*).

2.9 Historical and Current Status

Cucurbit and solanaceous crops have been grafted for over a century to increase disease resistance, tolerance to environmental stresses, and vigor. Eggplant was first grafted commercially in the 1950s to *Solanum aethiopicum.* Commercial tomato grafting began in Japan in the 1960s. There is an account of experimental grafting of solanaceous vegetables onto solanaceous weeds in the southeast U.S. Increasing numbers of growers in Japan and Korea began to adopt vegetable grafting, expanding the acreage of grafted eggplant, tomato, and watermelon steadily through the mid to late 1900s. By the 1980s, grafted plants accounted for 57% of the total eggplant, tomato, and watermelon production area in Japan (Lee 1994). In Japan during this time, over 90% of greenhouse-produced eggplant and watermelon were grafted, and 57% of the eggplant and 41% of the tomato in open field production were produced with grafted transplants (Lee 1994; Oda 2007).

Currently in Japan, 55% of the total eggplant production, 40% of the total tomato production, and 92% of the total watermelon production are with grafted plants. In South Korea, 20% of the total eggplant production, 25% of the total tomato production and 95% of the total watermelon production is with grafted plants (Lee et al. 2010). Grafting is especially popular for tomato, eggplant, and cucurbit production in Asia. In 1998, 540 million transplants were grafted in Korea and 750 million in Japan (Lee et al. 1998). Growers initially adopted grafting to manage high soilborne disease pressure that resulted from continuous cropping in greenhouse production or intensively managed agricultural land. In North America, grafted tomatoes have been used mainly in greenhouse production in Canada, in open field production in Mexico, and by some small-scale diversified vegetable growers in the U.S. using high tunnels. Current issues in producer adoption increased labor costs are one of the major barriers to producer adoption of grafted vegetable transplants (Kubota et al. 2008; Rivard et al. 2010).

In the U.S., where abundant agricultural land allows for more crop rotation and labor costs are high, these issues are even greater. However, as soil fumigants become increasingly expensive and regulated, interest in grafting has grown, and researchers are now striving to increase grafting efficiency and decrease labor costs (Rivard et al. 2010). Grafting requires increased labor and time investment at the beginning of the growing season. Grafting robots have been utilized in Asia and Europe since the 1990s to automate the grafting process and reduce labor costs. These machines have not been widely adopted by growers, as they are expensive and are unable to discern differences in rootstock and scion stem diameter and graft cut angle (Rivard and Louws 2006). Grafting robots can break down and require repairs during the crucial times when plants are at optimal stages for grafting. Furthermore, replacement parts and skilled mechanics capable of fixing the robots are mainly located in Europe and Asia, thus break downs can prevent robots from grafting for significant amount of time (Kubota et al. 2008).

A large plant propagation company that produces most of the grafted tomato transplants for the hothouse tomato industry in western North America found that skilled workers produced higher quality grafted plants than grafting robots and were capable of grafting approximately 300 tomato plants per person per hour. Japan and Canada have wage rates similar to the U.S., and manual grafting can be cost effective if the grafting process is divided among skilled workers in an assembly line process.

Although the possibility and benefits of using grafted plants were recognized much earlier, large-scale commercial growing of grafted vegetables can be traced from the late 1950s to the early 1960s in Japan and Korea. In solanaceous vegetables, 20~40% of tomatoes are grafting, 20~40% of eggplants, and 5~10% of capsicum peppers. Since grafting is mostly practiced in cucurbits and solanaceous vegetables, the percentages of grafting in all vegetables was only about 5% in 2007. More than 700 million grafted seedlings were estimated to be produced in 2008 in Korea as well as in Japan.

In Myanmar, the use of grafted plants in tomato production is not very common. Win (2003) has shown the graft success of tomato plants by using different eggplant cultivars. He used different types of eggplant rootstocks (Khayan padae tha , Khayan gyut, Eggplant M_4, Khayan kazawk) and it was resulted that all type rootstocks of eggplant can be used in tomato grafting. However, it is still necessary to select the suitable rootstock for better plant growth, development and crop yield not only in eggplant but also in other solanaceous crops.

CHAPTER III
MATERIALS AND METHODS

3.1 Experimental Site and Period

Three sets of experiments (two pot experiments and one field experiment) were conducted at the Department of Horticulture and Agricultural Biotechnology, Yezin Agricultural University from 2015 to 2016. Experiment I was carried out from May to September 2015, experiment II was carried out from October 2015 to February 2016 and experiment III was carried out from April to August 2016.

3.2 Experimental Design

A Randomized Complete Block Design (RCBD) with four replications was applied. Three different types of local cultivars; eggplant (Khayan pa dae tha - ခရမ်းပဒေသာ), tomato (Kyaught Me Gaung Sein- ကျောက်မဲခေါင်းစိမ်း) and hot pepper (Yemethin Moe Htaung- ရမည်းသင်းမိုးထောင်) were used as stock plants and commercial tomato cultivar (Platinum 701) was used as scion in all experiments. The general characteristics of three rootstock types were described in Plate 1. The treatments are as follows:

T_1-Commercial tomato cultivar grafted onto local eggplant cultivar

T_2-Commercial tomato cultivar grafted onto local tomato cultivar

T_3-Commercial tomato cultivar grafted onto local hot pepper cultivar

T_4-Non-grafted tomato (control, commercial tomato cultivar)

3.3 Seed Sowing and Grafting

Well decomposed cow dung manure, burned rice husk and garden soil at the ratio of 1:1:1 by volume were thoroughly mixed for the soil medium. The soil medium was filled into the seed tray and seeds of tomato, eggplant and pepper were sown separately in the well prepared plastic seed tray. Time of seed sowing for rootstocks and scion were adjusted in order to get the same diameter of stock and scion (Appendix 1). Hot pepper seeds were sown two weeks earlier than the seed of tomato to ensure the same diameter with rootstock and scion. In the same way, eggplant seeds were sown one week earlier than tomato (Appendix 1). Seeds were watered daily until the time of grafting. One month after sowing, the seedlings had grown to an appropriate grafting size (1-1.5 mm) with 2-3 true leaf stage.

Rootstocks (Local)	General Performance

Rootstocks (Local) **General Performance**

Name - eggplant (Khayan pa dae tha-
ခရမ်းပဒေသာ)

Resistant against diseases and hardy to environmental stress (flooding, heat or salinity).

Name - tomato (Kyaught Me Gaung
Sein - ကျောက်မဲခေါင်းစိမ်း)

Adaptable to local climatic conditions and widely cultivated in Nay Pyi Taw region.

Name - hot pepper (Yemethin Moe
Htaung - ရမည်းသင်းမိုးထောင်)

Tolerance to temperature, soilborne disease, adaptable to most local climatic conditions and widely cultivated in Nay Pyi Taw region.

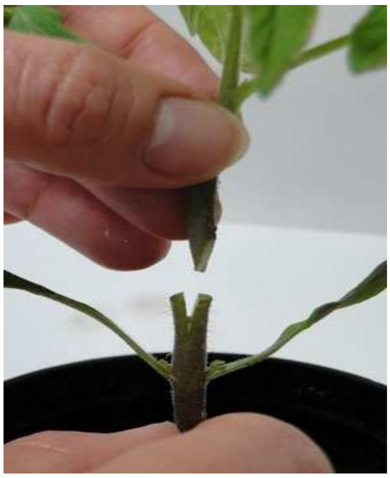
Plate 1. General characters of selected rootstocks

Stage 1. Horizontal cut made in both scion and rootstock

Stage 2. Longitudinal cut made on rootstock plant

Stage 3. Trimming of leaves and making wedge on scion plant

Stage 5. Hold the joint of stock and scion with rubber tube



Stage 4. Wedge side of scion placed in longitudinal cut of rootstock

Plate 2. Stages of cleft grafting method in tomato grafting

Stage 1. Grafting

Stage 2. Healing

Stage 3. Transplanting

Plate 3. Procedure of the experiment

3.4 Procedure of the Grafting

Wedge and cleft grafting method was used in all experiments because it is the most commonly used method for solanaceous crops (Lee and Oda 2003). Razor blade and rubber tube were used to perform the grafting.

Stage 1: The rootstock was cut below the cotyledon using razor blade.

Stage 2: The longitudinal cut was prepared about 1.5 cm depth from the 1^{st} cut.

Stage 3: The scion was pruned to 1-2 leaves and the lower stem was prepared to get a tapered wedge that should be the same with cleft portion of the rootstock.

Stage 4: The rubber tube was put to the stock portion in order to hold the scion tightly and improve stability.

Stage 5: The scion was inserted into the cleft portion of the stock by holding with rubber tube.

If one sided open rubber tube is used, the wedge scion is inserted into the cleft stock first and the graft union is held with one sided open rubber tube after the insertion. For all experiments, the type of rubber tube was the same with the one that are normally used in bicycle (Plate 2).

Grafting was carried out in a shady place to avoid the wilting of the grafted plants. After grafting, as indicated by Marsic and Osvald (2004) the grafted plants were maintained under the chamber at 28–30°C with more than 95% relative humidity for three days to get better healing and enhance the survival rate. A healing chamber was constructed with bamboo to form a dome in the nursery house. The first layer of the whole dome was covered with clear plastic and the second layer was with green net (Plate 3). High relative humidity was maintained by spraying with water around the plants three times daily. Then, the green net and plastic were gradually removed 7 days after grafting in order to increase light and lower humidity. Grafted plants were sprayed with water to improve the survival of plants.

3.5 Transplanting

Successful grafted plants were transplanted to the plastic bags and they were kept in the nursery. The grafted tomato seedlings were nursing in the nursery for one week before transferring to the field. The seedlings were thoroughly watered before transplanting to the field. The plants were transplanted into plastic bags filled with the mixture of compost, cow dung and burnt rice husk at the ratio of 1:1:1 by volume in experiment I and II. In experiment III, grafted plants were transplanted to the well prepared field directly.

3.6 Field Management Practices

Before sowing, Triple super phosphate and poultry manure were applied at a rate of 100 kg $ha^{-1}$and 20 t ha^{-1}respectively as basal application. Furadan was used during land preparation to control insects in the soil. Tomato plants were watered daily until they had recovered (one week after transplanting). After one week, the plants were watered necessarily. Weeding was done regularly, 1 or 2 days before every fertilizer application as side dressing.

As side dressing, the recommended rate of the inorganic compound fertilizer was applied 5 times at 10- day interval after transplanting. Foliar fertilizer (Comet Plus) was applied weekly starting from flowering stage to harvest at the rate of 500 g ha^{-1}.

Pests and diseases were controlled by the alternate application of recommended chemicals. Each plant was supported with bamboo stick to keep the tomato vine upright. Main tomato stem was loosely tied to the stick with the string.

3.7 Data Collection

The following growth parameters were recorded from five randomly selected plants from each plot at three days interval after transplanting.

1. Graft success rate (%)
2. Plant height (cm)
3. Stem diameter (cm)
4. Number of leaves
5. Leaf emergence rate
6. Number of days to 1^{st} flowering and
7. Fruit setting percent

At the time of harvest, final plant height (cm), number of branches per plant, number of truss per plant, number of flowers per truss, number of fruits per plant and number of days to harvest, single fruit weight (g), fruit diameter (cm), fruit weight per plant (g), total yield (t ha^{-1}) and brix value (%) were collected.

Graft success rate (%) was recorded three days after grafting. It was calculated by the following formula.

$$\text{Graft success rate} = \frac{\text{Number of success plants}}{\text{total plants}} \text{x}100$$

Field survival rate (%) was evaluated on seven days after transplanting. It was calculated by the following formula.

$$\text{Field survival rate} = \frac{\text{Number of survival plants}}{\text{total plants}} \text{x}100$$

Plant height (cm) was recorded in centimeter by measuring the height of sample plants from the ground level to the main apex.

