THE EFFECTS OF GRAFTING ON TOMATO (*Solanum lycopersicum* L.) YIELD AND QUALITY

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE.

MOROGORO, TANZANIA.

2017

ABSTRACT

F1 Hybrid tomato cultivars are preferentially grown in Tanzania due to their high yield but are susceptible to some common biotic stresses. Grafting tomato onto compatible and resistant rootstocks has a greater potential to overcome soil borne diseases, abiotic stresses, improve growth, yield and fruit quality. However, in Tanzania there is limited information regarding grafting between F1 hybrid tomato cultivars and selected eggplant rootstocks. Therefore, the objectives of this study were: (1) to determine graft success between selected eggplant rootstocks and selected F1 hybrid tomato cultivars, (2) to evaluate the effect of selected eggplant rootstocks on plant growth, yield and fruit quality of F1 hybrid tomato cultivars and (3) to determine profitability of grafted F1 hybrid tomato cultivars. Experiments were laid out in a Randomized Complete Block Design with 3 replications. Tomato cv. Assila, Monica and Tengeru 97 as a control were grafted onto rootstocks EG190, EG195 and EG203 and transplanted in the field. Data for specific objectives 1 and 2 were subjected to Analysis of Variance using GenStat version 14 software (VSN International, UK). Treatment means were separated by Tukey's Test at $P \leq 0.05$ whereas profitability data were analysed descriptively. Results revealed significantly low ($p = 0.001$) field grafting success after transplanting, reduced growth ($p = 0.001$), low yield ($p = 0.001$) and low profitability for grafted Assila and Monica in comparison to ungrafted Assila, Monica and grafted Tengeru 97. Conversely, grafting improved fruit taste based on enhanced total soluble solids (TSS) in rootstock/Assila and rootstock/Monica. Overall, tomato cv. Assila and Monica should not be grafted onto these eggplant rootstocks due to low graft success, low yield and low profitability. Further studies are required to identify rootstocks that are compatible with, and vigorous enough for growth, fruit quality and profit improvement.

DECLARATION

I, BASILIA SHIPEPE, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

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The above declaration is confirmed by:

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AKNOWLEDGEMENTS

I would like to extend special gratitude to my supervisor, Professor T. J. Msogoya of the Department of Crop Science and Horticulture for his unwavering academic advice, constructive criticisms and guidance throughout the course of this study. I took pride in working with him. I am grateful for invaluable contributions of any sort I had been accorded by other academicians and staffers of the same department who, despite their busy schedules went out of their ways to support my work. Many more thanks are extended to staffers at Horticulture Section for logistical and technical support to get this study up and running. I am equally indebted to the Division of Product Development, Training and Quality Assurance (DPDTQA) of the Ministry of Agriculture, Water and Forestry, Namibia for availing financial assistance to make this study a reality.

Further special acknowledgement is due to my fellow students and family whose fruitful interventions, constant encouragement and moral support gave me a reason to believe in myself and go on through thick and thin. Likewise, I take pride in acknowledging all individuals, too numerous to specify, who stood by me and went an extra mile to make certain that this work had become a part of literature the scientific community can draw from.

DEDICATION

This work is dedicated to:

The memories of my late father and my baby sister, Shivute and Viktoria respectively, who have certainly watched over me as this study unfolded and would have proudly and substantially contributed towards it. You always both hold a special spot in my heart.

My mother, Maria Paula who braved my absence as I pursued this study at a time in her life when she needed me most. I could not be prouder of you apple.

My best friend, my other half, Ann-Muteibile who wholeheartedly took over my personal life's driving seat, ensuring that I fully concentrated on pursuing this work. I owe you all my life's success stories.

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LIST OF ABBREVIATIONS AND SYMBOLS

%	Per cent
<	Less than
>	Greater than
°C	Degree celsius
ANOVA	Analysis of Variance
AVRDC	Asian Vegetable Research and Development Center
cm	Centimeter
CO_2	Carbon dioxide
cv.	Cultivar
	Development
DPDTQA	Division of Product Development, Training and Quality Assurance
E	East
EG190	Eggplant rootstock 190
EG195	Eggplant rootstock 195
EG203	Eggplant rootstock 203
etc.	Etcetera
F1	Filial generation
FAO	Food and Agriculture Organization
FAOSTAT	FAO statistical databases
Fe	Iron
FO	*Fusarium oxysporum*
FOL	*Fusarium oxysporum lycopersici*
ha	Hectare

IPM	Integrated Pest Management
Kg	Kilogram
m	Meter
MeBr	Methyl Bromide
Mg	Magnesium
mm	Milimeter
OECD	Organization for Economic Cooperation and
P	Phosphorus
pH	Potential Hydrogen
RCBD	Randomized Complete Block Design
RKN	Root Knot Nematode
S	South
SUA	Sokoine University of Agriculture
t	Ton
TA	Titratable acidity
TFWD	Tomato fusarium wilt disease
TSS	Total soluble solids
TYLCV	Tomato yellow leaf curl virus
US$	United States Dollars
USA	United States of America

CHAPTER ONE

1.0 INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a herbaceous, sprawling tropical plant in the order Solanales and family Solanaceae. It is one of the most important and popular vegetables in the world owing to its wider adaptability, high yielding potential and suitability for a variety of uses for both fresh and processed food industries (Meena and Bahadur, 2015). It is an economically important cash crop with high demand in the international market (Solieman *et al.*, 2013). Tomato is Tanzania's most important vegetable crop contributing 51% of total fruit and vegetable production (Mamiro *et al.*, 2015). The crop had a total annual production of more than 145 000 tons (Mamiro *et al.*, 2015) from an area of 34 713 ha in 2013 (FAOSTAT, 2013). It is the most important crop for cash and domestic uses produced mostly by small and medium scale farmers in large areas of Tanzania Mainland (Meya *et al.*, 2014).

Nutritionally, tomato is an important source of vitamins, minerals, essential amino acids, sugars and dietary fibres. Its vitamin C content is particularly high (Kanyomeka and Shivute, 2005) and is an excellent source of lycopene, a powerful antioxidant with anti-carcinogenic potential (Dagade *et al.*, 2015; Tasnia *et al.*, 2015). Its balanced mixture of minerals, vitamins, antioxidants and carbohydrates earns it an excellent nutritional profile (Tasnia *et al.*, 2015).

Tomato production is constrained by both biotic and abiotic stresses in the eastern zone of Tanzania in particular (Minja *et al.*, 2011) and worldwide. Though production in the eastern Tanzania has increased due to growing demand of the produce, productivity has remained low, with the average yield ranging between 2.2 to 3.3 t per ha (Minja *et al.*, 2011). These figures are way below the world's average of 27.5 t per ha (FAO, 2005 cited by Minja *et al.*, 2011). Yield losses nearing 100% are common under heavy infestation of insects, diseases or weeds singly or in combination (Maerere *et al.*, 2010). Common tomato diseases occurring in Tanzania are fusarium wilt (*Fusarium oxysporum* f. sp. *lycopersici* Sacc.), early blight (*Alternaria solani* Sorauer), septoria leaf spot (*Septoria lycopersici*), cladosporium leaf mould (*Mycovellosiella fulva* Cooke) and root knot nematodes (RKN) (*Meloidogyne* sp) (Mamiro *et al.*, 2015). Abiotic stresses include salinity, drought, excessive heat and declining soil fertility (Minja *et al.*, 2011).

Pesticide application is the major pest management strategy of tomato pests in the country (Maerere *et al*., 2010; Mamiro *et al*., 2015) usually applied on a weekly basis (Mtui, *et al*., 2015). This exacerbates both the cost of production, risks for human health and environmental risks associated with pesticides (Maerere *et al*., 2010; Meya *et al*., 2014; Mtui *et al*., 2015). Ineffectiveness of some pesticides, unaffordability of effective ones by resource limited farmers and inadequate know-how on their appropriate use are other appreciable setbacks (Mtui *et al*., 2010; Meya *et al*., 2014). Disease-resistant varieties are limited (Minja *et al*., 2011) and can be overwhelmed by novel pathogens and under higher disease pressure (Cerkauskas, 2005; Louws *et al*., 2010; Michel *et al*., 2010). This leaves farmers with few options for managing soil-borne diseases and therefore at the mercy of these stresses.

One of the most devastating tomato diseases in the Morogoro Region is tomato fusarium wilt disease (TFWD). It is a major cause for concern, particularly to resource limited producers who cannot afford effective but costly measures such as soil steaming. Soil steaming and grafting onto resistant rootstocks have been the most common and effective measures against the disease where tomato is intensively cultivated (Ibrahim *et al*., 2001; Bletsos and Olympios, 2008). Grafting in this context involves uniting a rootstock and a scion of two plants to produce a single functioning plant (Mudge *et al.,* 2009). Grafting technology can be employed by farmers that cannot afford soil steaming and pesticides as well as to reduce dependency on such chemicals. Today, grafting is also being employed to enhance crop response to a variety of abiotic stresses (Rivero *et al*., 2003; Louws *et al*., 2010; King *et al*., 2010; Schwarz *et al*., 2010; Rivard and Louws, 2011), thereby improving growth, yield and fruit quality. Some of the problems associated with grafting are rootstock/scion graft failure and increased production costs. Despite its economic potential the technology has not been fully explored in the Tanzanian environment.

1.1 Justification

Farmers in Tanzania are preferentially growing F1 hybrid tomato cultivars such as Monica, Anna, Assila, Shanty, and Eden for their high yield. These cultivars are also advocated to be resistant to TFWD, RKN, bacterial wilt and tomato yellow leaf curl virus (TYLCV). However, preliminary studies conducted in Kilosa and Kilombero valleys indicated that some of these cultivars are more susceptible to TFWD and RKN than some local open-pollinated tomato cultivars. TFWD and RKN are some of the most serious biotic stresses devastating tomato production in Tanzania, especially in Kilombero, Kilosa and Rufiji valleys. Crop rotation as a control measure is both time and space prohibitive while steaming is not affordable to some producers (Bletsos and Olympios, 2008; Rivard and Louws, 2008; Louws *et al*., 2010). Pesticides are hazardous to humans and environment, expensive and some are ineffective to control the diseases (Anitha and Rabeeth, 2009).

Grafting represents a viable strategy to mitigate biotic stresses (Leonardi and Giuffrida, 2006; Louws *et al*., 2010) and has been successfully employed to combat FWD, RKN and other diseases (Rivard and Louws, 2011). Grafting onto compatible and resistant rootstocks has a greater potential to overcome soil borne diseases including TFWD (Louws *et al*., 2010; Rivard and Louws, 2011). Eggplant rootstocks such as EG190, EG195, EG203 and EG219 are available at SUA and advocated as resistant to TFWD, RKN, bacterial wilt and flooding. Early studies on evaluation of grafted open pollinated tomato cultivars (Tanya, Tengeru 97, Cal-J and Riogrande) onto these rootstocks in Kilombero valley resulted in low TFWD incidences and severity. The same combination also resulted in grafting success ranging from 86-100%, significantly high yield and unaltered fruit quality (Msogoya and Mamiro, 2016).