Number of leaves per plant was counted on the number of expanded leaves from the main stem.

Stem diameter (cm) was measured the diameter of the plant just above the graft union by vernier caliper.

Leaf emergence rate was noted by measuring the youngest leaf (<2cm).It was calculated by the following formula (Erickson and Michelini 1957).

$$\text{PI} = \text{n} + \frac{\text{Log Ln} - \text{Log R}}{\text{Log Ln} - \text{Log Ln} + 1}$$

PI = Plastochron index

n = The serial number counting from the base, of that leaf longer than reference leaf

Ln = Leaf length that is greater than the reference leaf (R)

R = Length of the reference leaf (e.g. 10 mm)

Ln + 1 = The length of the leaf that is younger than leaf (Ln)

Number of branches per plant was noted on the number of primary branches arising from the main stem. It was counted at the maturity stage.

Chlorophyll content was measured by SPAD meter. The SPAD-502 Plus determined the chlorophyll concentration by measuring the leaf absorbance in red and near-infrared regions.

Photosynthesis efficiency was measured using Fluoro Pen FP 100 meter. Selected fully developed youngest leaves from the sample plants were dark-adapted for 30 min before starting the measurements using leaf clips provided by the manufacturer.

Days to 1st flower initiation was recorded by counting the number of days from the date of transplanting to first flowering.

Number of flowers per inflorescence was counted the number of flowers from each truss of lower, middle and upper cluster.

Number of flowers per plant was recorded as the total number of open flowers per plant.

Total number of fruits per plant was collected the number of fruits from each plant.

Fruit set (%) was calculated by the following formula.

$$\text{Fruit set } \% = \frac{\text{Number of fruits per plant}}{\text{Number of flowers per plant}} \text{ x } 100$$

Fruit diameter was measured the widest portion of the fruit by vernier caliper.

Brix value was recorded by reading with the refractometer. Tomato fruits were picked when the mature fruit begins to show red color.

3.8 Statistical Analysis

Analysis of variance was calculated by using SAS 9.1. Mean comparison was performed with the least significant difference (LSD) at 5 % level.

CHAPTER IV
RESULTS

4.1 Evaluation on Graft Success Rate and Field Survival Rate

The graft success rate and field survival rate of grafted tomato on different rootstocks are presented in Table (4.1). The survival rates of grafted tomato were evaluated on seven days after grafting (DAG). The results showed that the success rate of grafted tomato on all rootstocks ranged from 70 to 90%. In all experiments (Expt.I, Expt.II and Expt. III), grafted plant on eggplant rootstock showed the highest graft success percent (81.7 %, 89.0 % and 87.3 %), grafted tomato on tomato rootstock was the second (80.4 %, 79.0 % and 80.3%) and hot pepper rootstock was the third (72.2 %, 72.5 % and 70.7 %) in all experiments.

The percentages of surviving plants among the treatments were determined from seven days after transplanting up to the last harvest. The results showed that the maximum field survival rate was obtained from grafted tomato on eggplant rootstock in all experiments (91.6 %, 95.8 % and 92.7%). The minimum field survival rate was obtained from non-grafted tomato in all experiments (71.4%, 75.6 % and 74.5 %).

4.2 Effects of Different Rootstocks on Plant Growth and Reproductive Parameters of Grafted Tomato (Expt. I, Pot Experiment)

4.2.1 Plant height

The plant height of grafted and non-grafted plants is shown in Figure 4.1. No significant difference was observed at an early growth stage. Starting from 30 days after grafting (DAG), significant difference was observed. Starting from 30 DAG, grafted tomato on eggplant rootstock was the tallest and it was significantly taller than the others.

4.2.2 Number of leaves

Effect of different rootstocks on the number of leaves is shown in Figure 4.2. Significant difference was observed between the grafted and non-grafted tomato at the later plant growth stage. At 50 DAG, the number of leaves of grafted tomato on eggplant rootstock (14) was significantly higher than that of the hot pepper (11.8), tomato rootstock (11.1) and non-grafted tomato (11).

Table 4.1 Comparison of graft success rate and field survival rate among the rootstocks in all experiments

Rootstock type	Graft success rate (%)			Field survival rate (%)		
	Expt. I	Expt. II	Expt. III	Expt. I	Expt. II	Expt. III
Eggplant	81.7	89.0	87.3	91.6	95.8	92.7
Tomato	80.4	79.0	80.3	89.5	92.6	89.5
Hot pepper	72.2	72.5	70.7	78.6	81.9	79.8
Non-grafted	-	-	-	71.4	75.6	74.5

Table 4.2 Comparison of growth parameters of the grafted and non-grafted plants as affected by different rootstocks (Expt. I)

Rootstock type	No. of branches	Days to 1st flowering	Days to 1st harvesting
Eggplant	3.3 a	52.0 b	86.0 c
Tomato	3.1 a	50.6 b	86.9 b
Hot pepper	2.4 b	51.0 b	91.3 a
Non-grafted	2.4 b	55.0 a	93.0 a
Pr>f	**	**	**
$LSD_{(0.05)}$	0.5	1.7	4.1
CV (%)	10.8	2.1	3.1
Contrast analysis of grafted vs. non-grafted			
Grafted	3.1	51.2	88.1
Non-grafted	2.4	55.0	93.0
Pr>F	**	**	**

Means in the same column followed by the same letter are not significantly different at $P \leq 0.05$. * = Significant at P (0.05) ** = Highly significant at P (0.01) ns = Not significant

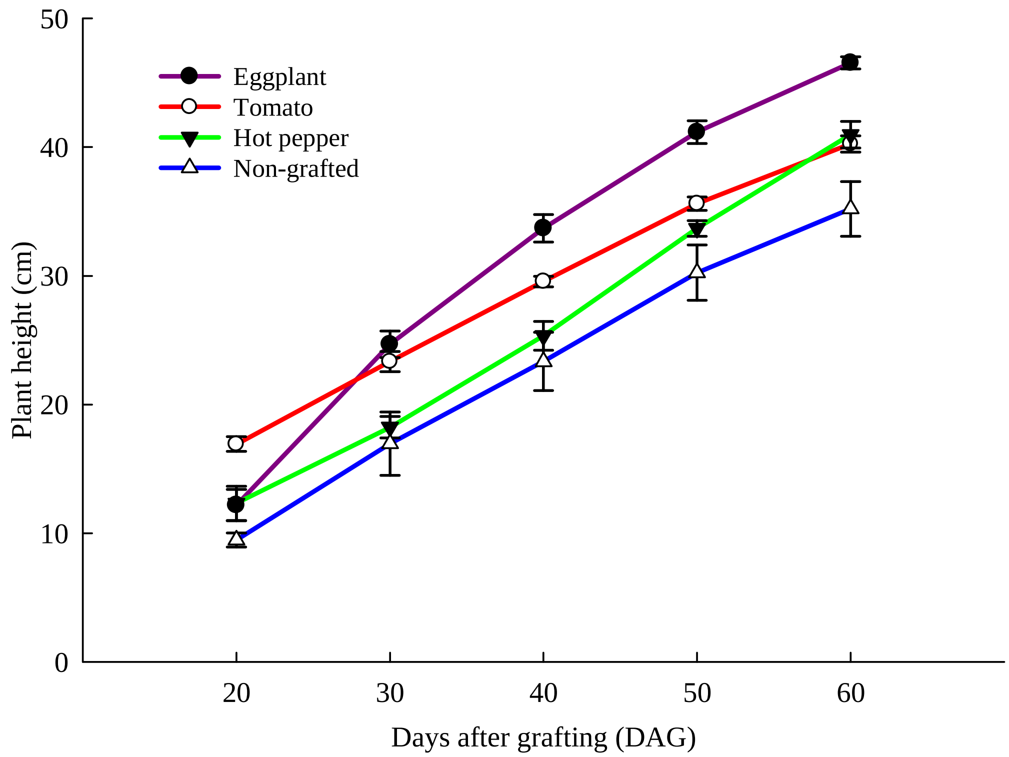


Figure 4.1 Comparison of plant height among the treatments (Expt. I)

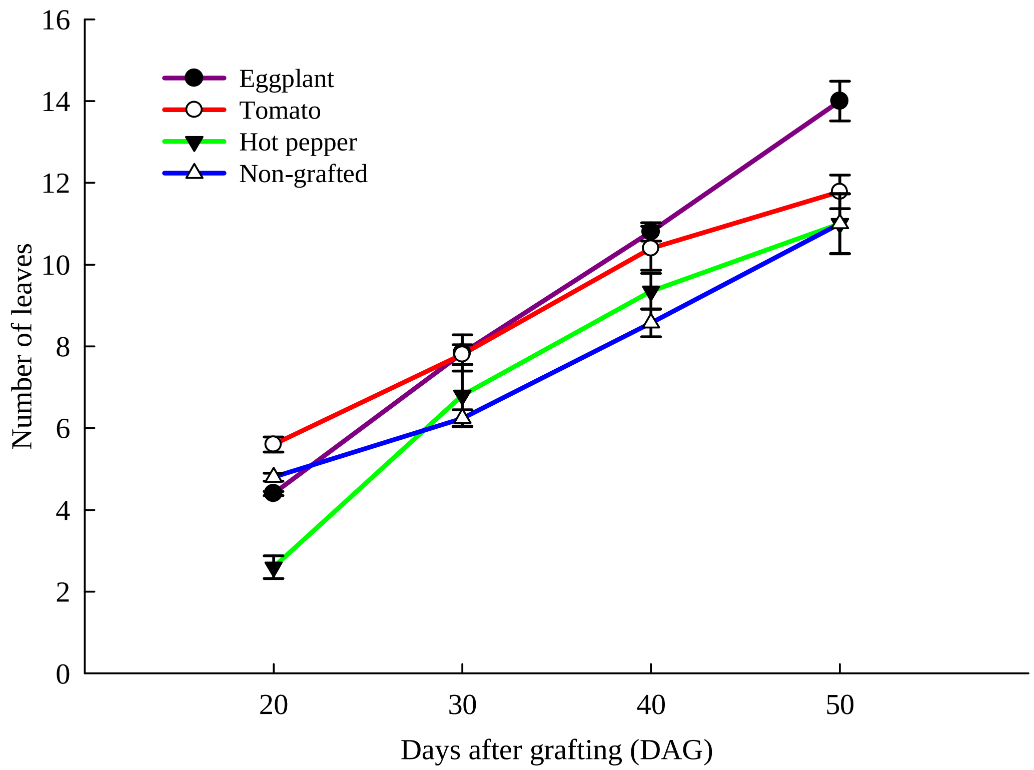


Figure 4.2 Comparison of the number of leaves among the treatments (Expt. I)

Table 4.3 Comparison of yield and yield components parameters of grafted and non-grafted plants as affected by different rootstocks (Expt. I)

Rootstock type	No. of truss plant^{-1}	No. of flowers truss^{-1}	No. of fruits truss^{-1}	Fruits set (%)	No. of fruits plant^{-1}	Single fruit weight (g)	Fruit yield plant^{-1} (g)	Total yield (t ha^{-1})
Eggplant	9.3	9.6 b	4.8 a	45.8 a	23.6 a	34.1 a	805.5 a	1.9 a
Tomato	9.3	11.6 ab	4.1 ab	44.7 a	21.6 b	31.2 b	673.8 b	1.6 b
Hot pepper	8.4	13.4 a	3.3 bc	45.5 a	21.2 bc	31.5 b	666.2 b	1.6 b
Non-grafted	8.4	13.7 a	3.0 c	43.9 a	20.3 c	26.2 c	530.1 c	1.3 c
Pr>f	ns	*	**	ns	**	**	**	**
$LSD_{(0.05)}$	2.6	2.8	1.0	3.6	1.1	2.4	70.1	0.2
CV (%)	18.8	15.1	17.5	5.2	3.1	5.1	6.8	6.8
Contrast analysis of grafted vs. non-grafted								
Grafted	9.0	11.5	4.1	45.3	22.1	32.3	715.5	1.7
Non-grafted	8.4	13.7	3.0	43.9	20.3	26.2	530.1	1.3
Pr>F	ns	ns	*	ns	**	**	**	**

Means in the same column followed by the same letter are not significantly different at P≤0.05

* = Significant at P (0.05) ** = Highly significant at P (0.01 ns = Not significant

4.2.3 Number of branches

Table 4.2 describes the effects of different rootstocks on branch number of grafted and non-grafted tomato. The number of branches of grafted tomato using eggplant rootstock and tomato rootstock were significantly higher than that of the hot pepper rootstock and non-grafted tomato. Maximum number of branch was observed in grafted tomato using eggplant rootstock (3.3) followed by tomato rootstock (3.1), hot pepper rootstock (2.4) and non-grafted tomato (2.4).

4.2.4 Days to 1st flowering

The days taken to 1st flowering was significantly affected by the use of different rootstock (Table 4.2). Grafted plants produced flowers earlier than that of non-grafted plants however; there was no significant difference among the rootstocks. The earliest flowering was observed in grafted tomato on tomato rootstock (50 days) followed by hot pepper rootstock (51 days) and eggplant rootstock (52 days).The latest flowering was found in non-grafted tomato (55 days).

4.2.5 Number of truss per plant

Effect of different rootstocks on the number of truss per plant is shown in Table 4.3. Rootstock type had no significant impact on the number of truss per plant of grafted and non-grafted tomato. However, the number of truss per plant of grafted tomato on eggplant rootstock was numerically greater than that of non-grafted tomato. The highest numbers of truss per plant were observed in grafted plant on eggplant and tomato rootstock (9.3, 9.3). The lowest numbers of truss per plant were observed in hot pepper rootstock (8.4) and non-grafted tomato (8.4).

4.2.6 Number of flowers per truss

Effect of different rootstocks on the number of flowers per truss is shown in Table 4.3 Number of flowers per truss of grafted tomato varied significantly depending on the use of rootstock type. Non-grafted tomato produced the highest number of flowers per truss and it was significantly higher than that of eggplant rootstock. Among the rootstocks, number of flowers per truss of grafted tomato on hot pepper rootstock (13.4) was the highest, followed by tomato rootstock (11.3) and eggplant rootstock (9.6).

4.2.7 Fruit setting percentage

Effect of different rootstocks on fruit setting percent of grafted tomato is described in Table 4.3. There was no significant difference in fruit setting (%) among the treatments. Fruit setting percent of grafted plants (45.3%) was relatively greater than that of non-grafted plants (43.9%) though they are not significantly different. Among the rootstocks, the highest fruit setting was resulted in grafted tomato on eggplant rootstock (45.8%) followed by hot pepper rootstock (45.5%) tomato rootstock (44.7%), and non-grafted tomato (43.9%).

4.2.8 Number of days to 1^{st} harvesting

High significant difference of the number of days to 1^{st}harvesting was observed in different rootstocks as shown in Table 4.2. Number of days to 1^{st} harvesting was significantly affected by the types of rootstocks. Grafted tomato showed earlier harvesting than that of non- grafted tomato. Earliest harvest was occurred in grafted tomato on eggplant rootstock (86 days) and followed by tomato (87 days) and hot pepper (91 days). The latest harvest was found in non- grafted tomato (93 days). These results indicated that the fruits from grafted tomato on eggplant rootstock can be harvested seven days earlier than non-grafted tomato.

4.2.9 Number of fruits per plant

Number of fruits as affected by different rootstocks is shown in Table 4.3. There was a significant effect of the rootstock type on the number of fruits per plant. More number of fruits was noticed in grafted plants (22.1) than that of the non-grafted plants (20.3). Grafted tomato on eggplant rootstock showed significantly higher number of fruits (23.6) than the other treatments.

4.2.10 Single fruit weight

Significant difference of single fruit weight was observed (Table 4.3). The fruits from grafted plants were bigger than that of non-grafted plants. Among the grafted plants, the maximum fruit weight was observed in the grafted tomato on eggplant rootstock (34.1 g) followed by hot pepper rootstock (31.5 g) and tomato rootstock (31.2 g) and the non-grafted tomato showed the minimum single fruit weight (26.2 g).

4.2.11 Fruit yield

Fruit yield per plant and total fruit yield were significantly different among the treatments shown in Table 4.3. Yield per plant and total fruit yield of grafted tomato increased significantly in comparison with that of the non-grafted plants. Among the rootstocks, grafted tomato on eggplant rootstock gave the highest fruit yield (805.5 g) followed by tomato rootstock (673.8 g) and hot pepper rootstock (666.2 g) while non-grafted tomato was the minimum fruit yield (530.1 g).

4.3 Effects of Different Rootstocks on Plant Growth and Reproductive Parameters of Grafted Tomato (Expt. II, Pot Experiment)

4.3.1 Plant height

Figure 4.3 shows the comparison of plant height among the treatments. It was observed that plant height was significantly different among the treatments in most evaluation periods. At 20 and 30 DAG, all grafted plants were significantly shorter than non- grafted plant. No significant result was observed until 40 DAG. Significant difference was observed starting from 50 DAG. At 60 DAG, the height of grafted tomato on eggplant rootstock was significantly higher than the other treatments. The highest plant height occurred in the plant grafted on eggplant rootstock (47.3 cm) followed by tomato rootstock (44.7 cm) and hot pepper rootstock (40.1 cm). Non-grafted tomato showed the shortest plant height (39.8 cm).

4.3.2 Shoot growth and leaf emergence rate

Figure 4.4 describes the effect of different rootstocks on shoot growth of grafted and non-grafted tomato. The Plastochron index (shoot growth) was significantly different among the treatments in most of evaluation periods. At 20 DAG, the shoot growth was not significantly different among the treatments. However, at 50 DAG, the shoot growth of grafted tomato on eggplant rootstock (47.3) was significantly higher than the other treatments. Leaf emergence rate was showed by Plastochron per day (Table 4.4). There was a significantly difference of leaf emergence rate among the treatments. Maximum leaf emergence rate was observed in the tomato plant grafted on eggplant rootstock (0.25).

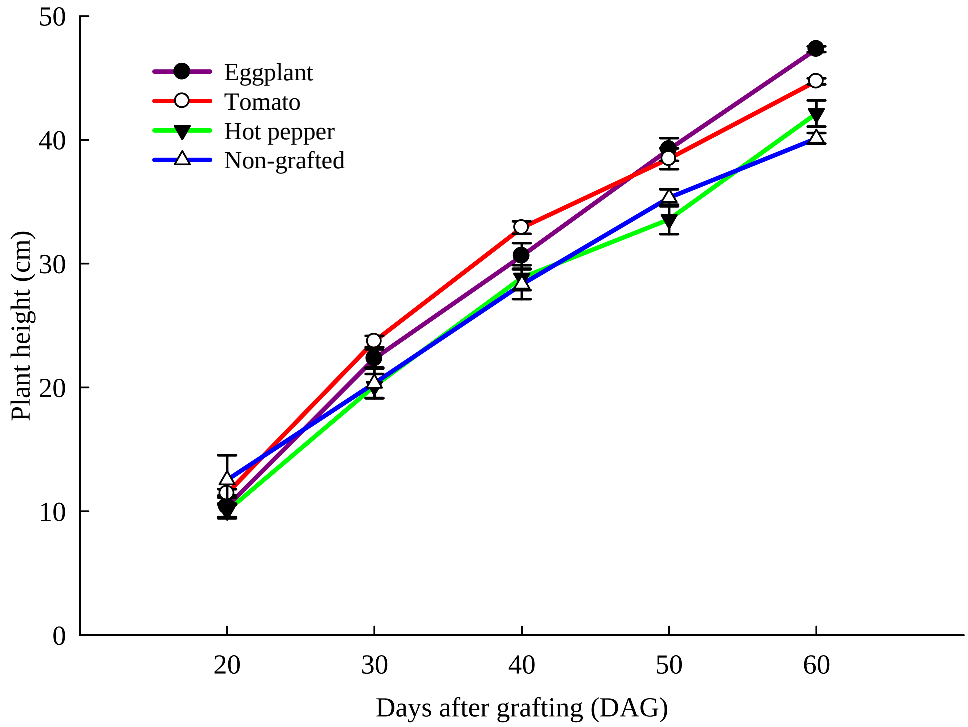


Figure 4.3 Effect of different rootstocks on plant height of grafted and non-grafted tomato (Expt. II)

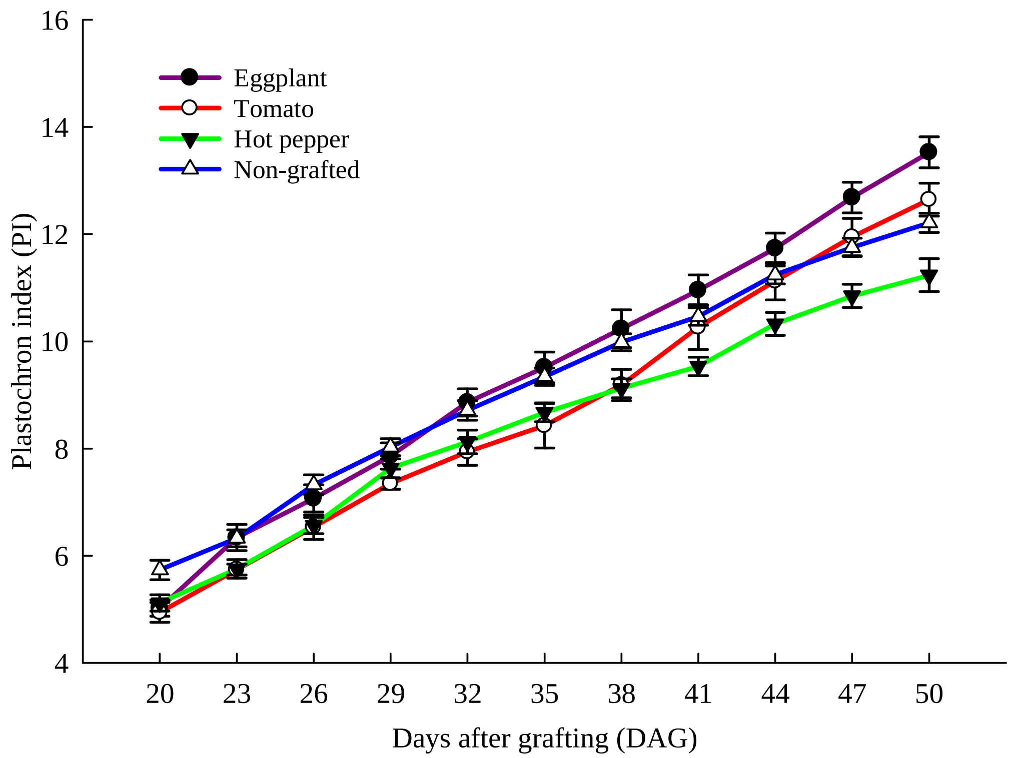


Figure 4.4 Effect of rootstocks on plastochron index (PI)) of grafted and non-grafted tomato (Expt. II)

Table.4.4 Effect of different rootstocks on leaf emergence rate (Plastochron day^{-1}) (Expt. II)