Grafting onto vigorous rootstocks also improves growth, yield and quality even in the absence of a disease as a result of tolerance against abiotic stresses (Rivero *et al*., 2003; Louws *et al*., 2010; Schwarz *et al*., 2010; Rivard and Louws, 2011). Graft incompatibility is one of the major challenges especially when rootstocks and scions differ in growth vigour. Therefore, there is limited information on graft success between the selected rootstocks (EG190, EG195, EG219 and EG203) and selected F1 hybrid tomato cultivars (Monica and Assila). Plant growth, yield, fruit quality and economic feasibility of the combinations under question are also yet to be explored. Therefore, this study was designed to evaluate graft compatibility between the rootstocks and scions under consideration. The study was undertaken to also determine the effect of grafting on plant growth, yield, fruit quality and profitability of Assila, Monica and Tengeru 97.

1.2 Objectives

1.2.1 Overall objective

Improvement of tomato productivity in a biotically stressful environment in Morogoro through grafting technology.

1.2.2 Specific objectives

i. To determine graft success between selected eggplant rootstocks and selected F1 hybrid tomato cultivars.

ii. To evaluate the effect of selected eggplant rootstocks on plant growth, fruit yield and fruit quality of F1hybrid tomato cultivars.

iii. To determine profitability of grafted F1 hybrid tomato cultivars.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Importance of Tomato

2.1.1 World tomato production status

Tomato originated from the South American Andes Region (Shankara *et al*., 2005). It is a herbaceous tropical perennial plant grown as an annual crop for its fruits, destined for both fresh and processing market. The crop is highly productive, rendering it an economically valuable commodity worldwide. It is an important cash crop for commercial farmers of all scales (Shankara *et al*., 2005). Tomato has achieved tremendous popularity over the last century, being cultivated practically in every country under field, greenhouse and nethouse conditions (Wener, 2016). It is the world’s largest vegetable category, representing 16% and has attained an increase in production of 49% between 2000 and 2013 (Eurofresh Distribution, 2016). The top five leading tomato producing countries are the United States, China, Turkey, Italy, Mexico and India (Dagade *et al*., 2015; Tomato world production statistics, 2015), accounting for 70% of global production. Mexico is the world’s largest tomato exporter with over 1.5 million tons (Eurofresh Distribution, 2016). Morocco is Africa’s export leader, having doubled its tomato export volume to the European Union (EU) over the last 10 years to 387 000 tons in 2014 (Eurofresh Distribution, 2016).

2.1.2 Tomato production status in Tanzania

Ranked as the main economic vegetable crop in Tanzania after onion and cabbage, tomato production is widespread in the country. It has a total annual production of more than 145 000 tons from an area of 34 713 ha in 2013 (FAOSTAT, 2013). Tomato contributes 51% of total fruit and vegetable production (Mamiro *et al*., 2015). It is the most important crop for cash and domestic use and is produced mostly by small and medium scale farmers in large areas of Tanzania Mainland (Meya *et al*., 2014). It is a vital source of income for resource limited small-scale farmers particularly women and is produced mainly under open field conditions destined primarily for domestic market Tomato production boasts more than 20 000 smallholder farmers in the Arusha, Kilimanjaro, Iringa, Tanga, Morogoro and Mbeya regions (Philemon, 2011). Morogoro Region is the country's largest producer of the commodity, with an area under cultivation of 6,519 ha (Philemon, 2011). The number of tomato growers has been increasing yearly owing to the commodity's high economic gains.

Tomato production in the country is plagued by both biotic and abiotic challenges (Mbega *et al.,* 2011; Minja *et al.,* 2011), terminating in substantial yield losses. The average tomato yield under smallholder farming ranges from 2.2 to 16 metric tons per ha (FAOSTAT, 2013) while large commercial farmers elsewhere produce 40 to 60 metric tons per ha (Msogoya, T. J. personal communication, 2016). There are no varieties with resistance or tolerance to these stresses adapted to eastern Tanzania's agro ecologies (Minja *et al*., 2011). Currently, in the Morogoro Region there is a huge reliance on routine pesticide application as a management strategy along with two to three hand weeding operations per season (Maerere *et al.,* 2010). Alternative pest management strategies being explored include integrated pest management such as healthy planting materials and mulching (Maerere *et al.,* 2010; Shenge *et al.,* 2010).

2.1.3 Nutritional significance of tomato

Tomato plays an important role in contributing to a healthy, well-balanced diet due to its high nutritional status. Being rich in minerals, vitamins, essential amino acids, sugars and dietary fibres, it is one of major ingredients in numerous dishes and products (Shankara *et al.,* 2005). Tomato boasts much vitamin A, B and C, iron and phosphorus (Shankara *et al*., 2005; Wener, 2016). Furthermore, tomato contains antioxidants like lycopene and betacarotene compounds that protect cells against carcinogenic substances (Shankara *et al*., 2005; Dagade *et al.,* 2015; Tasnia *et al*., 2015). The commodity is consumed fresh in salads or cooked in sauces, soup and meat or fish dishes (Tasnia *et al*., 2015; Bawa, 2016). It is processed into a variety of products like purées, juices, ketchup, chutney and paste (Tasnia *et al*., 2015; Bawa, 2016).

2.2 Grafting Technology

2.2.1 Origin and evolution of grafting technology

Grafting is defined as a deliberate fusion of two or more living plant parts so that vascular continuity is established between them and the resultant genetically composite organism functions as a single plant (Mudge *et al*., 2009; Savvas, *et al*., 2010). The part that provides the root system is called a rootstock while the one providing the aerial part is a scion. The fusion allows the grower to combine a scion possessing desirable fruit producing traits with a rootstock that may be resistant to a multitude of biotic and abiotic stresses, resulting in a more productive plant (Petran and Hoover, 2014).

Traditionally, grafting was confined to woody perennial species that did not root well from vegetative cuttings (Petran and Hoover, 2014). In vegetable production grafting was first practiced in Korea and Japan in the early 20th century when watermelon (*Citrullus lanatus*) was grafted onto squash rootstock (*Cucurbita moschata*) to manage fusarium wilt (Rivero *et al*., 2003; Kubota *et al*., 2008; King *et al*., 2010). Research on cucumber (*Cucumis sativus* L.) grafting started in the late 1920s, though wider commercial applications could only be realized in the 1960s (Sakata *et al*., 2008). As for the Solanaceae family the first record was of eggplant (*Solanum melongena* L.) grafted on scarlet eggplant (*Solanum integrifolium* P.) in the 1950s (Oda, 1998) while tomato grafting was introduced commercially in the 1960s (Lee and Oda, 2003; Bletsos and Olympios, 2008).

Grafting in vegetable production systems has since been exploited to manage such pathogens as other fungi, oomycetes, bacteria, nematodes and viruses in vegetable producing areas dominated by monocropping and intensive cultivation (Khah *et al*., 2006; Louws *et al.*, 2010; Turhan *et al.*, 2011). In the Mediterranean regions grafting has been adopted as a major component of an integrated program to manage soilborne pathogens (Rivard and Louws, 2008). The technology was introduced to western countries in the early 1990s (Lee *et al*., 2010) initially in response to a need to grow residue free produce and due to the phasing out of Methyl bromide (Besri, 2003). According to Bletsos and Olympios (2008), the other rationale for grafting was the increasing demand for produce grown under organic and Integrated Pest Management systems (IPM).

The increasing advantages of grafting coupled with its possible application in commercial vegetable production have led to employment of this technology beyond disease management (Lee, 1994; Bletsos and Olympios, 2008). That encompasses grafting for tolerance against high and low temperatures, flood, (Black *et al*., 2003; King *et al*., 2010) drought, salinity, heavy metals, enhanced growth vigour, yield and quality, amongst others (Lee, 1994; Rivero *et al*., 2003; Bletsos and Olympios, 2008; Davis *et al*., 2008, Colla *et al*., 2014).

Consequently, grafting is now a common practice in many countries of Europe, the Middle East, Northern Africa, Central America, and other parts of Asia (Kubota *et al*., 2008). Today 81% and 59% of Korean and Japanese vegetables respectively, are produced on grafted plants (Rivero *et al*., 2003; Bletsos and Olympios, 2008). Vegetable grafting has been a standard procedure for many greenhouse operations (Rodriquez and Bosland, 2010). Meanwhile the technology has also gained momentum under open field conditions

(Rodriquez and Bosland, 2010) and further research is still underway to evaluate its application thereunder (Kubota *et al.,* 2008).

2.2.2 Grafting techniques applicable to vegetables

Grafting methods applicable to vegetables including tomato are tube grafting, tongue approach grafting, hole insertion grafting, cleft grafting and horizontal pin grafting (Bletsos and Olympios, 2008; Lee *et al.*, 2010). A grafting method to be employed varies with the kind of crop being grafted, preferences and experience of growers (Lee, 1994; Lee *et al.*, 2010) and the kind of grafting machines or robots available (Lee *et al*., 2010). The most common methods for grafting fruit vegetables are tube, tongue approach and cleft grafting. In particular, tomato and eggplants are grafted mainly by conventional tube and cleft grafting methods (Marsic and Osvald, 2004).

2.2.2.1 Tube (splice) grafting

Tube grafting is the most common tomato grafting technique for commercial propagation worldwide (Oda, 1998) due to its relative speedy manual grafting rate of 300 to 500 plants per hour per worker (Kubota *et al*., 2008). It can be performed on very small plants, thereby increasing throughput (Lee, 2003). The technique has a typical success rate of 85 to 95% (Rivard and Louws, 2008; Johnson *et al*., 2011b) attributable to a complete fusion of all vascular bundles of both parts (Lee *et al*., 2010). It is relatively simple to perform (Johnson *et al*., 2011b) and has become popular for watermelon and melon (Marsic and Osvald, 2004).

2.2.2.2 Cleft grafting

Cleft grafting, also called apical grafting has been used in cucurbits for a while, however its use is usually confined to solanaceous crops (Lee *et al*., 2010). (Marsic and Osvald,

2004) observed a 100% survival rate of tomato cultivar “Monroe” grafted onto “Beaufort” and “PG3” tomato rootstocks with cleft grafting while “Belle” on the same rootstocks resulted in 92% and 93% survival rate, respectively.