Rootstock type	Plastochron day^{-1}
Eggplant	0.25 a
Tomato	0.24 a
Hot pepper	0.18 b
Non-grafted	0.20 ab
Pr>F	**
$LSD_{(0.05)}$	0.03
Contrast analysis of grafted vs. non-grafted	
Grafted	0.23
Non-grafted	0.2
Pr>F	*

Means in the same column followed by the same letter are not significantly different at $P \leq 0.05$. * = Significant at P (0.05) ** = Highly significant at P (0.01) ns = Not significant

Table 4.5 Effects of different rootstocks on growth parameters of grafted tomato (Expt. II)

Rootstock type	No. of branches	Days to 1st flowering	Days to 1st harvesting
Eggplant	4.2 a	41.2 c	93.6 b
Tomato	3.9 ab	42.2 b	93.3 b
Hot pepper	3.9 b	44.2 a	95.3 a
Non-grafted	3.5 c	44.9 a	95.6 a
Pr>F	**	**	**
$LSD_{(0.05)}$	0.3	0.9	1.3
CV (%)	4.2	1.4	4.2
Contrast analysis of grafted vs. non-grafted			
Grafted	4.0	42.5	94.0
Non-grafted	3.5	44.9	95.6
Pr>F	**	**	**

Means in the same column followed by the same letter are not significantly different at $P \leq 0.05$. * = Significant at P (0.05) ** = Highly significant at P (0.01) ns = Not significant

Table 4.6 Comparison of yield and yield components parameters of grafted and non-grafted plants as affected by different rootstocks (Expt. II)

Rootstock type	No. of truss plant^{-1}	No. of flowers truss^{-1}	No. of fruits truss^{-1}	Fruits set (%)	No. of fruits plant^{-1}	Single fruit weight(g)	Fruit yield plant^{-1} (g)	Total yield (t ha^{-1})
Eggplant	10.4	13.1 a	6.6 a	56.5 a	43.2 a	47.2 a	2036.7 a	4.9 a
Tomato	9.9	11.3 b	5.8 ab	44.3 b	40.9 b	45.8 b	1874.8 b	4.5 b
Hot pepper	9.6	9.4 c	5.0 b	42.0 b	40.0 b	45.7 b	1827.8 b	4.4 b
Non-grafted	8.9	9.0 c	4.4 b	43.8 b	39.5 c	41.7 c	1645.2 c	3.9 c
Pr>F	ns	**	*	**	**	**	**	**
$LSD_{(0.05)}$	1.8	1.3	1.2	6.8	1.0	1.2	62.8	0.2
CV (%)	11.8	7.6	13.0	9.0	1.6	1.7	2.2	2.2
Contrast analysis of grafted vs. non-grafted								
Grafted	10.1	12.7	5.8	47.6	41.4	46.9	1913.1	4.6
Non-grafted	8.9	9.0	4.4	43.8	39.5	41.7	1645.2	3.9
Pr>F	ns	**	ns	**	**	**	**	**

Means in the same column followed by the same letter are not significantly different at P≤0.05

*= Significant at P (0.05) **= Highly significant at P (0.01) ns = Not significant

4.3.3 Number of branches

Effects of rootstocks on the number of branches are shown in Table 4.5. Significant difference of the number of branches was observed between the grafted and the non- grafted tomato. The maximum number of branch was observed in grafted tomato on eggplant rootstock (4.2) followed by tomato rootstock (3.9) and hot pepper rootstock (3.9) while the minimum branch number was observed in non-grafted tomato (3.5).

4.3.4 Days to 1^{st} flowering

Effect of different rootstocks on days to 1^{st} flowering is described in Table 4.5. Days to 1^{st} flowering were significantly different among the treatments. Grafted plants with eggplant rootstock and tomato rootstock produced flowers earlier than hot pepper rootstock and non-grafted plants. Grafted tomato on eggplant rootstock showed the earliest flowering date (41 days) while latest flowering occurs in non-grafted tomato (45 days). Comparing grafted and non-grafted tomato, grafted tomato produced flowers earlier than that of non-grafted one.

4.3.5 Number of truss per plant

Effect of different rootstocks on the number of truss per plant is shown in Table 4.6. Rootstock type had no significant impact on the number of truss per plant of grafted and non-grafted tomato though the number of truss per plant of grafted tomato on eggplant rootstock was numerically greater than that of non-grafted tomato. The highest numbers of truss per plant were observed in grafted plant on eggplant rootstock (10.4) followed by tomato rootstock (9.9) and hot pepper rootstock (9.6). The lowest number of truss per plant was observed in non-grafted tomato (8.9).

4.3.6 Number of flowers per truss

Effect of different rootstocks on number of flowers per truss is described in Table 4.6. Rootstock influences the number of flowers per truss significantly. Number of flowers per truss of grafted plants was significantly higher than that of non-grafted ones. Among the treatments, tomato grafted on eggplant rootstock showed significantly higher number of flowers per truss (13.1) than that of the other treatments.

4.3.7 Number of fruits per truss

Table 4.6 describes the number of fruits per truss of grafted tomato as affected by different rootstocks. There was no significant difference in the number of fruits per truss between the grafted and non-grafted plants. However, the number of fruits per truss of grafted tomato on eggplant rootstock (6.6) was significantly greater than that of hot pepper rootstock (5.0) and non-grafted plants (4.4).

4.3.8 Fruit setting percentage

Fruit setting (%) was strongly related with number of flowers per truss and number of fruits per truss. Fruit setting (%) was significantly different among the treatments (Table 4.6). The fruit setting (%) of grafted tomato on eggplant rootstock (56.5%) was significantly higher than the other treatments.

4.3.9 Number of days to 1st harvesting

The number of days taken to 1st harvesting was significantly affected by the use of rootstocks (Table 4.5). This was also directly related with the days to 1st flowering. Grafted tomato with eggplant rootstock and tomato rootstock were harvested earlier than other treatments. Earliest harvest was occurred in grafted tomato on eggplant rootstock (93 days). Among the different rootstocks, eggplant rootstock was three days earlier harvesting than the non-grafted one.

4.3.10 Number of fruits per plant

The number of fruits as affected by different rootstocks is shown in Table 4.6. The number of fruits of grafted plants (41.4) was significantly higher than that of non-grafted plants (39.5). Highest number of fruits (43.2) was noticed in grafted tomato on eggplant rootstocks and it was significantly higher than tomato (40.9) and hot pepper rootstock (40.0).

4.3.11 Single fruit weight

The single fruit weight of grafted tomato was influenced by the use of rootstock as shown in Table 4.6. The single fruit weight of all grafted plants was significantly higher than the non-grafted ones. The maximum fruit weight was observed in the grafted tomato on eggplant rootstock (47.2 g) followed by tomato rootstock (45.8 g), hot pepper rootstock (45.7 g) and the non-grafted tomato (41.7 g).

4.3.12 Fruit yield

Table 4.6 describes effects of different rootstocks on tomato fruit yield. The total fruit yield per plant of grafted tomato increased significantly in comparison with that of the non-grafted plants. Total yield of grafted tomato (1913.1 g) was significantly higher than the non-grafted ones (1645.2 g). The fruit yield per plant of grafted tomato with eggplant rootstock was the highest (2036.7 g) followed by tomato rootstock (1874.8 g) and hot pepper rootstock (1827.8 g) while non-grafted tomato showed the lowest fruit yield (1645.2 g).

4.3.13 Brix value

Figure 4.5 shows the brix value of tomato as affected by different rootstocks. Grafted plants produced fruits with significantly higher brix value than that of non-grafted tomato. The brix value of hot pepper rootstock was significantly higher than that of non-grafted tomato. There was no significant difference in brix value among the rootstocks. The highest brix value (5.6 %) was resulted from grafted tomato on hot pepper rootstock and the lowest brix value was observed from non-grafted tomato (4.8 %).

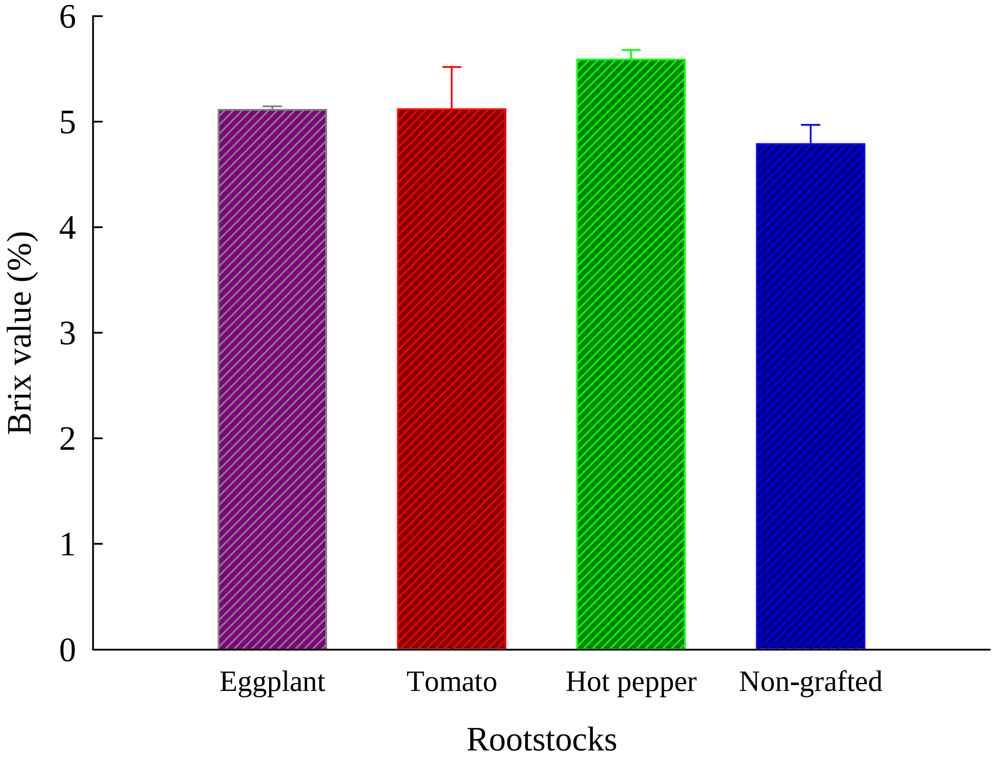


Figure 4.5 Brix value of tomato fruits as affected by different rootstocks (Expt. II)

4.4 Effects of Different Rootstocks on Plant Growth and Reproductive Parameters of Grafted Tomato (Expt. III, Field Experiment)

4.4.1 Plant height

Plant height was significantly different among the treatments (Figure 4.6). Type of stock plant has a strong influence on plant height of grafted tomato. At 20 DAG, the plant height of non-grafted tomato was significantly higher than grafted tomato. Starting from 40 DAG, the height of grafted on eggplant rootstock was significantly higher than the other treatments and it became the highest one at harvest (78.8 cm). Tomato rootstock showed the second highest (73.8 cm) and followed by hot pepper rootstock (70.5 cm). The shortest plant height was observed in the non-grafted tomato (66.5 cm).

4.4.2 Shoot growth and leaf emergence rate

Figure 4.7 describes the effect of different rootstocks on shoot growth of grafted and non-grafted tomato. Shoot growth was measured by Plastochron index (PI). In all treatments, shoot growth showed a steady increase throughout the growth period. At 20 DAG, shoot growth of non-grafted tomato was significantly higher than that of grafted tomato. At 50 DAG and 60 DAG, shoot growth of grafted tomato was significantly higher than that of non-grafted tomato. However, shoot growth of grafted tomato on eggplant rootstock was significantly higher than the other treatments starting from 32 DAG. The highest shoot growth was observed in the eggplant rootstock (17.2) followed by tomato rootstock (16.4) and hot pepper rootstock (15.9). The minimum shoot growth was observed in the non-grafted tomato (13.6). Effect of different rootstocks on leaf emergence rate of grafted and non-grafted tomato is described in Table 4.7. Leaf emergence rate was measured by Plastochron per day. Leaf emergence rate of grafted tomato (0.27) was significantly higher than that of non-grafted tomato (0.19). Among the rootstock, grafted tomato on eggplant rootstock showed the maximum leaf emergence rate (0.33) followed by tomato (0.29) and hot pepper rootstock (0.28).