2.3 Grafting Materials

A number of grafting tools to facilitate automated and manual grafting are available though most of them are not widely used by commercial growers (Lee *et al*., 2010). Grafting clips, tubes, tapes, and pins are some such grafting aids. Plastic clips with circular springs have been most extensively used for tongue approach and splice grafting techniques in cucurbits and other crops (Bletsos and Olympios, 2008; Lee *et al*., 2010). Specially designed knives, and hole insertion equipment have been manufactured for manual grafting (Bletsos and Olympios, 2008).

2.4 Sowing Scheduling for Grafting

For successful alignment of cambiums stem diameters of rootstocks and scions must be of comparable sizes (Johnson *et al*., 2011b; Rivard and Louws 2011; Miles *et al*., 2013), depending on the grafting method to be employed. This necessitates well thought out sowing scheduling of a rootstock and a scion involved. The relative duration to emergence and growth rate of rootstock and scion seedlings strongly influences sowing and grafting schedules (Black *et al*., 2003).

Most fresh market tomato lines germinate in two to three days while eggplant requires up to six days at 21 to 24ºC (Black *et al*., 2003). As such AVRDC generally sows eggplant seeds three days before sowing tomato scions (Black *et al*., 2003). When tomato is to be grafted onto tomato rootstocks, seed of the scions and rootstocks are sown on the same day (Black *et al*., 2003). More seed than necessary should be sown to secure a greater selection for matching stem diameters and to account for less than 100% grafting success rates (Rivard *et al*., 2010; Johnson *et al*., 2011b; Miles *et al*., 2013). Plants are ready for grafting when they attain two to four true leaves (Black *et al*., 2003; Johnson *et al*., 2011b).

2.5 Grafting Process

The grafting process constitutes rootstock and scion selection, application of the grafting technique, healing of the graft union, evaluation of graft success and acclimatization (hardening off) of grafts (Bletsos and Olympios, 2008; Lee *et al*., 2010).

2.5.1 Rootstock selection

Rootstock selection is the single most important step in grafting tomato for disease resistance (Rivard and Louws, 2011). A suitable rootstock is one that is compatible with a scion under question, resists biotic and abiotic stresses, enhances scion growth, yield and fruit quality (Bletsos and Olympios, 2008; Savvas *et al*., 2009). Selection of rootstocks should also be based on suitability for growing seasons, climate and growing conditions (Bletsos and Olympios, 2008; Bumgarner and Kleinhenz, 2015).

2.5.2 Application of grafting technique

Both rootstock and scion seedlings must be watered 12–24 hours before grafting (Johnson *et al*., 2011b; Miles *et al*., 2013). A day before grafting the inside surfaces of the healing chamber should be misted with water to raise relative humidity to 95% before grafts are placed inside (Johnson *et al*., 2011a; Ozores-Hampton and Frasca, 2013). Grafting should be performed in a shady, wind free place and during the cooler part of a day to reduce wilting of grafts (Rivard and Louws, 2011). Hands and working surfaces should be cleaned with anti-microbial detergents and hand latex gloves and sterile tools should be used to reduce exposure of plants to pathogenic bacteria, fungi and viruses (Rivard and Louws, 2011).

2.5.3 Healing of graft union

The rootstock must establish vascular connection which is the most critical part of the healing process in grafted vegetable transplants (Ozores-Hampton and Frasca, 2013) A complete vascular connection takes approximately five to eight days, during which water translocation to the scion is still not enabled (Fernández-García *et al*., 2004; Johnson *et al*., 2011a cited by Ozores-Hampton and Frasca, 2013). This requires that environmental conditions be managed accordingly to prevent graft desiccation. As such grafts are held in a low light intensity healing chamber at 25-32 ˚C and 85-100 % relative humidity for four–seven days (Black *et al*., 2003; Kubota *et al*., 2008; Ozores-Hampton and Frasca, 2013). Ninety five percent relative humidity is considered optimum for this purpose (Lee, 2007; Oda, 2007) and should be maintained throughout the entire healing process (Ozores-Hampton and Frasca, 2013). The stipulated temperature range stimulates cell division which is fundamental for the healing process (Lee, 2007). Misting, instead of direct water application to grafts is employed to prevent diseases, necrotic tissue formation and graft failure (Johnson *et al*., 2011b).

2.5.4 Acclimatization of grafts

Approach to acclimatization depends on the prevailing environmental conditions. Thus, on the fifth day following grafting the healing chamber should be opened for about 30 minutes, and chamber’s surfaces and grafts misted if necessary. (Miles *et al*., 2013). On the sixth day, the chamber should be opened for two to four hours (Ozores-Hampton and Frasca, 2013). Grafts can be removed from the healing chamber on the seventh day (Ozores-Hampton and Frasca, 2013). Grafts should then be held in the greenhouse for five to 10 days, before transferring them outside for three to five days for further hardening off

(Miles *et al.*, 2013). The major hydraulic connections within the graft union of tomato becomes functional five days after grafting (Fernández-García *et al*,. 2004). Full healing and functioning takes 14 to 15 days thereafter (Fernández-García *et al*., 2004; Miles *et al*., 2013; Tamilselvi and Pugalendhi, 2017).

2.6 Transplanting and Field Management of a Grafted Vegetable Crop

When transplanting the graft interface should remain well above the soil line. A graft interface in contact with the soil will result into adventitious rooting of a scion into the soil, nullifying any advantages such as disease resistance sought from a rootstock (Black *et al.*, 2003; Johnson *et al.*, 2011b; Rivard and Louws, 2011; Miles *et al.*, 2013). Adventitious roots should therefore be routinely removed before reaching the soil (Johnson, 2011a; Miles *et al.*, 2013). Likewise, suckers developing on the rootstock near the cotyledons should be removed (Rivard and Louws, 2011). Plants should be staked and indeterminate tomato varieties should be pruned to two main stems two to three weeks after transplanting (Black *et al.*, 2003).

2.7 Benefits of Vegetable Grafting

Vegetables are high value commodities, however they are also subject to grave losses, both pre and post-harvest particularly in tropical regions (Wills *et al.*, 1996). These losses assume considerable economic and social significance (Wills *et al.*, 1996). The primary causes of such losses are disease outbreaks of fungal, bacterial, and viral pathogens. Research has demonstrated that grafting has a potential to restrain some of these diseases (Rivard and Louws, 2011).

Furthermore, environmental stresses constitute some of the most important limiting factors for plant growth and horticultural productivity worldwide (Wahb-Allah, 2014). Consequently, the technology is currently being employed to induce tolerance against thermal stresses (Rivero *et al*., 2003; Schwarz *et al*., 2010), reduce uptake of persistent organic pollutants (Schwarz *et al*., 2010) and salt (Colla *et al*., 2010), resulting in improved growth, yield and quality. Grafting has also proven to curtail alkalinity stress, drought and flooding (Schwarz *et al*., 2010).

2.7.1 Grafting to manage biotic stresses

The earliest prime purpose for commercial grafting efforts was to manage fusarium wilt in watermelon production (Davis *et al*., 2008; Sakata *et al*., 2008; Louws *et al*., 2010). Grafting in vegetable production systems has since then rapidly expanded to manage other pathogens in other solanaceous and cucurbit vegetables (Davis *et al*., 2008; Louws *et al*., 2010). The accelerated expansion was necessitated by increased pathogen inoculum densities due to intensification of production practices (Khah *et al*., 2006) and reliance on susceptible cultivars to meet specific market demands (Sakata *et al*., 2007). Global movement and local invasion of novel pathogens, increased use of organic practices, rapid adoption of high tunnel production systems, and the loss of methyl bromide (MeBr) also contributed to such expansion (Louws *et al*., 2010), thus seeking alternative approaches.

2.7.1.1 Diseases commonly managed by grafting in solanaceae and cucurbit vegetables

Some of the diseases successfully controlled by grafting in solanaceous and cucurbitaceous crops are fusarium wilt (*F. oxyporum)*, RKN (*Meloidogyne* spp.), verticillium wilt (*Verticillium dahlia*), bacterial wilt (*Ralstonia solanacearum*), monosporascus sudden wilt (*Monosporascus cannonballus*) and phytophthora blight (*Phytophthora capsici*) (Bletsos and Olympios, 2008; Davis *et al*., 2008; Guan *et al*., 2012). In Morocco, 95% of greenhouse tomato is produced on grafted plants due to resistance against *F. oxyporum* f. sp. *lycopersici, F. oxyporum* f. sp. *radices-lycopersici*, and *Ralstonia solanacearum*, assured by select rootstocks and therefore ensuring higher yield (Bletsos and Olympios, 2008). AVRDC recommends tomato line rootstock Hawaii 7996 due to its high resistance to bacterial wilt and fusarium wilt while eggplant rootstocks EG190, EG195, EG203 and EG219 are resistant to fusarium wilt, bacterial wilt and RKN (Black *et al*., 2003). Grafting against diseases in vegetable production is also becoming a common practice in open field conditions (King *et al*., 2008) and is considered as an important IPM package (Besri, 2003; Rivard and Louws 2008; Louws *et al*., 2010).

2.7.1.2 Intraspecific, interspecific grafting and strategies to maintain rootstock resistance to diseases

Grafting to defy diseases may either be intraspecific or interspecific. Intraspecific grafting refers to grafting plants of the same species, for example grafting tomato onto tomato. Interspecific grafting on the other hand involves grafting plants of different species such as eggplant and tomato. Intraspecific grafting often relies on use of specific major resistance genes that maybe overcome by indigenous or novel races of a compatible pathogen (Louws *et al*., 2010). Intraspecific grafting may be preferred due to its less negative effects on crop productivity, fruit quality or graft compatibility (Louws *et al*., 2010; Guan *et al*., 2012). Single gene-mediated host resistance has been an important mechanism to manage fusarium diseases in solanaceous crops (Louws *et al*., 2010). On the other hand, interspecific and intergeneric rootstock confers multigenic resistance or nonhost reactions rendering them broader spectrum and durable (Louws *et al*., 2010; Guan *et al*., 2012). Intergeneric grafting has proven to be an effective management tactic, particularly in cucurbit crops (Louws *et al*., 2010).

In the absence of other IPM tactics resistance of grafted plants may break down under high disease pressure, or with evolution of new races and strains (Louws *et al*., 2010; Michel *et* *al*., 2010). In Switzerland, the resistance of tomato rootstock “Maxifort” to *V. dahliae, F. oxysporum* and *Pyrenochaeta lycopersici* broke down after an infection of roots by *C. coccodes* (Michel *et al*., 2010). Therefore, grafting with resistant rootstock is most successful when developed with an understanding of the complex nature of diverse biotic agents and in combination with IPM programs (Cohen *et al*., 2000 cited by King *et al*., 2008; Louws *et al*., 2010). In addition, over-reliance on specific rootstocks also leads to shifts in host specificity of the pathogen population (Rivard *et al*., 2010). Reliance on rootstocks in the absence of fumigation led to resurgence problems with tomato brown root rot caused by *Colletotrichum coccodes* and other pathogens (Rivard *et al*., 2010).

2.7.2 Grafting to manage abiotic stresses

2.7.2.1 Grafting against water deficit and extreme temperatures

Fruit vegetable production can be constrained by high temperatures under hot semi-arid conditions (Abdelmageed and Gruda, 2009) and during the hot-wet and hot-dry season in the tropics (Palada and Wu, 2008). Supraoptimal temperatures cause increase in respiration, reduced water and ion uptake/movement, cellular dehydration, reduced photosynthetic rate and consequently reduced growth rate (Schwarz *et al*., 2010).

Grafting onto rootstocks with large and vigorous roots can improve water use efficiency (Rivero *et al*., 2003; Guan *et al*., 2012) under drought conditions and reduces losses in production (García-Sánchez *et al*., 2007; Satisha *et al*., 2007). Eggplant rootstock cv. “Yuanqie” grafted onto a heat-tolerant rootstock cv. “Nianmaoquie” resulted in a prolonged growth stage and yield increase of up to 10% (Wang *et al*., 2007).

Low soil temperatures threaten survival of cold sensitive plants, inflicting heavy economic losses in yield, due to retarded plant growth and development, wilt, necrosis and retarded fruit ripening (Ahn *et al*., 1999). This emanates from limited water and essential mineral nutrients uptake leading to slower leaf initiation and expansion rate as well as late crop productivity (Schwarz *et al.*, 2010). Cold-tolerant rootstocks increase root hydraulic conductance, decrease induction of cell wall suberin layers, lipid peroxidation, and stomatal closure (Bloom *et al.* 2004). Both uptake and transport of nitrate and phosphate, increased in figleaf gourd rootstocks in response to decreased root-zone temperature (Schwarz *et al.*, 2010).

2.7.2.2 Grafting against hypoxia and anoxia

Flooding and submergence are serious problems for growth and yield of flood sensitive crops including tomato. The conditions inflict oxygen starvation which arises from slow diffusion of gases in water and from oxygen consumption by microorganisms and plant roots (Schwarz *et al.*, 2010). A decrease in chlorophyll content was less pronounced in water melon grafted onto *Lagenaria siceraria* in comparison to a non-grafted one (Yetisir *et al.*, 2006). Flooding occurs also during the heat period in the lowland tropics for which Black *et al.* (2003) and Palada and Wu (2009) recommend grafting tomato onto eggplants EG195 or EG203 and pepper onto chili accessions “PP0242-62” and “Lee B”. Adventitious roots, improved nutrient absorption, hypertrophied stem and aerenchyma formed in grafted eggplant, tomato and chili under flooding conditions are said to be the mechanisms conferring tolerance to flooding (Schwarz *et al.*, 2010).

2.7.3 Grafting to improve vegetable growth and yield

The objectives of grafting have over the years expanded beyond disease management to include abiotic stress tolerance, improved growth, yield and produce quality (Savvas *et al.*, 2009; Lee *et al.*, 2010). Moreover, the primary purpose for grafting tomato in Europe and the USA has been to extend the harvest season in greenhouse production (King *et al.*, 2010) thereby increasing yield. This enables offseason production and caters for a lucrative niche market.

A vigorous and larger rootstock on a vigorous scion increases absorption and translocation of water and nutrients, enhancing plant growth and yield (Davis *et al.,* 2008; Lee, 2010; Martinez-Ballesta *et al*., 2010). N, K and Mg uptake efficiency and use were improved by grafting vegetables onto vigorous rootstocks under deficit irrigation (Rouphael *et al*., 2008). Eggplant rootstocks are more efficient for water uptake than their tomato counterparts (Colla *et al*., 2014) due to their dense and extensive root systems (Bletsos and Olympios, 2008). They are better adapted to hot arid climate, performs better under wet conditions and can serve as rootstocks for tomato under these conditions to optimize yield (Black *et al*., 2003; Palada and Wu, 2008). Black *et al*. (2003) recommends rootstocks EG195 and EG203 for these conditions. Tomato grafted onto eggplant has a larger leaf surface area, greater root and shoot dry weight and yield higher at higher temperature (Bletsos and Olympios, 2008). Likewise, Al-Harbi *et al.* (2016) reported a significant increase in stem diameter, plant height and shoot fresh weight of grafted tomato as compared to non grafted tomato. Khah *et al*. (2006) observed an increase in height and yield for open field grafted tomato plant.

The frequency of agrochemical application can be significantly reduced by using vigorous rootstocks, enhancing successful production of organically grown fruit set (Lee *et al*., 2010; Martinez-Ballesta *et al*., 2010). In grafted watermelon for example it is recommended to reduce the amount of fertilizer to about one-half to two-third as standard recommendations compared to non-grafted crop (Lee and Oda, 2003). In cucumber a vigorous root system of the rootstock can effectively absorb water, necessitating less frequent irrigation (Lee *et al*., 2010).

Higher yield in a grafted crop as opposed to a non-grafted one results from larger and many fruits per plant (Pogonyi *et al*., 2005). Turhan *et al*. (2011) reported a higher number of fruit index, fruits per truss, fruit weight and fruits per plant of grafted tomato in comparison to controls. Mini-watermelons grafted onto a commercial rootstock resulted in more than 115% total yield when grown under conditions of deficit irrigation as compared to ungrafted melons (Rouphael *et al.,* 2008). Likewise Huitron- Ramirez *et al.* (2009) observed a yield increase of 66% and 115% for watermelon cv. “Tri-X 313” grafted onto “RS841”.

On the other hand grafting has also been reported to confer deleterious effects on growth and yield. Khah *et al.* (2006) and Turhan *et al.* (2011) asserted that grafting tomato onto a suitable rootstock has a positive effect on cultivation performance and yield while some rootstocks can reduce scion growth and production. For example, tomato and eggplant grafted onto *Datura patula* exhibit less growth, lower production and smaller fruit size in comparison to self-rooted plants (Bletsos and Olympios, 2008).

Grafting has also been reported to delay flowering in vegetable crops. Khah *et al.* (2006) observed this phenomenon in both greenhouse and open field grafted tomato in comparison to controls. Likewise, Ibrahim *et al.* (2001) reported more days to first flowering, first fruit set, and first fruit maturity of grafted tomato plants in comparison to ungrafted ones. Both researchers ascribed the phenomenon to stress experienced by these plants following the operation. Ibrahim *et al.* (2001) further found that non-grafted plants had the maximum plant height at both first and last harvest.

2.7.4 Grafting to improve quality of vegetable produce

The principal objective of horticulture has been to increase yield for the growing world population. However, high quality is even more important than total yield, for attaining a competitive edge in modern horticulture (Rouphael *et al.*, 2010). This is owing to the beneficial role of vegetables in human diet (Rouphael *et al.*, 2010). From a horticulture perspective quality can be defined as the absence of defects or degree of excellence or superiority of a produce. It is a composite of those characteristics that differentiate produce, and have significance in determining the degree of acceptability of those produce to an end user. According to Flores *et al.* (2010) and Rouphael *et al.* (2010) quality parameters comprise those pertaining to appearance, (size, shape, colour, and absence of defects and decay), firmness, flavour (sensory properties like sweetness, acidity and aroma) and health-related compounds (minerals, vitamins, and carotenoids).

The apparent quality characteristics and composition of a final product of grafted plants should remain unchanged or be improved with respect to nongrafted plants (Gisbert *et al.*, 2011). However, conflicting reports on changes in fruit quality parameters resulting from grafting have surfaced (Davis *et al.*, 2008; Flores *et al.*, 2010; Gisbert *et al.*, 2011). These may be ascribed in part to different production environments (light intensity and air temperature), production methods (soilless vs. soil culture, irrigation, and fertilization), rootstock-scion combinations used, and harvest date (Davis *et al.*, 2008; Rouphael *et al.*, 2010). It has been suggested that changes in the scion are controlled by the rootstock through controlled uptake and translocation of water, minerals, and plant hormones (Lee and Oda, 2003).

2.7.4 1 Marketable yield

Grafting can increase tomato marketable yield by up to 54% (Lee *et al.*, 2010). Mini-watermelons grafted onto a commercial rootstock resulted into more than 60% higher marketable yield when grown under conditions of deficit irrigation as compared to ungrafted melons (Rouphael *et al.*, 2008). The technology has also significantly decreased abnormal fruits (Martinez-Ballesta *et al.*, 2010). The higher marketable yield is mainly due to an improved water and nutrient uptake by vigorous rootstocks (Di Gioia *et al*., 2010; Schwartz *et al*., 2010; Turhan *et al*., 2011). This is evidenced in a higher N, K, and Mg concentration in the leaves, and higher CO_2 assimilation (Colla *et al*., 2014). In grafted oriental melons, fresh fruit weight increase of 25–55% has been correlated with the maintenance of good plant vigour until late in the growing season in addition to disease resistance (Martinez-Ballesta *et al*., 2010). Deleterious effects may also appear as a consequence of grafting (Gisbert *et al*., 2011). For example, an enhanced incidence of fruit blossom end rot in tomato grafted onto *S. integrifolium* rootstocks (Oda *et al*., 1996) and high nicotine in tomato from plants grafted onto *Nicotiana tabacum* L. have been reported (Yasinok *et al*., 2009).

2.7.4.2 Fruit firmness

Firmness, a typical attributes used to describe fruit texture is a factor in withstanding long distance shipping stress to avoid extensive losses due to physical injuries. Contradictory reports regarding vegetable fruit firmness have surfaced. According to Rouphael *et al*. (2010), firmness is significantly influenced by grafting. Huitrón-Ramírez *et al*. (2009) reported an increase in firmness of grafted watermelon in comparison to fruits from ungrafted plants, independent of cultivar, rootstock and growing conditions (greenhouse vs open field).

On the contrary, EG203/Tengeru 97 and EG219/Tengeru 97 treatments resulted in decreased fruit firmness during rainy and dry seasons in comparison to fruits from ungrafted tomato plants (Msogoya, T. J. personal communication, 2016). On the other hand, Khah *et al*. (2006) observed a non-significant difference between treatments with respect to tomato fruit firmness. The influence of rootstocks on vegetable fruit firmness may be ascribed to a variation on cellular morphology, cell turgor, chemical and mechanical properties of fruit cell walls. These are in relation to increasing synthesis of endogenous hormones, changing water relationships and nutritional status of scion (Rouphael *et al*., 2010).

2.7.4.3 Total soluble solids (TSS) and titratable acidity (TA)

High TSS and TA are highly desirable in both processing and fresh-market cultivars due to their contribution to the overall flavour and nutritional value of tomato (Pogonyi *et al*., 2005; Flores *et al*., 2010; Krumbein and Schwarz, 2012). High concentration of acids and low sugar content produces a tart tomato, while high sugar content and low concentration of acids results in a bland taste (Pogonyi *et al*., 2005). When both sugar and acid contents are low, the end result is a tasteless and insipid tomato. The best result is attained when ratio of the two ranges from nine to 10 (Pogonyi *et al*., 2005).