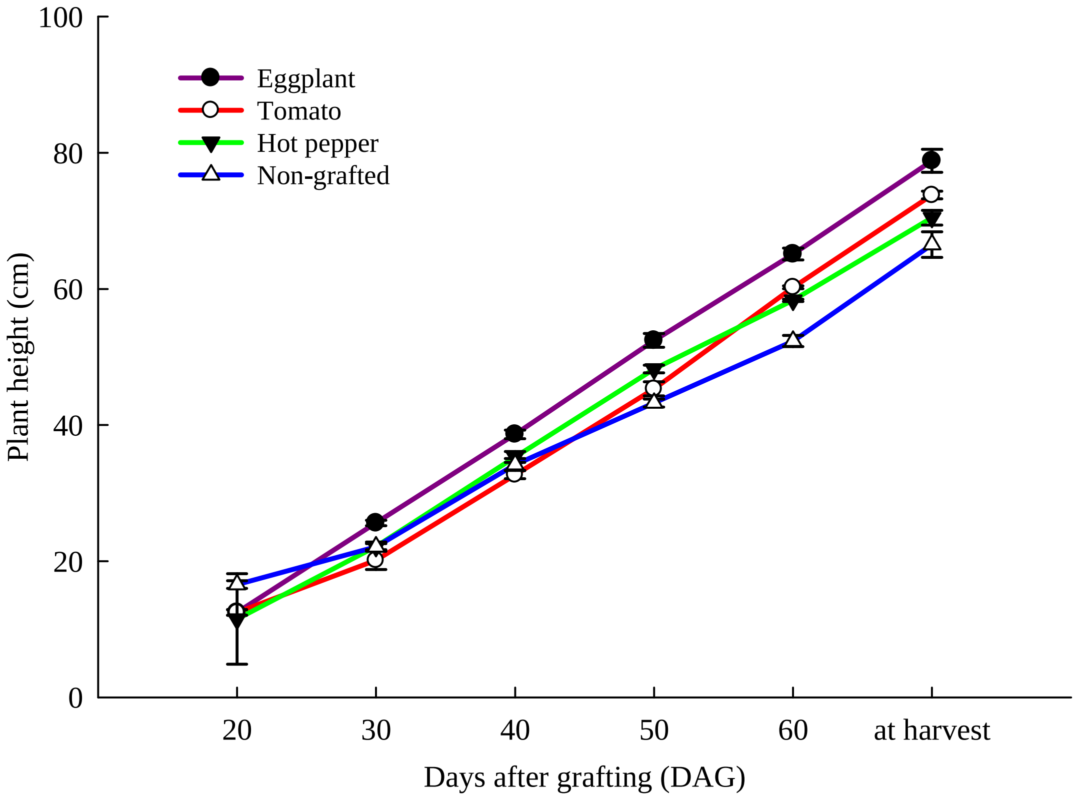


Figure 4.6 Effect of different rootstocks on plant height of grafted tomato (Expt. III)

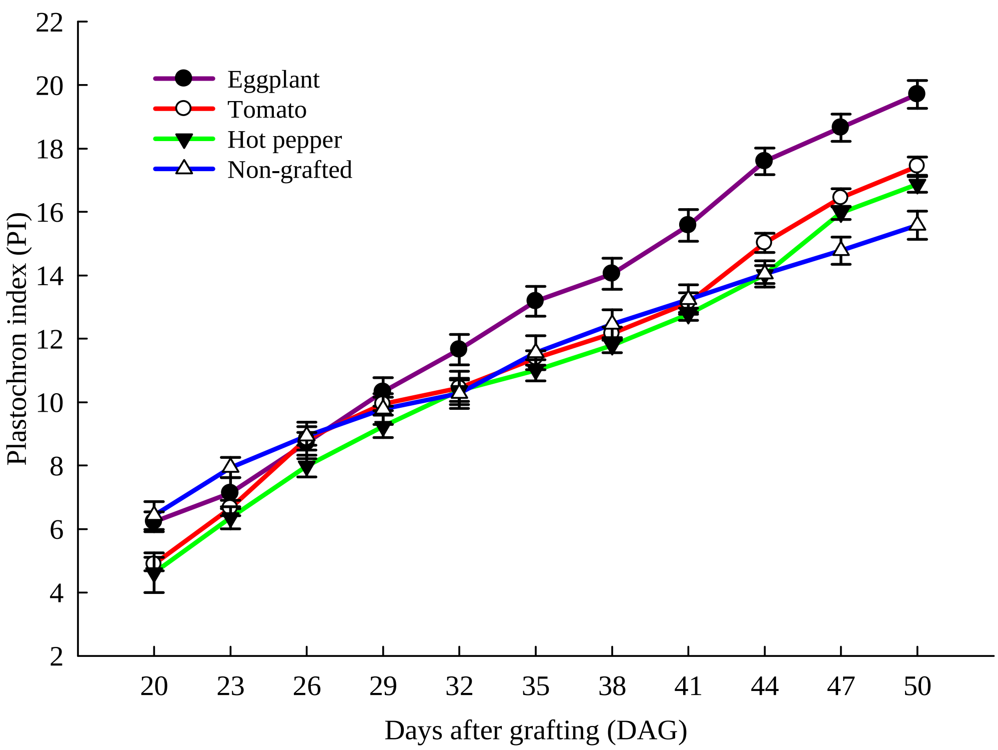


Figure 4.7 Effect of different rootstocks on plastochron index (PI)) of grafted

tomato (Expt. III)

Table 4.7 Effect of different rootstocks on leaf emergence rate of grafted and non-grafted tomato (Expt. III)

Rootstock type	Plastochron day^{-1}
Eggplant	0.33 a
Tomato	0.29 b
Hot pepper	0.28 b
Non-grafted	0.19 c
Pr>F	**
$LSD_{(0.05)}$	0.02
Contrast analysis of grafted vs. non-grafted	
Grafted	0.27
Non-grafted	0.19
Pr>F	**

Means in the same column followed by the same letter are not significantly different at P≤0.05. *= Significant at P (0.05) **= Highly significant at P (0.01) ns = Not significant

Table 4.8 Evaluation on chlorophyll content and photosynthesis efficiency of grafted and non-grafted tomato (Expt. III)

Rootstock type	Photosynthesis efficiency	Chlorophyll content
Eggplant	0.83 a	59.4 a
Tomato	0.79 b	58.5 a
Hot pepper	0.81 ab	58.3 a
Non-grafted	0.76 c	52.3 b
Pr>F	**	**
$LSD_{(0.05)}$	0.02	2.81
Contrast analysis of grafted vs. non-grafted		
Grafted	0.81	58.72
Non-grafted	0.75	52.34
Pr>F	**	**

Means in the same column followed by the same letter are not significantly different at P≤0.05. *= Significant at P (0.05) **= Highly significant at P (0.01) ns = Not significant

4.4.3 Chlorophyll content and photosynthesis efficiency

Table 4.8 describes chlorophyll content and photosynthesis efficiency of grafted and non-grafted tomato as affected by rootstock. Chlorophyll content of grafted plants was significantly higher than that of non-grafted ones. However, there was no significant difference among the rootstocks. Photosynthesis efficiency was significantly different between the grafted and non-grafted tomato. Among the treatments, the highest photosynthesis efficiency was observed in grafted tomato from eggplant rootstock (0.83) followed by hot pepper rootstock (0.81) and tomato rootstock (0.79) while non-grafted tomato showed the lowest value (0.76). It can be said that the photosynthesis efficiency varies depending on type of rootstocks.

4.4.4 Number of branches per plant

Number of branches of grafted tomato plants was significantly higher than non- grafted tomato (Table 4.9). Among the grafted plants, the grafted plant on eggplant rootstock produced the highest number of branch (5.0) while non-grafted tomato recorded the number of branch (4.1).

4.4.5 Days to 1st flowering

Types of rootstock affected on the date of flower formation (Table 4.9). Grafted plants flowered significantly earlier than non-grafted plants. Days to 1st flowering was significantly affected by the types of rootstocks. The 1st flowering date of grafted tomato on eggplant rootstock was significantly earlier than the other rootstocks. Grafted tomato on eggplant rootstock flowered the earliest (44 days) followed by hot pepper rootstock (45 days) and tomato rootstock (47 days).

Table 4.9 Comparison of the number of branches, days to first flowering and days to 1st harvesting among the treatments (Expt. III)

Rootstock type	No. of branches	Days to 1st flowering	Days to 1st harvesting
Eggplant	5.0 a	43.7 d	85.3 d
Tomato	4.6 b	46.6 c	90.1 b
Hot pepper	4.7 ab	44.8 b	87.9 c
Non-grafted	4.1 c	47.7 a	95.9 a
Pr>f	**	**	**
$LSD_{(0.05)}$	0.4	0.7	1.7
CV (%)	6.2	1.1	1.2
Contrast analysis of grafted vs. non-grafted			
Grafted	4.7	45.1	87.8
Non-grafted	4.1	47.7	95.9
Pr>F	*	**	**

Means in the same column followed by the same letter are not significantly different at P≤0.05. *= Significant at P (0.05) **= Highly significant at P (0.01) ns = Not significant

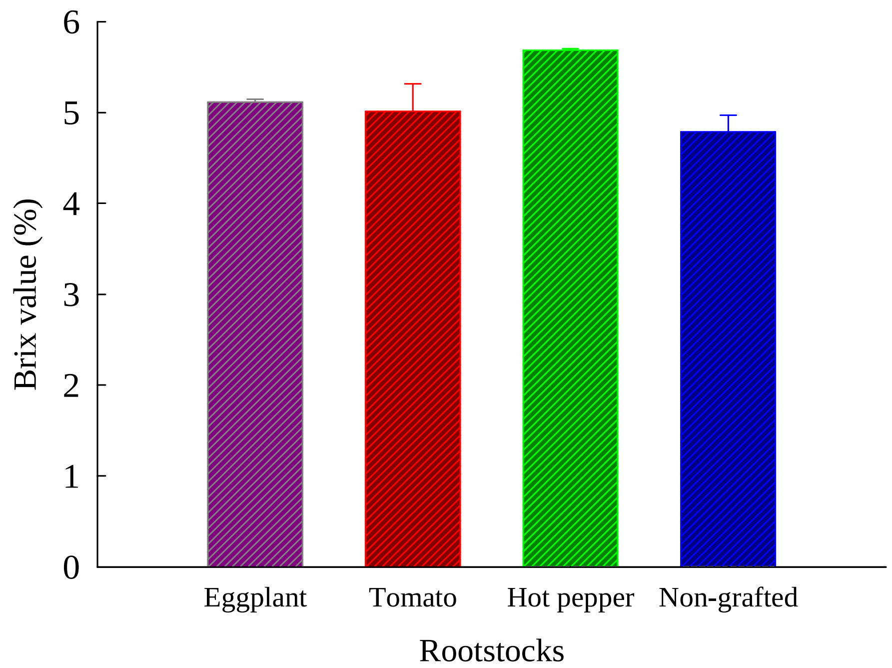


Figure 4.8 Comparison of Brix value of tomato fruits as affected by different rootstocks (Expt. III)

Table 4.10 Comparison of yield and yield components of grafted and non-grafted plants as affected by different rootstocks (Expt. III)

Rootstock type	No of truss plant^{-1}	No. of flowers truss^{-1}	No. of fruits truss^{-1}	Fruit setting (%)	No. of fruits plant^{-1}	Single fruit weight(g)	Fruit diameter (cm)	Fruit yield plant $^{-1}$ (g)	Total yield (t ha^{-1})
Eggplant	16.6 a	8.9	5.5 a	61.2 a	91.3 a	62.4 a	4.5 a	5071.4 a	12.3 a
Tomato	16.2 ab	8.6	4.7 b	55.9 b	75.3 b	59.6 ab	4.4 ab	3894.3 b	9.4 b
Hot pepper	15.3 b	8.4	4.7 b	55.3 b	72.8 bc	55.3 b	4.4 ab	3472.6 b	8.4 b
Non-grafted	13.9 c	8.0	4.4 b	51.8 c	61.5 c	48.4 c	4.3 b	2491.7 c	6.0 c
Pr>F	**	ns	**	**	**	**	ns	**	**
$LSD_{(0.05)}$	1.0	1.1	0.6	2.6	11.5	4.8	0.2	0.7	1.8
CV (%)	4.1	2.2	7.7	3.1	9.9	5.5	3.2	12.6	12.6
Contrast analysis of grafted vs. non-grafted									
Grafted	16.1	8.6	4.9	57.5	79.8	59.1	4.4	4146.1	10.0
Non-grafted	13.9	8.0	4.4	51.8	61.5	48.4	4.3	2491.7	6.0
Pr>F	**	ns	ns	*	**	**	ns	**	**

Means in the same column followed by the same letter are not significantly different at P≤0.05

*= Significant at P (0.05)   **= Highly significant at P (0.01)   ns = Not significant

4.4.6 Number of truss per plant

Significant difference in number of truss per plant was noted between the grafted and non-grafted plants (Table 4.10). The highest number of truss per plant was observed in the grafted tomato on eggplant rootstock (16.6) followed by tomato rootstock (16.2), hot pepper rootstock (15.3 g) and the non-grafted tomato (13.9). The number of truss per plant was significantly different between the treatments.

4.4.7 Number of flowers per truss

Effect of different rootstocks on the number of flowers per truss is shown in Table 4.10. Rootstock type had no significant impact on the number of flowers per truss of grafted and non-grafted tomato. The number of flowers per truss was maximum in grafted tomato on eggplant rootstock (8.9) followed by tomato rootstock (8.6) and hot pepper rootstock (8.4) and minimum in control (8.0).

4.4.8 Number of fruits per truss

The number of fruits per truss was not significantly different between grafted plants and non-grafted plants (Table 4.10). However, the number of fruits per truss of grafted plant on eggplant rootstock was significantly higher than the other treatments. The maximum number of fruit per truss was recorded from grafted tomato on eggplant rootstock (5.5) followed by tomato (4.7) and hot pepper rootstock (4.7) while the minimum number of fruit was observed in non-grafted plants (4.4).

4.4.9 Fruit setting percentage

Fruit setting (%) was significantly different among the treatments as stated in Table 4.10. The fruit setting (%) of grafted plants was significantly higher than the non-grafted ones. Grafted plant on eggplant rootstock was significantly higher than the other rootstocks. The maximum fruit setting (%) was observed in grafted tomato on eggplant rootstock (61.2) followed by tomato rootstock (55.9) and hot pepper rootstock (55.3) while the minimum value was observed in control (51.8).

4.4.10 Number of days to 1st harvesting

The number of days taken to 1st harvesting was significantly affected by the use of rootstocks. As shown in Table 4.9 the earliest harvesting was observed in grafted tomato on eggplant rootstock (86 days) and followed by hot pepper rootstock (88 days) and tomato rootstock (90 days). The latest harvest was found in non- grafted tomato (96 days).

4.4.11 Number of fruits per plant

Significant difference in number of fruits per plant was noted between the grafted and non-grafted plants (Table 4.10). Among the treatments, grafted tomato on eggplant rootstock resulted significantly highest in number of fruit (91.3). Tomato rootstock, hot pepper rootstock and non- grafted tomato resulted 75.3, 72.7 and 61.5, respectively.

4.4.12 Single fruit weight and fruit diameter

Single fruit weight was significantly affected by rootstocks (Table 4.10). The highest single fruit weight was observed in the grafted tomato on eggplant rootstock (62.4 g) followed by tomato rootstock (59.6 g), hot pepper rootstock (55.3 g) and the non-grafted tomato (48.4 g). The diameter of fruit was significantly different between the treatments. Fruit diameter from non grafted tomato plant was smaller than that of grafted tomato. Fruits from grafted tomato using eggplant rootstock had maximum fruit diameter (4.5 cm) and non-grafted tomato had minimum fruit diameter (4.3 cm).

4.4.13 Fruit yield

Total fruit yield of grafted tomato as affected by different rootstocks is shown in Table 4.10. The fruit yield of grafted plant was significantly higher than the non-grafted ones. The greatest total fruit yield was achieved from grafted tomato on eggplant rootstock (12.3 t ha^{-1}) followed by tomato rootstock (9.4 t ha^{-1}), hot pepper rootstock (8.4 t ha^{-1}), and non- grafted tomato (6.0 t ha^{-1}).

4.4.14 Brix value

Figure 4.8 indicates the brix value of tomato. Brix value is one of the most important characteristics for good quality tomato. The brix value of grafted tomato (5.3 %) was significantly higher than that of non-grafted ones (4.8 %). Among the rootstocks, grafted tomato onto hot pepper rootstock gave the highest brix value fruits (5.7 %).

CHAPTER V
DISCUSSION

Three experiments were carried out to determine the effects of different rootstocks on photosynthesis efficiency, plant growth, development and yield of grafted tomato. Three experiments were conducted at different growing seasons (May-September, October- February, April - August) to determine the performance of plant growth and yield of grafted tomato. Three different types of local cultivars (local eggplant, local tomato and local hot pepper) were used as rootstocks and only one commercial tomato cultivar (Platinum 701) was used as scion in all experiments.

Graft success rate and field survival rate: Grafted plant on eggplant rootstock showed maximum value in both graft success and field survival rate in all experiments (Table 4.1). These results indicated that the type of rootstock has an impact on the graft success percent. The highest graft percent by eggplant rootstock among the other rootstocks indicated that eggplant is those with good compatibility during healing period. Another reason could be due to the nature of stock plants in which eggplants are very hardy during the healing period and they withstand well after grafting. Bisognin et al. (2005) also described that many other factors influence grafting success including post-grafting environmental conditions, plant vigor, carbohydrate content, and the proper match of vascular bundles. Highest field survival percent in eggplant rootstock from all experiments depicted that eggplant rootstock was more tolerant to environmental stress than the other rootstocks. However, all grafted plants showed over 70 % of graft success and field survival rate. This data suggested that all types of rootstocks are feasible for tomato grafting.

Plant height: Effects of different rootstocks on plant height of grafted tomato was described in Figure 4.1, Figure 4.3 and Figure 4.6. These results indicated that plant height performance of the grafted tomato varies depending on the use of rootstock types. Shorter plant height of grafted plants at an early growth stage is due to the grafting stress. However, plant height was significantly different among them. Eggplant rootstock showed the tallest plant height starting from 40 days after grafting to final harvest. This could be due to vigorous plant growth of local eggplant rootstock. Bletios (2005) also highlighted that local eggplant type (*S. torvum)* rootstock was very vigorous as measured by plant height, stem diameter and root biomass and thus its vigorous root system are often capable of absorbing water and plant nutrients more efficiently than self-rooted scion plants. This result also agrees with the result of Lee (1994) and Ioannou and Hadjiparaskevas (2002) who found the grafted plants was taller and more vigorous than self-rooted ones and had a larger central stem diameter. The other explanation of taller grafted plants than that of non-grafted plants may be due to the effect of vigorous growth of rootstock that was resistant to biotic and abiotic stress.

Number of leaves, leaf emergence rate and shoot growth: Significant difference of the number of leaves between the grafted and non-grafted plants indicated that the number of leaves vary with the use of rootstock type (Figure 4.2). This could be due to the variation of rootstock vigour, root system and their uptake ability of water and nutrients. Pulgar et al. (2000) also observed the increased production of leaves in grafted plants as a result of an increased uptake of water and nutrients. Significantly lower number of leaves of the grafted tomato in comparison with the non-grafted one at an early stage of grafting is due to the grafting stress at an early stage of grafting. Leaf emergence rate shown as plastochron per day in Table 4.4 and 4.7 described that the leaf emergence rate of all grafted plants was significantly higher than the non-grafted ones. It may be due to vigorous growth of rootstocks. Maximum leaf emergence rate from the grafted plant on eggplant rootstock in all experiments suggesting that eggplant rootstock was most vigorous among the rootstocks. Shoot growth analysis indicated that Plastochron index (PI) is consistently applicable for describing the morphological status of the vegetative tomato shoot. Shoot growth (Plastochron index) shown in Figure 4.4 and 4.7 indicated that the highest shoot growth was observed in grafted plant on eggplant rootstock. This could be due to the vigorous growth of eggplant root-stock as described by highest leaf emergence rate (Plastochron per day) of eggplant rootstock among the others.

Number of branches per plant: Depending on rootstock type, the numbers of branches of grafted tomato plants vary. All grafted plants have significantly higher number of branches than the non-grafted plants (Table 4.2, 4.5 and 4.9). This could be due to the variation of plant growth depending on rootstocks. Eltayb et al. (2014) also observed the variation of number of branches on grafted plants. The maximum branch number observed in eggplant rootstock in all experiments described that eggplant rootstock was more vigorous growth than the other rootstocks. Similar result was reported by Marsic' and Osvald (2004) and Khah et al. (2006) who found that grafted tomatoes have more branching compared to self-rooted tomato plants.

Photosynthesis efficiency and chlorophyll content: Significant difference in photosynthesis efficiency between the grafted and non-grafted tomato indicated that the photosynthesis efficiency alters depending on the type of rootstock (Table 4.8). This could be due to the vigorous plant growth due to higher chlorophyll content of the grafted plants. Significantly higher value of chlorophyll content of grafted plants than the non-grafted ones impacted on the photosynthesis efficiency of the plants. These results are in agreement with those of Zheng et al. (2009) who found that grafting reduced damage to the photosynthetic apparatus, since this maintained higher photochemical activity of Photosystem II (He et al. 2009). Bhatt et al. (2015) also showed the increased photosynthesis efficiency in eggplant rootstock even under stress condition.

Reproductive parameters of grafted and non-grafted tomato: Significant difference of reproductive parameters was observed between the grafted and non-grafted tomato (Table 4.3, Table 4.6 and Table 4.10). Grafted plants produced flowers earlier with higher number of flowers than those of the non-grafted plants. The probable reason could be that grafted plants are stronger and thus it is possible to achieve much faster growth rate and flowering speed. Kurata (1976) and Sakata et al. (2007) stated that watermelon grafted on bottle gourd rootstock causes early formation of female flowers due to stock/scion combination. Satoh et al. (1996) also indicated that rootstock/scion combination alters the amount of flowering hormones produced and influences the grafted plant organs. Similar finding was also observed by Lardizabal and Thompson (1990) who found the increased flower number as a result of grafting. Fruit setting percent was strongly related with number of flowers per truss and number of fruits per truss. Fruit setting percent of eggplant rootstock was significantly higher than that of hot pepper rootstock and non-grafted tomato. Similar result was reported by Khah et al. (2006) who found grafted plants produced more percent of fruits than non-grafted plants when seedling of aubergine were grafted on two tomato rootstocks. Therefore, it can be said that the fruit setting percent of grafted tomato depends on the use of rootstock type.