Changes in flavour compounds of grafted fruits are both scion and rootstock dependent (Rouphael *et al*., 2010). Depending on the tomato rootstock-scion combination, an increase, a decrease or no change in carotenoid and sugar concentrations occurred (Fernandez- Garcia *et al*., 2004; Pogonyi *et al*., 2005; Khah *et al*., 2006). According to Krumbein and Schwarz (2012) grafting onto vigorous rootstocks such as Maxifort can result in low sugar concentration. Turhan *et al*. (2011) observed that fruits of grafted tomato plants can have higher water content resulting in a dilution effect of compounds such as TSS, total sugar, and vitamin C. On the other hand, Qian *et al*. (2004) and Huitrón-Ramírez *et al*. (2009) reported a non significant effect of rootstocks “RS841” and “Shintosa” camelforce on watermelon’s TSS content. By the same token Miguel *et al*. (2004) found no effect of “Shintoza” rootstock on TSS concentration of field grown watermelon fruit. In yet another study Khah *et al*. (2006) observed that TSS, TA, and pH concentrations and TSS/TA in tomato fruits were not altered by grafting under field and greenhouse conditions. Rootstock-scion incompatibility also has a direct bearing on fruit quality. Graft incompatibility between a tomato cultivar and *S. intergrifolium* resulted in high TSS concentration due to impaired water flow through the graft interface (Bletsos and Olympios, 2008).

It can safely be deduced that grafting can affect various quality aspects of vegetables in different ways. Therefore, rootstock/scion combinations should be carefully selected for specific climatic and geographic conditions (Davis *et al.*, 2008) as this can help improve yield and fruit quality. Based on the gap identified, this study seeks to determine graft success between Assila, Monica and Tengeru 97 grafted onto eggplant rootstocks namely EG190, EG195 and EG203 as well as to evaluate plant growth performance, yield fruit quality and profitability.

2.8 Limitations of Grafting

2.8.1 Low grafting success rate

One of the limitations of grafting technology is low grafting success or graft failure. Graft failure emanates from unsuccessful vascular system formation, inappropriate grafting technique in relation to species to be grafted, seedling age at grafting, non-optimal post grafting environmental conditions and rootstock-scion incompatibility (Andrews and Marquez, 1993; Bletsos and Olympios, 2008; Bumgarner and Kleinhenz, 2015; Tamilselvi and Pugalendhi, 2017). Other causes include incomparable stem diameters of rootstocks and scions, diseases introduced in the graft interface during the graft operation and craftsmanship. (Andrews and Marquez 1993; Bletsos and Olympios, 2008; Bumgarner and Kleinhenz, 2015). Graft failure exhibited by some tomato scion/rootstock combinations represents a major challenge for a wider dissemination of tomato grafting technology (Fernández-García *et al.*, 2004).

Seedling stage at grafting: The seedling stage at grafting time is important with respect to the efficiency of the rootstock-scion interaction (Martínez-Ballesta *et al.,* 2010). Lee *et al.* (2010) asserted that grafting success rate is improved when seedlings are grafted at three weeks of age. Sweet pepper (*Capsicum annuum* L.) grafted at 58 days had poor development of xylem connections at the graft interface, resulting in low stomatal resistance and water potential compared to 34 day old grafts.

Grafting technique employed: A grafting technique may have a direct bearing on grafting success rate. Tube grafting has a success rate of 85 to 95% (Rivard and Louws, 2008) attributed to a complete fusion of all vascular bundles of both parts (Lee *et al*., 2010). Likewise, a grafting success range of to 86 to 100% between eggplant rootstocks and Tanzania's local tomato cultivars by cleft grafting method has been reported (Msogoya and Mamiro, 2016).

Stem diameters of rootstock and scion seedlings at grafting: Grafting success also requires proper alignment of the vascular systems at the graft union. Therefore, stem diameters of a rootstock and a scion seedling must be of comparable size at the time of grafting (Black *et al*., 2003; Tamilselvi and Pugalendhi, 2017). Traka-Mavrona *et al.* (2000) observed reduced survival rate of grafts due to differences in stem diameter between *Cucurbita* spp and *Cucumis melo.*

Post-grafting environmental conditions: Improper management of post-grafting environmental conditions such as extreme temperatures can desiccate plants or slow graft union healing. Likewise, extreme humidity levels can soften and break down the graft union or allow it to dry (Johnson *et al.,* 2011a; Bumgarner and Kleinhenz, 2015). Excessive light levels right after grafting forces grafts to undertake physiological activities, such as photosynthesis, that are difficult or impossible until the graft union heals (Bumgarner and Kleinhenz, 2015). Direct overhead watering saturates the rooting medium, raising root pressure, induce necrotic tissues and diseases, thereby weakening the graft union in the process (Johnson *et al*., 2011b; Bumgarner and Kleinhenz, 2015).

Therefore to promote graft success, grafts should be held in a low light intensity healing chamber at 25-32 °C and > 85% relative humidity for four to seven days (Black *et al*., 2003; Kubota *et al*., 2008) before these conditions are gradually reversed during acclimatization. Direct application of water should be avoided and misting should be employed (Johnson *et al*., 2011b). The formation of trans-union xylem in grafted tomato begins between the fourth and eighth day following grafting and is fully developed between the 14th and 15th day thereafter (Fernández-García *et al.*, 2004; Johnson *et al*., 2011a cited by Ozores-Hampton and Frasca, 2013).

Degree of rootstock-scion graft compatibility: Another limitation of grafting is rootstock-scion graft incompatibility (Davis *et al.*, 2008; Tamilselvi1 and Pugalendhi, 2017). Graft incompatibility is defined as failure (immediate or delayed) of a graft union to successfully form due to insufficiently close genetic relationship between rootstock and scion (Edelstein, 2004). Graft compatibility on the other hand is defined as a sufficiently close genetic (taxonomic) relationship between a rootstock and a scion for a successful graft union to form, assuming that all other factors (grafting technique, temperature, etc.) are satisfactory.

Intraspecific grafting has been common in vegetable production due to higher compatibility in comparison to interspecific grafting (Davis *et al.*, 2008; Rivard and Louws, 2008, cited by Petran and Hoover, 2014). It also leads to enhanced resistance to various environmental pressures such as flood, drought, cold, heat and pathogen stresses (Petran and Hoover, 2014). Ironically, intraspecific grafting between rootstock Hawaii 7996 and Tanzania's local tomato cultivars terminated in lower graft success of 30-50% at healing stage (Msogoya and Mamiro, 2016). These findings are a departure from an assertion by Oda *et al*. (2005) that formation of xylem across the graft union and hydraulic conductance increases as the genetic distance between the scion and rootstock decreases. The low graft success in homografts may possibly be due to formation of a cavity of dead cells in a pith of tomato rootstock, which Fernandez-Garcia *et al*. (2004) stated that it leads to a slight incompatibility. It may well be owing to factors such as environment-genotype interactions (Andrews and Marquez, 1993).

Heterografts are usually compatible however their graft compatibility is difficult to predict as the degree of taxonomic affinity necessary for compatibility varies widely across different taxa (Mudge, 2009). Individual grafting trials must therefore be conducted to assess compatibility of every desired graft union and achieve the ultimate grafting objectives (Petran and Hoover, 2014).

Grafting is considered successful when a complete union of the vascular system of a rootstock and a scion is achieved (Fernández-García *et al*., 2004). This allows unhindered transfer of water and nutrients from the rootstock to the scion and transfer of photosynthates and growth substances from the scion to the rootstock (Bletsos and Olympios, 2008). A graft union is formed following callus proliferation, callus bridge formation, differentiation of new vascular tissues from callus cells and production of secondary xylem and phloem (Fernández-García *et al*., 2004; Martínez-Ballesta *et al*., 2010; Johnson *et al*., 2011b). However this can be jeopardized by rootstock-scion incompatibility. Rootstock-scion incompatibility can stem from tissue and anatomical, physiological and biochemical differences (Edelstein, 2004; Davis *et al.,* 2008).

The major causes implicated in graft incompatibility in solanaceous crops are anatomical and/or biochemical (Deloire and Hebant, 1982; Kawaguchi *et al*., 2008). Anatomical incompatibility is a lack of, or a decrease in the number of differentiated vascular bundles at the graft union thereby inhibiting water and nutrient translocation, (Martínez-Ballesta *et al*., 2010; Ives *et al.,* 2012). This affects other physiological traits (Martínez-Ballesta *et al*., 2010). The reduction of water and nutrient transport to the scion is due to low hydraulic conductance, causing graft failure (Oda *et al*., 2005). Small root systems of a rootstock and limited formation or blockage of trans-union xylem connections at the graft union are some of the factors responsible for low hydraulic conductance (Parkinson *et al*., 1987).

This can lead to yield reduction, poor fruit quality, and even plant collapse (Edelstein, 2004). Kawaguchi *et al*. (2008) observed growth inhibition and high mortality in tomato/pepper (and pepper/tomato) grafts due to discontinuities in the vascular bundles at the graft union. Conversely, the accumulation of polyphenols at the graft union was termed biochemical incompatibility (Deloire and Hebant, 1982). Also a low or incorrect callus formation could lead to defoliation, reduction of scion growth and low survival of grafted plants (Oda *et al*., 2005; Johkan *et al*., 2009).

Physiological incompatibility may emanate from lack of cellular recognition, lack of wounding responses, presence of growth regulators, or incompatibility toxins (Andrews and Marquez, 1993; Tamilselvi and Pugalendhi, 2017). The problem induces undergrowth or overgrowth of the scion, leading to decreased water and nutrient flow through the graft union and ultimately causing wilting (Davis *et al.*, 2008). Bletsos and Olympios (2008) reported incompatibility between tomato scion and *Solanum intergrifolium* rootstock causing a smaller diameter of rootstock than scion, less root growth and consequently low yield as well as low fruit quality.

Graft incompatibility usually occurs at early stages, when vascular connections are forming (Martínez-Ballesta *et al*., 2010) and emanates from physiological incompatibility (Tamilselvi and Pugalendhi, 2017). However, initial healing of the graft union does not in itself ensure long-term compatibility (Goldschmidt, 2014). Graft combinations can unite initially with apparent success, but gradually develop incompatibility symptoms with time, due either to failure at the union or the development of abnormal growth patterns (Kawaguchi *et al*., 2008).

Consequently, incompatibility can also appear as late as the fruiting stage, termed delayed incompatibility, when plant water and nutrient requirements are higher (Martínez-Ballesta *et al*., 2010). Ives *et al*. (2012) and Tamilselvi and Pugalendhi (2017) reported delayed incompatibility 30 and 28 days after grafting respectively due to discontinuous xylem elements in the graft union and large areas of unbroken necrotic lines along the wounded edges of the rootstock and the scion. By the same token, Tai *et al*. (2004) observed belated incompatibility between Capsicum and Solanum heterografts. Plants expressed symptoms of purplish vein, leaf chlorosis and defoliation, terminating into stunted growth and subsequent death of all graft combinations (Tai *et al*., 2004).

In delayed incompatibility Ives *et al*. (2012) observed development of adventitious roots at the scion base of pepper/tomato heterografts which further confirmed vascular discontinuity at the graft union. The lack of, or limited vascular continuity restricts transportation of carbohydrates and auxin and lead to their subsequent accumulation at the graft interface (Ives *et al*., 2012). Kawaguchi *et al*. (2008) suggested that the accumulation of auxin and carbohydrates at the graft interface promote adventitious root formation at the scion base. Other symptoms of delayed graft incompatibility comprise dwarfing, wilting, high chlorophyll content of leaves, and small fruit (Oda *et al*., 2005). Furthermore, a low or incorrect callus formation could lead to defoliation, reduction of scion growth and low survival of grafted plants (Oda *et al*., 2005; Johkan *et al*., 2009).

2.8.2 Costs associated with grafting technology

Additional costs associated with vegetable grafting are a well-documented impediment. The intensive labour input and resulting high costs of grafted seedling production have been drawbacks in getting this technology from being widely adopted outside of Asia (Kubota *et al*., 2008). The grafting operation itself is extremely laborious and time-consuming (Oda *et al*., 1994; Kubota *et al*., 2008). In addition, grafting requires investment in rootstock seed, grafting materials and supplies. Healing facilities, labour for healing and acclimatizing grafts are other setbacks associated with this technology as compared to a nongrafted crop (Kubota *et al*., 2008; Rivard *et al*., 2010; Barrett *et al*., 2012). Moreover, seed must be over-sown to account for less than 100% graft success (Rivard *et al*. 2010; Johnson *et al*., 2011b; Miles *et al*., 2013).

These costs result in increased prices of grafted seedlings and increased production costs (Rivard *et al*., 2010). Barrett *et al*. (2012) has estimated grafted and nongrafted transplants to cost $0.78 and $0.17 per plant, respectively. These authors reported that the cost of rootstock seeds accounted for 36% of the total cost of the grafted transplants and 46% of the cost difference between grafted and nongrafted plants. Rivard and Louws (2011) concluded that rootstock seeds and not labour, constituted the highest cost.

Despite the costs, grafting has been found to be economically profitable in a number of studies. In the Mediterranean countries of Greece, Morocco, Lebanon and Spain grafted tomato production has been found to be economically profitable owing to resistance of rootstocks to *F. oxyporum* f. sp. *radices-lycopersici* or nematodes (Bletsos and Olympios, 2008). In other studies under field conditions grafting led to improved yield which in turn generated significant gross returns to offset costs associated with use of grafted tomato transplants (Djidonou *et al*., 2013), and significant net return. Rivard and Louws (2011) observed that a grafted tomato crop yielded a profit of 38% per plant higher than a nongrafted one. In high value systems such as organics, transitional organics or heirlooms, tomato grafting can provide a net economic gain for tomato fruit growers as well as transplant propagators (Rivard and Louws, 2011; Barrett *et al*., 2012). Nonetheless, further research regarding economic viability of grafting under different commercial growing conditions and open field production system is important (Barrett *et al*., 2012; Djidonou *et al*., 2013).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

The study was conducted at the Sokoine University of Agriculture (SUA) Morogoro, Tanzania. The study area is located at 6^{o}05'S, 35^{o}37'E, at an elevation of 568 m above the sea level. The experiment was conducted out in the open field at Horticulture Section between March and August 2017. The rainfall pattern in the study area is bimodal. The first short rain falls from November to January while the second long rain falls from February to May. The annual rainfall ranges between 800 and 950 mm (Kisetu *et al.*, 2013).

3.2 Sowing and Pricking

Scion seeds for F1 hybrid tomato cv. Monica (indeterminate type) and Assila (semi-determinate type) and open pollinated cv. Tengeru 97 were purchased from local agro-dealers in Morogoro. Rootstock seeds for EG190, EG195 and EG203 were obtained from SUA seed bank. Seeds were sown in seedling trays filled with compost before pricking them into 10.16 cm diameter polythene tubes a week later. Eggplant rootstocks were sown three weeks earlier than scion cultivars to secure comparable seedling stem diameters at grafting time (Tamilselvi and Pugalendhi, 2017). Seedlings were raised in a nursery. RidomilGold MZ 68 WG (Metalayl-M 40g/kg+Mancozeb 640 kg) was applied against dumping-off disease at a rate of 3 g L^{-1} of water. Seedlings were watered every third day.

3.3 Determination of Grafting Success between Selected Eggplant Rootstocks and Selected F1 Hybrid Tomato Cultivars

3.3.1 Grafting success at nursery level

3.3.1.1 Experimental design and preparation for grafting

The experiment was set out in a RCBD and constituted nine grafted treatments namely EG190/Assila, EG195/Assila, EG203/Assila, EG190/Monica, EG195/Monica, EG203/Monica, EG190/Tengeru 97, EG195/Tengeru 97 and EG203/Tengeru 97. Each treatment comprised 20 grafts and was replicated three times. Grafts were held in polythene tubes of 10.16 cm diameter. A day before, grafting the grafting house was cleaned. Water was poured on the floors of the dark healing chamber while its side surfaces were mist-sprayed to raise the relative humidity (Johson *et al.*, 2011a; Ozores-Hampton and Frasca, 2013). The working surfaces, grafters' hands and materials were disinfected with 70% ethanol to minimize possible contamination (Rivard and Louws, 2011).

3.3.1.2 Grafting, healing and hardening off

Grafting was performed on 17 March 2017 in a grafting house (Fig.1) when rootstock and scion seedlings were 28 and 21 days old, respectively. Monica, Assila and Tengeru 97 seedlings were each cleft grafted (Black *et al.*, 2003) onto rootstocks EG190, EG195 and EG203. Tengeru 97 served as a control in this experiment. The graft union was secured with a grafting tape as illustrated in Fig. 2. Grafts were mist-sprayed and then transferred into the dark healing chamber (Fig. 3) where they were held for three days.

The grafts were then moved into a transparent healing chamber where they were held for another three days. The transparent healing chamber's floor and inside surfaces were filled with water and mist-sprayed, respectively, before seedling transfer. In both chambers temperatures and relative humidity were monitored using a thermo hygrometer (Dickson TH550, The Dickson Company, Addison, IL). The two parameters were maintained at 22-25C and 90-95% (Black *et al*., 2003; Kubota *et al*., 2008; Ozores-Hampton and Frasca, 2013). Healing chamber's doors were opened whenever relative humidity rose above 95% (Ozores-Hampton and Frasca, 2013). The grafts were hardened off for seven days in the nursery prior to transplanting.

Figure 1: Grafting house with dark healing and transparent healing chambers therein

(a) (b)

Figure 2: Grafting tape and grafting clips (a). Grafting tape secured grafting union (b).

Figure 3: Dark and transparent healing chambers in which grafts were held for healing

3.3.1.3 Data collection on graft success at nursery level

The number of grafts that survived at the end of stay in each healing environment (dark healing chamber, transparent healing chamber and nursery for hardening off) was recorded. Grafting success was then arrived at by the following equation:

$$\text{Grafting success} = \frac{\text{Number of successful grafts}}{\text{Total number of grafts}} \times 100$$

3.3.2 Grafting success at field level

3.3.2.1 Experimental design and transplanting

The experiment was laid out in a RCBD with 12 treatments and three replications. The graft treatments namely EG190/Asilla, EG190/Monica, EG190/Tengeru 97, EG195/Asilla, EG195/Monica, EG195/Tengeru 97, EG203/Asilla, EG203/Monica and EG203/Tengeru 97 from section 3.3.1.2 above were transplanted out in the field. Ungrafted Asilla, Monica and Tengeru 97 served as controls. Each plot comprised two rows of 12 plants each. Plants were spaced at 120 cm x 60 cm with a 100 cm long walkway between replications. The experiment was carried out under a drip irrigation system.

3.3.2.2 Crop management

NPK compound fertilizer (17:17:17) was applied as top dressing at the rate of 150 kg per ha three weeks after transplanting. Tengeru 97 was pruned to retain one stem two weeks after transplanting. All cultivars were staked three weeks after transplanting. Suckers developing below, and adventitious roots forming at, the graft interfaces were removed on a weekly basis. This was done in order to prevent the roots from reaching the ground and nullify any advantages such as disease resistance sought from a rootstocks (Black *et al.*, 2003; Johnson *et al.*, 2011b; Rivard and Louws, 2011; Miles *et al.*, 2013). Allowing adventitious roots to reach the ground would also nullify fair comparison between grafted and ungrafted treatments as the grafted treatments would benefit from dual roots in terms of nutrient and water uptake. RidomilGold (Metalaxyl-M 40g/kg + Mancozeb 640/kg) was applied weekly against fungal diseases at a rate of 3 g L^{-1} of water. Coragen 20 SC (chlorantraniliprole) was applied at a rate of 0.25 ml $L\text{-}^{1}$ of water against South American leaf miner (*Tuta absoluta*). Sumectin 10 EC (Emamectin benzoate) was applied to manage whitefly (*Aleyrodoidea*). The crop was kept weed-free by hand weeding.

3.3.2.3 Data collection on grafting success at field level

After transplanting data were collected on the number of plants that formed adventitious roots at the graft interface and number of plants that wilted and died.

3.4 Effects of Rootstocks on Plant Growth, Yield and Fruit Quality of F1 hybrid Tomato Cultivars

The experimental design and transplanting were as stated in section 3.3.1.1.

3.4.1 Data collection on plant growth

Data were collected from six plants in the middle of each plot. Data on days to first flowering and days to first and last harvest were recorded by counting the number of days from transplanting. Data were also collected on plant heights at first flowering and at first and last harvest and stem diameter at first and last harvest. Plant height was measured from the root collar to the growing points using a 2-m ruler. Stem diameter was measured 20 cm from the soil surface with a digital vernier calliper (USDA-AMS, Burlingame, CA).