Number of days to harvest: The number of days taken to 1st harvesting was significantly affected by the use of rootstocks (Table 4.2, 4.5 and 4.9). Grafted plants from eggplant rootstock showed the earliest production of tomato fruits among the treatments. Similar results were reported by other researchers (Bletsos. 2005; Khah et al. 2006, Voutsela et al. 2012) who showed that early marketable yield of grafted plants was significantly higher than those of self-rooted ones.

Number of fruits, single fruit weight and fruit diameter: Number of fruits per plant, single fruit weight and fruit diameter of grafted tomato were influenced by the use of rootstock (Table 4.3, 4.6 and 4.10). The number of fruits per plant of grafted plant was significantly higher than that of non-grafted plants in all experiments. Among the rootstocks, eggplant showed the maximum number of fruits. Single fruit weight and fruit diameter of grafted plants were significantly higher than the non-grafted ones. In field experiment, the maximum fruit weight and fruit diameter was obtained by local eggplant rootstocks. Similar findings of increasing fruit size in grafted watermelon (Miguel et al. 2004) and eggplant (Passam et al. 2005) were also observed. In a similar study, fruit weight of grafted plants was found to be higher than that of non-grafted plants (Khah et al. 2006).

Yield per plant: The total fruit yield of grafted tomato increased significantly in comparison with that of the non-grafted plants (Table 4.3, 4.6 and 4.10). This could be as a result of increased fruit size, fruit weight and number of fruits in the grafted plants. It is well known that the root system of the plants affects vegetative growth and yield with the increase of water and nutrient uptake due to the vigorous root system of rootstocks (Lee 1994) and thus grafting affects growth and ensures higher yields than in non-grafted plants. Maximum fruit yield obtained from eggplant rootstock in all experiments is likely due to eggplant being more vigorous. Schwarz et al. (2010) also found that root system of eggplant is very effective in water uptake than tomato root systems. Similar yield increase in grafted tomato and cucurbits have been reported by other researchers (Leonardi and Giuffrida 2006; Chung and Lee 2007; Proietti et al. 2008).These data suggested that grafted tomato has a positive and improved effect on plant growth, development and fruit yield.

Brix value: Significant difference was observed in brix value between the grafted and non-grafted tomato (Figure 4.5 and 4.8). Among the rootstocks, mean value of brix percent of hot pepper rootstock was slightly higher than the others. This result agrees with Riga (2015) who reported that rootstock genotype greatly influenced fruit quality parameters. Similar result was observed by other researchers (Yetisir and Sari 2003; Cushman and Huan 2008) who found that fruit soluble solids content was affected by grafting (effect of stock-scion relationship).

CHAPTER VI
CONCLUSION

The results indicated that grafted tomato has a great impact on photosynthesis efficiency, plant growth and fruit yield. Grafted plants showed faster leaf emergence and greater shoot growth leading to greater plant growth and development. Grafted plants are taller than non-grafted plants. Grafted plants also result in earlier reproductive development, faster flowering, earlier harvesting and higher fruit yield compared to non-grafted plants. Therefore, tomato grafting has positive effects on plant growth and development, fruit yield and earliness.

Type of rootstock also has a positive impact on chlorophyll content enhancing photosynthesis efficiency. Local types of rootstocks of eggplant, tomato and hot pepper are feasible rootstocks for tomato grafting. Among the rootstocks, eggplant rootstock showed the best performance in terms of graft success percent, field survival rate, plant growth as well as higher fruit yield and earlier harvest. Therefore, local eggplant can be used as rootstock in tomato production.

Grafted tomato minimizes biotic and abiotic stress and helps reduce the use of agro-chemicals. Therefore, tomato grafting is a good way to apply in off-season tomato production as well as in organic farming.

REFERENCES

Abdelmageed, A. H. A. and N. Gruda. 2009. Influence of grafting on growth, development and some physiological parameters of tomatoes under controlled heat stress conditions. European Journal of Horticultural Science 16-20.

Abdelmageed, A. H., N. Gruda, and B. Geyer. 2004. Effects of temperature and grafting on the growth and development of tomato plants under controlled conditions. Rural Poverty Reduction through Research for Development and Transformation 5-7.

Ali, I.A., U. Kafkafi, Y. Sugimoto, and S. Inanaga. 1994. Response of sand-grown tomato supplied with varying ratios of nitrate/ammonium to constant and variable root temperatures. Journal of Plant Nutrition 17 (11): 2001-2024.

Andrews, K. P. and C. S. Marquéz. 1993. Graft incompatibility. Horticultural Reviews 15: 183-232.

Arao, T., H. Takeda, and E. Nishihara. 2008. Reduction of cadmium translocation from roots to shoots in eggplant (*Solanum melongena*) by grafting onto *Solanum torvum* rootstock. Soil Science and Plant Nutrition 54 (4): 555-559.

Augustin, B., V. Graf, and N. Laun. 2002. Temperature influencing efficiency of grafted tomato cultivars against root-knot nematode (*Meloidogyne arenaria*) and corky root (*Pyrenochaeta lycopersici*). Journal of Plant Diseases and Protection 109: 371-383.

Bausher, M. 2011. Grafting technique to eliminate rootstock sucking of grafted tomato. HortScience 46 (4): 596-598.

Bersi, M. 2002. Tomato grafting as an alternative to methyl bromide in Marocco. Institute Agronomi equeet Veterinaire Hasan II. Marocco.

Besri, M. 2007. Current situation of tomato grafting as alternative to methyl bromide for tomato production in Morocco. Hassan II Institute of Agronomy and Veterinary Medicine Marocco.

Bhatt, S., D. J. Weiss, E. Cameron, D. Bisanzio, B. Mappin, U. Dalrympie, K. E. Battle, C. L. Moyes, A. Henry, P. A. Eckhoff, and E. A. Wenger. 2015. The effect of malaria control on *Plasmodium falciparum* in Africa between 2000 and 2015. Nature 526 (572): 207-211.

Black, L. L., D. L. Wu, J. F. Wang, T. Kalb, D. Abbass, and J. H. Chen. 2003. Grafting tomatoes for production in the hot-wet season. Asian Vegetable Research and Development Centre 503–551.

Bletsos, F. A. 2005. Use of grafting and calcium cyanamide as alternatives to methyl bromide soil fumigation and their effects on growth, yield, quality and fusarium wilt control in melon. Journal of Phytopathology 153 (3): 155-161.

Bisognin, D. A., L. Velasquez, and I. Widders. 2005. Cucumber seedling dependence on cotyledonary leaves for early growth. Brazilian Journal of Agricultural Research 40 (6): 531-539.

Chung, H. D. and J. M. Lee. 2007. Rootstocks for grafting. Journal of The Korean Society for Horticultural Science 162-167.

Cohen, R., C. Horev, Y. Burger, S. Shriber, J. Hershenhorn, J. Katan, and M. Edelstein. 2002. Horticultural and pathological aspects of Fusarium wilt management using grafted melons. Horticulture Science 37: 1069–1073.

Cramer, G. R., K. Urano, S. Delrot, M. Pezzotti, and K. Shinozaki. 2011. Effect of abiotic stress on plants: a systems biology perspective. BMC Plant Biology 11 (163): 514-518.

Cuartero, J., M. C. Bolarin, M. J. Asins, and V. Moreno. 2006. Increasing salt tolerance in the tomato. Journal of Experimental Botany 57 (5): 1045-1058.

Cushman, K. E. and J. Huan. 2008. Performance of four triploid watermelon cultivars grafted onto five rootstock genotypes: Yield and fruit quality under commercial growing conditions. ISHS Proc IV, Seed, Transplant and Stand Establishment of Horticultural Crops. Acta Horticulturae 782: 335–342.

Eltayb, M. T. A., T. D. A. Magid, A. A. Ibrahim, and A. M. A. Dirar. 2014. Effect of grafting (rootstock) on morphological changes of scions in some acacia species. Journal of Forest Products and Industries 3 (1): 27-36.

Erickson, R. O. and F. J. Michelini. 1957. The plastochron index. Amarican Journal of Botany 257-305.

Estan, M. T., M. M. Martinez-Rodrigues, F. Perez-Alfoce, T. J. Flowersn, and M. C. Bolarin. 2005. Grafting raises the salt tolerance of tomato through limiting the transport of sodium and chloride to the shoot. Journal of Experimental Botany 56 (412): 703-712.

FAOSTAT. 2012. http://www.fao.org/faostat/en/#home (received on September 6, 2015*)*.

Flores, F. B., P. Sanchez-Bel, M. T. Estan, M. M. Martinez-Rodriguez, E. Moyano, B. Morales, J. F. Campos, J. O. Garcia-Abellán, M. I. Egea, N. Fernández-Garcia, and F. Romojaro. 2010. The effectiveness of grafting to improve tomato fruit quality. Scientia Horticulturae 125 (3): 211-217.

Giannakou, I. O. and D. G. Karpouzas. 2003. Evaluation of chemical and integrated strategies as alternatives to methyl bromide for the control of root-knot nematodes in Greece. Pest Management Science 59 (8): 883-892.

Hang, S. D., Y. P. Zhao, G. Y. Wang, and G. Y. Song. 2005. Vegetable grafting. Beijng, China: China Agriculture Press.

Hasna, M. K., E. Ogren, P. Persson, A. Martensson, and B. Ramert. 2009. Management of corky root disease of tomato in participation with organic tomato growers. Crop Protection 28 (2): 155-161.

He, Y., Z. J. Zhu, J. Yang, X. L. Ni, **and B. Zhu**. **2009.** Grafting increases the salt tolerance of tomato by improvement of photosynthesis and enhancement of antioxidant enzymes activity. Journal Environmental and Experimental Botany 66: 270–278.

Ibrahim M., M. K. Munira, M. S. Kabir, A. K. M. S. Islam, and M. M. U. Miah. 2001. Seed germination and graft compatibility of wild solanum as rootstock of tomato. Asian Journal of Biological Sciences 1: 701–703.

Ioannou, N. M. and K. Hadjiparaskevas. 2002. Evaluation of watermelon rootstocks for off season production in heated greenhouses. Acta Horticulturae 579: 501-506.

Johkan, M., K. Mitukuri, S. Yamasaki, G. Mori, and M. Oda. 2009. Causes of defoliation and low survival rate of grafted sweet pepper plants. Scientia Horticulturae 119: 103–107.

King, S. R., A. R. Davis, W. G. Liu, and A. Levi. 2008. Grafting for disease resistance. HortScience 43: 1673-1676,

King, S. R., A. R. Davis, X. Zhang, and K. Crosby. 2010. Genetics, breeding and selection of rootstocks for Solanaceae and Cucurbitaceae. Scientia Horticulturae 127 (2): 106-111.

Khah E. M., E. Kakava, A. Mavromatis, D. Chachalis, and C. Goulas. 2006. Effect of grafting on growth and yield of tomato (*Lycopersicon esculentum* Mill.) in greenhouse and open-field. Journal of Applied Horticulture 8: 3–7.

Kubota, C., M. McClure, N. Kokalis-Burelle, M.Bausher, and E. Rosskopf. 2008. Vegetable grafting: history, use, and current technology status in North America. HortScience 43: 1664–1669.

Kurata, H. 1976. Studies on the sex expression of flowers induced by day-length and temperature in pumpkin and watermelon. Faculty of Agriculture of Kagawa University 29: 1-49.

Lardizabal, R.D. and P.G. Thompson. 1990. Growth regulators combined with grafting increase flower number and seed production in sweet potato. Horticulture Science 25: 79-81.