3.4.2 Data collection on yield and yield components

Data on yield were collected on number of flowers per truss, number of fruits per truss, number of fruits per plant, fruit weight per plant (kg) and yield per ha (t). Harvest was done weekly at fruit turning stage. The above data were computed as follows:

$$\text{Number of fruits/plant} = \frac{\text{Total number of fruits from sample plants}}{\text{Number of sample plants}}$$

$$\text{Fruit weight/plant (kg)} = \frac{\text{Total fruit weight from sample plants}}{\text{Number of sample plants}}$$

$$\text{Yield/ha (kg)} = \frac{\text{Total yield from sample area (kg)}}{\text{Sample area (m}^2\text{)}} \times 10\,000 \text{ m}^2$$

3.4.3 Data collection on fruit quality

3.4.3.1 Fruit marketability and diameter

Fruit marketability was based on visual observations. Data were collected on marketable yield and non-marketable yield per ha. Fruits free from cracks, blossom end rot, disease symptoms and those that attained standard size were considered marketable (Estan *et al.* 2005). Fruits with defects were consequently considered unmarketable. Marketability data were computed as follows:

Marketable yield (t/ha) = Total yield (t/ha) – Nonmarketable yield (t/ha)

Ten fruits per sample were measured for diameters using a digital vernier calliper (USDA-AMS, Burlingame, CA).

3.4.3.2 Fruit firmness

Ten defect free fully ripe tomato fruits of all sizes from each plot were selected for firmness evaluation. A penetrometer (Wagner Fruit Test^{TM} FT Fruit Ripeness Tester, Wagner Instruments and Greenwich, CT) was used for firmness testing. A disc of a peel was removed from two opposite sides of the equatorial area of fruits before measurements were taken as described by OECD (2009).

3.4.3.3 TSS, TA, and TSS/ TA

Ten defect free tomato fruits at red stage of maturity were selected for TSS and TA measurements. From each fruit longitudinal slices were taken. Slices were homogenized into a composite sample using a blender. TSS was measured using a hand held digital refractometer (Mettler Toledo, Model LXC 59107, Japan) as described by OECD (2009). The TSS values were expressed in °Brix.

TA and TSS/ TA ratios were also determined as per the OECD (2009) protocol. TA was determined by titrating 10 ml of tomato juice extract using 0.1M NaOH to pH 8.1 using a pH meter. The results were expressed as a percentage of citric acid in the juice (OECD, 2009). TSS/TA ratios were computed as follows:

$$\text{TSS/TA ratio} = \frac{\text{TSS}}{\text{TA}} \times 100$$

3.5 Profitability Analysis of Grafted F1 Hybrid Tomato Cultivars

3.5.1 Total variable costs

All cross-cutting variable costs emanating from procurement of materials and labour were recorded and these constituted the sum of total variable costs. Costs of materials and labour are provided in Table 1 and Table 2, respectively.

Table 1: Costs of materials procured for grafting and managing the experiment

Item	Quantity	Unit price (TSh)	Cost (TSh)
Assila seeds (1000 seed pack)	1	130 000	130 000
Monica seeds (1 pack)	1	60 000	60 000
Tengeru 97 seeds (25 g pack)	1	10 000	10 000
Polytube roll	1	32 500	32 500
Ridomil (250g)	1	6 000	6 000
NPK(50kg)	1	75 000	75 000
Coragen 20 SC (30ml)	1	23 000	23 000
Sumectin 10 EC (30ml)	1	8 000	8 000
Paper towel roll	1	1 500	1 500
Blades	5	100	500
Strings	2	10 000	20 000
Stakes	144	100	14 400
Total cost			**380 900**

Table 2: Labour costs incurred in the experiment

Activity	**Cost (TSh)**
Scion sowing	2 000
Rootstock sowing	2 000
Scion watering	5 000
Roostock watering	5 500
Scion pricking	10 000
Rootstock pricking	9 000
Scion spraying (nursery)	3 000
Rootstock spraying (nursery)	3 000
Grafting	21 000
Graft management	30 000
Transplanting	5 000
Weeding	14 000
Spraying (field)	20 000
Staking	15 000
De-suckering	20 000
Adventitious root removal	12 000
Harvesting	12 000
Total cost	**188 500**

3.5.2 Revenue

Revenue was computed as a product of total marketable yield and farm gate price as follows:

Revenue = Total marketable yield x. farm gate price

The prevailing local market price (TSh 500 per kg) during harvest period was used to establish revenue.

3.5.3 Profit margin

Profit margin was computed as the difference between revenue and total variable costs as follows:

Profit margin = Revenue – Total variable costs

3.6 Data Analysis

Data on wilting and death incidences were log transformed prior to analysis. Data on graft success, plant growth, yield and fruit quality were subjected to Analysis of Variance (Table 3) using Genstat v.14 statistical package (VSN International, UK). Treatment means were separated by Tukey's Honest Significant Difference ($p \leq 0.05$). Data on profitability were analysed descriptively.

Table 3: Data type and analysis method used

Data type	**Analysis method used**
Grafting success	ANOVA
Plant growth	ANOVA
Yield and components	ANOVA
Fruit quality	ANOVA
Profitability	Descriptive statistics

CHAPTER FOUR

4.0 RESULTS

4.1 Determination of Grafting Success between Selected Eggplant Rootstocks and F1 Hybrid Tomato Cultivars

4.1.1 Grafting success at nursery level

A statistical analysis unveiled high grafting success in all three environments (Table 4). In the dark healing chamber grafting success was statistically similar ($p \leq 0.05$) for all treatments, ranging between 93-100 %. Grafting success in the transparent healing chamber revealed statistically significant differences ($p = 0.008$) between treatments. EG203/Assila which was statistically similar ($p \leq 0.05$) to EG190/Assila scored the lowest grafting success. The rest of the treatments were statistically similar ($p \leq 0.05$) and had scores ranging from 90 to 100% grafting success. Grafting success after hardening off was not significantly different ($p \leq 0.05$) amongst all treatments, ranging from 83 to 100 %.

4.1.2 Grafting success at field level

Incidences of adventitious roots: Grafting had a statistically significant ($p = 0.001$) effect on incidences of adventitious roots (Table 5). EG190/Assila and EG190/Monica treatments had the highest percentage of plants that formed adventitious roots followed by EG203/Assila and EG203/Monica. The next highest incidences of adventitious roots were observed in EG195/Assila and EG195/Monica. EG190/Tengeru 97 and EG195/Tengeru 97 had the lowest incidences of adventitious roots and were statistically similar ($p \leq 0.05$) to EG203/Tengeru 97.

While adventitious roots were observed in all treatments, it was their degree of severity that set these treatments apart. By visual observation, adventitious root severity was much more pronounced in EG190/Monica and EG190/Assila treatments in that order and much less so in rootstock/Tengeru 97, EG195/Assila and EG195/Monica (Fig.4). EG203/Assila and EG203/Monica expressed intermediate root severity.

Figure 4: Incidences of adventitious roots at the graft interface

Wilting and death incidences: Grafting resulted in significantly ($p = 0.001$) different plant wilting and death incidences (Table 5) EG190/Assila and EG190/Monica which were statistically similar ($p \leq 0.05$) to EG203/Assila had the highest plant wilting incidences. EG195/Assila, EG195/Monica and EG203/Monica scored the next highest plant wilting incidences. The lowest plant wilting incidences were observed in ungrafted control Assila, Monica, Tengeru 97 and rootstock/Tengeru 97. EG190/Monica and EG190/Assila had significantly ($p = 0.001$) the highest death incidences. EG195/Tengeru

97, EG203/Tengeru/97, ungrafted Tengeru 97, Monica, Assila, EG203/Monica and EG203/Assila scored the lowest death incidences. The latter did not significantly differ ($p \leq 0.05$) from EG195/Assila, EG195/Monica and EG190/Tengeru 97.

Table 4: Grafting success (%) of rootstock/scion treatments during the healing process at nursery level

Treatment	**Dark healing chamber**	**Transparent healing chamber**	**Hardening off**
EG190/Assila	93	90ab	83
EG195/Assila	100	100b	90
EG203/Assila	97	80a	80
EG190/ Monica	100	100b	100
EG195/Monica	100	100b	90
EG203/Monica	100	93b	90
EG190/ Tengeru 97	100	100b	93
EG195/Tengeru 97	100	100b	97
EG203/Tengeru 97	100	100b	87
Grand mean	99.0	96.0	90.0
sd±	3.2	7.4	9.6
CV (%)	3.2	7.7	10.7
P-Value	0.300	0.008	0.243

Means in the same column followed by the same letter are not significantly different (P≤0.05) based on Turkey’s Honest Significant Difference. CV= coefficient of variation; sd = standard deviation; Eggplant rootstocks = EG190, EG195 and EG203; Tomato scions = Assila; Monica and Tengeru 97

Table 5: Graft success of rootstock/scion treatments at field level

Treatment	ARI (%)	W I (%)	DI (%)
EG190/Assila	100f	3.3c	2.3c
EG195/Assila	53.3cd	2.6b	1.8ab
EG203/Assila	80.0e	2.9bc	1.0a
Assila		1.0a	1.0a
EG190/Monica	100f	3.3c	2.4c
EG195/Monica	43.3c	2.8b	1.3ab
EG203/Monica	73.3e	2.6b	1.0a
Monica		1.0a	1.0a
EG190/Tengeru 97	10.0a	1.0a	1.3ab
EG195/Tengeru 97	16.7a	1.0a	1.0a
EG203/Tengeru 97	26.7ab	1.0a	1.0a
Tengeru 97		1.0a	1.0a
Grand mean	55.93	1.9	1.3
sd±	33.76	1.0	0.6
CV (%)	13.18	7.8	28.3
P-Value	0.001	0.001	0.001

Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$) based on Turkey's Honest Significant Difference. CV= coefficient of variation; sd = standard deviation; Eggplant rootstocks = EG190, EG195 and EG203; Tomato scions = Assila; Monica and Tengeru 97; ARI =adventitious root incidences; WI = wilting incidences; DI = death incidences

4.2 Effect of Rootstocks on Plant Growth, Yield and Fruit Quality of F1 Hybrid Tomato Cultivars

4.2.1 Grafting effect on plant growth

4.2.1.1 Days to first flowering and first harvest

Grafting resulted in statistically significant (p = 0.008) differences with respect to days from transplanting to first flower set (Table 6). Grafted treatments flowered earlier than the ungrafted treatments. Rootstock/Assila flowered first and was statistically similar

($p \leq 0.05$) to EG195/Monica and EG190/Monica. EG203/Monica flowered next followed by ungrafted Monica and Assila in that order. Ungrafted Assila was followed by EG190/Tengeru 97 and EG203/Tengeru 97 which did not significantly differ ($p \leq 0.05$) from EG195/Tengeru 97. Ungrafted Tengeru 97 was the last to flower.

Grafting significantly ($p = 0.001$) influenced numbers of days taken from transplanting to first harvest (Table 6). Grafting advanced fruit maturity in Assila, Monica and Tengeru 97 in comparison to ungrafted treatments. Rootstock/Assila and rootstock/Monica matured the earliest followed by ungrafted Assila. Ungrafted Assila and Monica did not significantly ($p \leq 0.05$) differ. EG195/Tengeru 97 was the next to mature followed by EG190/Tengeru 97 which was statistically similar to EG203/Tengeru 97. Ungrafted Tengeru 97 was the last to mature.