Lee J. M. 1994. Cultivation of grafted vegetables I. Current status, grafting methods and benefit. HortScience 29: 235-239.

Lee, J. M., H. J. Bang, and H. S. Ham.1998. Grafting of vegetables (grafting and raising of seedlings, for further development of horticulture in East Asia). Journal of the Japanese Society for Horticultural Science 67 (6): 1098-1104.

Lee, J. M. and M. Oda. 2003. Grafting of herbaceous vegetable and ornamental crops. Horticultural Reviews 28: 61-123.

Lee, J. M., C. Kubota, S. J. Tsao, Z. Bie, P. H. Echevarria, L. Morra, and M. Oda. 2010. Current status of vegetable grafting: Diffusion, grafting techniques, automation. Scientia Horticulturae 127 (2): 93-105.

Leonardi, C. and F. Giuffrida. 2006. Variation of plant growth and macronutrient uptake in grafted tomatoes and eggplants on three different rootstocks. European Journal of Horticultural Science 71: 97–101.

Leoni, S., R. Grudina, M. Cadinu, B. Madeddu, and M. C. Garletti. 1990. The influence of four rootstocks on some melon hybrids and a cultivar in greenhouse. Acta Horticulture 287: 127-134.

Maršić, N. K. and J. Osvald. 2004. The influence of grafting on yield of two tomato cultivars (*Lycopersicon esculentum* Mill.) grown in a plastic house. Acta Agriculturae Slovenica 83: 243-249.

Matsuzoe, N., H. Okubo, and K. Fujieda. 1993. Resistance of tomato plants grafted on solanum rootstocks to bacterial wilt and root-knot nematode. Journal of the Japanese Society for Horticultural Science 61: 865-872.

McAvoy, T., J. H. Freeman, S. Rideout, S. M. Olson, and M. L. Paret. 2012. Evaluation of grafting using hybrid rootstocks for management of bacterial wilt in field tomato production. HortScience 47: 621-625.

Miguel, A., J. V. Maroto, A. San Bautista, C. Baixauli, V. Cebolla, B. Pascual, S. Lopez, and J. L. Guardiola. 2004. The grafting of triploid watermelon is an advantageous alternative to soil fumigation by methyl bromide for control of Fusarium wilt. Scientia Horticulturae 103 (1): 9-17.

Naika, S., J. de Jeude, M. de Goffau, M. Hilmi, and B. Van Dam. 2005. Cultivation of tomato: Production, processing and marketing. Agromisa Foundation and CTA, Wageningen, Netherlands.

Nicoletto, C., F. Tosinib, and P. Samboa. 2012. Effect of grafting and ripening conditions on some qualitative traits of 'Cuore di bue' tomato fruits. Journal Science Food Agriculture 23: 112-116

Oda, M. 1995. New grafting methods for fruit-bearing vegetables in Japan. Japan Agricultural Research Quarterly 29: 187–198.

Oda, M. 1999. Grafting of vegetables to improve greenhouse production. Food & Fertilizer Technology Center 480: 1-11.

Oda, M. 2002. Grafting of vegetable crops. Scientific Reports Agricultre and Biology Science. Osaka Prefecture University 54: 49-72.

Oda, M., M. Maruyama, and G. Mori. **2005.** Water transfer at graft union of tomato plants grafted onto Solanum rootstocks. Journal of the Japanese Society for Horticultural Science 74: 458–463.

Oda, M. 2007. Vegetable seedling grafting in Japan. Acta Horticulture 759: 175–180.

Passam, H. C., M. Stylianoy, and A. Kotsiras. 2005. Performance of eggplant grafted on tomato and eggplant rootstocks. European Journal of Horticultural Science 70 (30): 130-134.

Pogonyi A., Z. Pek , L. Helyes, and A. Lugasi. 2005. Effect of grafting on the tomato yield, quality and main fruit components in spring forcing. Acta Elimentaria 34: 453-462.

Proebsting, W. M., P. Hedden, M. J. Lewis, S. J. Croker, and L. N. Proebsting. 1992. Gibberellins concentration and transport in genetic lines of pea effects of grafting. Plant Physiology 100 (3): 1354-1360.

Proietti, S., Y. Rouphael, G. Colla, M. Cardarelli, M. De Agazio, M. Zacchini, E. Rea, S. Moscatello, and A. Battistelli. 2008. Fruit quality of mini-watermelon as affected by grafting and irrigation regimes. Journal of the Science of Food and Agriculture 88 (6): 1107-1114.

Pulgar, G., G. Villora, D. A. Moreno, and L. Romero. 2000. Improving the mineral nutrition in grafted watermelon plants: nitrogen metabolism. Biologia Plantarum 43 (4): 607-609.

Rahman, M. A., M. A. Rashid, M. A. Salam, M. A. T. Masud, A. S. M. H. Masum, and

M. M. Hossain. 2002. Performance of some grafted eggplant genotypes on wild solanum rootstocks against root-knot nematodes. Journal of Biological Sciences 2: 446-448.

Riga, P. 2015. Effect of rootstock on growth, fruit production and quality of tomato plants grown under low temperature and light conditions. Horticulture, Environment, and Biotechnology 56 (5): 626-638.

Rivard, C. L. and F. J. Louws. 2006. Tomato grafting for disease resistance in heirloom tomatoes. North Carolina Cooperative Extension Service 1-8.

Rivard, C. L and F. J. Louws. 2008. Grafting to manage soilborne diseases in heirloom tomato production. HortScience 43: 2104–2111.

Rivard, C. L., S. O. Connell, M. M. Peet, and F. J. Louws. 2010. Grafting tomato with interspecific rootstock to manage diseases caused by *Sclerotium rolfsii* and southern root-knot nematode. Plant Disease 94 (8): 1015-1021.

Rivero, R. M., J. M. Ruiz, and L. Romero. 2003. Role of grafting in horticultural plants under stress conditions. Journal of Food Agriculture and Environment 1: 70-74.

Ruiz, J. M. and L. Romero. 1999. Nitrogen efficiency and metabolism in grafted melon plants. Scientia Horticulturae 81 (2): 113-123.

Sakata, Y., O. Takayoshi, and S. Mitsuhiro. 2007. The history and present state of the grafting of cucurbitaceous vegetables in Japan. Acta Horticulturae 731: 159-170.

Santa-Cruz, A., M. M. Martinez-Rodriguez, F. Perez-Alfocea, R. Romero-Aranda, and M. C. Bolarin. 2002. The rootstock effect on the tomato salinity response depends on the shoot genotype. Plant Science 162 (5): 825-831.

Satoh, S. 1996. Inhibition of flowering of cucumber grafted on rooted squash stocks. Plant Physiology 97: 440–444.

Savvas, D., D. Papastavrou, G. Ntatsi, A. Ropokis, C. Olympios, H. Hartmann, and D. Schwarz. 2009. Interactive effects of grafting and manganese supply on growth, yield, and nutrient uptake by tomato. HortScience 44 (7): 1978-1982.

Savvas, D., A. Savva, G. Ntatsi, A. Ropokis, I. Karapanos, A. Krumbein, and C. Olympios. 2011. Effects of three commercial rootstocks on mineral nutrition, fruit yield, and quality of salinized tomato. Journal of Plant Nutrition and Soil Science 174 (1): 154-162.

Schwarz, D., Y. Rouphael, G. Colla, and J. H. Venema. 2010. Grafting as a tool to improve tolerance of vegetables to abiotic stresses: Thermal stress, water stress and organic pollutants. Scientia Horticulturae 127 (2): 162-171.

Venema, J. H., B. E. Dijk, J. M. Bax, P. R. van Hasselt, and J. T. M. Elzenga. 2008. Grafting tomato (*Solanum lycopersicum*) onto the rootstock of a high-altitude accession of *Solanum habrochaites* improves suboptimal-temperature tolerance. Environmental and Experimental Botany 63 (1): 359-367.

Voutsela, S., G. S. A. Pertropoulos, and E. M. Khan. 2012. The effect of grafting of five different rootstocks on plant growth and yield of tomato plants cultivated outdoors and indoors under salinity stress. African Journal of Agricultural Research 7 (11): 5553-5557.

Win, T. 2003. Feasibility of grafted tomato plants in commercial fruit production. Master Thesis, Yezin Agricultural University, Naypyitaw.

Yetisir, H. and N. Sari. 2003. Effect of different rootstock on plant growth, yield and quality of watermelon. Animal Production Science 43 (10): 1269-1274.

Zheng, N., M. L. Wang, H. T. Wang, and X. Z. Ai. 2009. Effects of grafting on photosynthesis of sweet pepper seedlings under low temperature and weak light intensity. Ying Yong Shengtai Xuebao 20: 591–596.

APPENDICES

Appendix 1. Details of the crop cultivation practices in the experiment

Operation	Stock plants			Scion plant
Expt. I	Hot pepper (local)	Tomato (local)	Eggplant (local)	Commercial tomato cultivar
Date of sowing	10 May 2015	24 May 2015	17 May 2015	24 May.2015
Date of grafting	9 June 2015	9 June 2015	9 June 2015	9 June 2015
Date of transplanting to the nursery	19 June 2015	19 June 2015	19 June 2015	19 June 2015
Date of transplanting into the field	29 June 2015	29 June 2015	29 June 2015	29 June 2015
Expt. II				
Date of sowing	17 Sept 2015	2 Sept 2015	25 Sept 2015	2 Oct 2015
Date of grafting	16 Oct2015	16 Oct 2015	16 Oct 2015	16 Oct 2015
Date of transplanting to the nursery	23 Oct 2015	23.Oct 2015	23 Oct 2015	23 Oct 2015
Date of transplanting into the field	30 Oct 2015	30 Oct 2015	30 Oct 2015	30 Oct 2015
Expt. III				
Date of sowing	20 April 2016	8 May 2016	1 May 2016	8 May 2016
Date of grafting	22 May 2016	22 May 2016	22 May 2016	22 May 2016
Date of transplanting to the nursery	29 May 2016	29 May 2016	29 May 2016	29 May 2016
Date of transplanting into the field	29 May 2016	29 May 2016	29 May 2016	5 June 2016

Appendix 2. Details of the crop management practices in the experiment

	Fertilizer application	Weeding	Pesticide application	Harvesting
Expt. I				
1st time	7 July 2015	6 July 2015	7 July 2015	9 Sep 2015
2nd time	17 July 2015	15July 2015	16 July 2015	12 Sep 2015
3rd time	27 July 2015	25 Aug 2015	26 July 2015	16 Sep 2015
4th time	6 Aug 2015	5 Aug 2015	5 Aug 2015	19 Sep 2015
5th time	16 Aug 2015	15 Aug 2015	15 Aug 2015	22 Sep 2015
Expt. II				
1st time	7 Nov 2016	6 Nov 2016	8 Nov 2016	16 Jan 2016
2nd time	17 Nov 2016	15 Nov 2016	16 Nov 2016	19 Jan 2016
3rd time	27 Nov 2016	24 Dec 2016	26 Nov 2016	22 Jan 2016
4th time	7 Dec 2016	5 Dec 2016	6 Dec 2016	25 Jan 2016
5th time	17 Dec 2016	15 Dec 2016	16 Dec 2016	28 Jan 2016
Expt. III				
1st time	13 June 2016	12 June 2016	13 June 2016	6 Aug 2016
2nd time	23 June 2016	22 June 2016	21 June 2016	11 Aug 2016
3rd time	3 July 2016	2 July 2016	1 July 2016	16 Aug 2016
4th time	13 July 2016	12 July 2016	11 July 2016	21 Aug 2016
5th time	23 July 2016	22 July 2016	21 July 2016	26 Aug 2016