4.2.1.2 Plant heights at first flowering, first harvest and last harvest

Grafting resulted in significant effects on plant heights at first flowering ($p = 0.001$), first harvest ($p = 0.001$) and last harvest ($p = 0.001$) (Table 6). Ungrafted Assila, Monica and Tengeru 97 were taller than the grafted treatments at first flower set Ungrafted Tengeru 97 plants were the tallest at this stage followed by EG195/Tengeru 97 and ungrafted Assila. EG190/Tengeru 97 had the next tallest plants followed by ungrafted Monica and EG203/Tengeru 97. Rootstock/Monica and EG203/Assila attained the lowest plant heights at first flowering.

At first harvest, grafting significantly ($p = 0.001$) reduced plant heights in Assila and Monica while increasing the same parameter in Tengeru 97 in comparison to the ungrafted treatments. EG195/Tengeru 97 had the tallest plants followed by EG190/Tengeru 97 and EG203/Tengeru. Ungrafted Tengeru 97 which did not significantly differ ($p \leq 0.05$) from ungrafted Assila and Monica had the next tallest plants at first harvest. The next tallest plants were observed in EG195/Assila and EG203/Assila, in that order. The shortest plants were observed in EG190/Assila and EG190/Monica.

At last harvest EG195/Tengeru 97 had the tallest plants followed by EG190/Tengeru 97 which did not significantly differ ($p \leq 0.05$) from EG203/Tengeru 97. Ungrafted Tengeru 97 had the next tallest plants. Ungrafted Tengeru 97, Monica, Assila, EG195/Monica, EG195/Assila, and EG203/Assila did not significantly differ ($p \leq 0.05$). The shortest plant height at last harvest was observed in EG190/Monica which was statistically similar ($p \leq 0.05$) to EG190/Assila.

4.2.1.3 Stem diameters at first and last harvest

Grafting significantly ($p = 0.001$) influenced stem diameter at both first and last harvest (Table 6). Grafting reduced this parameter in both Assila and Monica. However, grafting resulted in increased stem diameter for rootstock/Tengeru 97 in comparison to ungrafted Tengeru 97. The largest stem diameters were observed in EG195/Tengeru 97 followed by EG190/Tengeru 97 and EG203/Tengeru 97 in that order. Ungrafted Assila and Tengeru 97 which were statistically similar ($p \leq 0.05$) to ungrafted Monica had the fourth largest stem diameters at first harvest. EG195/Assila, EG195/Monica, EG203/Monica and EG203/Assila scored the next largest stem diameters. The smallest stem diameters were observed in EG190/ Monica and EG190/Assila.

At last harvest EG195/Tengeru 97 had significantly ($p = 0.001$) the largest stem diameters (Table 6). EG203/Tengeru 97, EG190/Tengeru 97 and ungrafted Tengeru 97 had the second largest stem diameters followed by ungrafted Assila. The next largest stem diameters at last harvest were observed in EG195/Assila, EG195/Monica and ungrafted Monica and these did not significantly differ ($p \leq 0.05$) from EG203/Monica. The smallest score of this parameter was observed in EG190/Monica which was statistically similar (p≤0.05) to EG190/Assila.

Table 6: Grafting effect on plant growth parameters

Treatment	Days to first flowering	Plant height at first flowering (cm)	Days to first harvest	Plant height at first harvest (cm)	Stem diameter at first harvest (mm)	Plant height at last harvest (cm)	Stem diameter at last harvest (mm)
EG190/Assila	22.0a	34.1b	65.7a	60.4a	6.4a	71.0ab	8.3ab
EG195/Assila	22.0a	34.9b	66.0a	89.2f	9.3b	91.2e	10.8ef
EG203/Assila	22.0a	32.0a	64.7a	74.2de	8.8b	92.1e	10.1cd
Assila	26.33g	57.9e	71.3b	112.2g	12.2cd	115.9ef	12.6gh
EG190/Monica	22.3ab	32.0a	64.0a	55.3a	6.3a	60.7a	8.0a
EG195/Monica	23.7ab	30.9a	66.0a	70.7b	9.2b	85.1e	10.9ef
EG203/Monica	24.0cd	30.9a	65.0a	74.2bc	9.0b	78.5cd	10.6e
Monica	25.7ef	51.5c	72.3bc	109.6g	10.9c	113.4f	11.0ef
EG190/Tengeru 97	34.0h	55.40d	75.7f	125.1ij	13.6g	134.7h	14.1i
EG195/Tengeru 97	34.3hi	59.1e	74.7de	128.1k	16.2h	141.9i	17.0k
EG203/Tengeru 97	34.0h	51.0c	76.3fg	124.ij	12.8ef	129.0gh	14.18i
Tengeru 97	36.0j	71.1f	79.0h	117.8gh	11.60cd	125.8efg	13.7i
Grand mean	27.2	45.0	70.06	95. 8	10.5	103.28	11.79
sd±	5.480	13.61	5.324	13.59	3.046	2.9	2.91
CV (%)	2.4	2.7	1.4	8.8	11.6	10.8	13.6
P-Value	0.008	0.001	0.001	0.001	0.001	0.001	0.001

Means in the same column followed by the same letter are not significantly different (P≤0.05) based on Turkey’s Honest Significant Difference. CV= coefficient of variation; sd = standard deviation; Eggplant rootstocks = EG190, EG195 and EG203; Tomato scions = Assila; Monica and Tengeru 97

4.2.2 Grafting effect on yield and yield components

4.2.2.1 Number of flowers and fruits per truss

As illustrated in Table 7 results revealed statistically significant differences in number of flowers per truss ($p = 0.001$) and number of fruits per truss ($p = 0.001$). Grafting reduced the number of flowers per truss in Assila and Monica ($p = 0.001$), however the technology did not influence the same parameter in Tengeru 97. Ungrafted Monica produced the highest number of flowers per truss followed by rootstock/Tengeru 97 and ungrafted Tengeru 97. Ungrafted Assila which did not significantly differ ($p \leq 0.05$) from EG195/Monica and EG203/Monica produced the next highest number of flowers per truss. The smallest number of flowers per truss was observed in EG190/Monica which was statistically similar ($p \leq 0.05$) to EG190/Assila and EG203/Assila.

Grafting reduced the number of fruits per truss in both Assila and Monica while enhancing the same parameter in Tengeru 97 ($p = 0.001$). EG195/Tengeru 97 yielded the highest number of fruits per truss. EG190/Tengeru 97, EG203/Tengeru 97 and ungrafted Monica which were statistically similar ($p \leq 0.05$) to ungrafted Assila had the second highest numbers of fruits per truss. The next highest number of fruits per truss was observed in ungrafted Tengeru 97. The lowest number of fruits per truss was observed in EG190/Monica, which did not significantly differ ($p \leq 0.05$) from EG190/Assila, EG195/Monica, EG195/Assila and EG203/Monica.

4.2.2.2 Number of fruits per plant

Grafting significantly ($p = 0.001$) influenced the number of fruits per plant (Table 7). The technology increased the number of fruits per plant in Tengeru 97.On the contrary, grafting decreased this parameter in Assila and Monica. The largest number of fruits per plant was observed in ungrafted Assila followed by ungrafted Monica and EG195/Tengeru

97 in that order. Ungrafted Monica and EG195/Tengeru 97 were also statistically similar ($p \leq 0.05$). Ungrafted Tengeru 97 and EG190/Monica yielded the smallest number of fruits per plant. Ungrafted Tengeru 97, EG190/Monica, EG190/Assila, EG203/Assila and EG203/Tengeru 97 did not significantly differ ($p \leq 0.05$).

4.2.2.3 Fruit diameters and yield per plant

Rootstocks had a statistically significant ($p = 0.001$) influence on fruit diameters (Table 7). The largest fruit diameters were observed in EG203/Tengeru 97 and EG195/Tengeru 97 followed by EG190/Tengeru 97, EG195/Monica and ungrafted Assila. EG195/Assila, EG203/Monica and ungrafted Monica produced fruits with the third largest fruit diameters. The next largest fruit diameters were observed in EG203/Assila which did not significantly differ ($p \leq 0.05$) from EG190/Assila and EG190/Monica. Ungrafted Tengeru 97 produced fruits with the smallest diameters.

Grafting significantly ($p = 0.001$) impacted on yield per plant (Table 7). The technology reduced yield per plant for Assila and Monica while improving it in Tengeru 97. Ungrafted Assila produced the highest yield per plant and did not significantly differ ($p \leq 0.05$) from ungrafted Monica. EG195/Tengeru 97 which did not significantly differ ($p \leq 0.05$) from ungrafted Monica produced the next highest yield per plant. Rootstock/Tengeru 97, EG195/Assila, EG195/Monica and EG203/Monica, were statistically similar ($p \leq 0.05$). EG190/Assila, EG190/Monica and ungrafted Tengeru 97 had the lowest yield per plant and were not significantly different from EG203/Assila ($p \leq 0.05$).

Table 7: Grafting effect on yield components of tomato

Treatment	**Number of flowers truss^{-1}**	**Number of fruits truss^{-1}**	**Number of fruits plant^{-1}**	**Fruit diameter (mm)**	**Yield plant^{-1} (kg)**
EG190/Assila	5.7ab	2.4ab	10.6ab	47.7b	0.6a
EG195/Assila	5.9b	2.1ab	15.1bc	52.2de	1.1bc
EG203/Assila	5.5ab	2.7b	11.0ab	49.3bc	0.7ab
Assila	7.0c	4.3cd	29.4f	55.8f	2.9f
EG190/ Monica	4.9a	1.7a	8.6a	47.4b	0.5a
EG195/Monica	6.3bc	2.5ab	14.1bc	53.7f	1.2bc
EG203/Monica	6.3bc	2.3ab	12.3b	52.9de	1.0bc
Monica	9.3e	4.3d	20.3de	53.3de	2.0ef
EG190/ Tengeru 97	8.2d	5.0d	15.7bc	54.f	1.2bc
EG195/Tengeru 97	8.1d	5.9e	18.5cd	63.7g	1.8cde
EG203/Tengeru 97	8.2d	4.8d	11.5ab	61.7g	1.3bc
Tengeru 97	8.1d	3.7c	8.1a	42.7a	0.6a
Grand mean	6.9	3.5	14.6	52.9	1.3
SD±	1.52	1.47	6.49	7.49	0.76
CV (%)	10.7	19.1	25.5	9.5	31.6
P-Value	0.001	0.001	0.001	0.001	0.001

Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$) based on Tukey's Honest Significant Difference. CV= coefficient of variation; sd = standard deviation; Eggplant rootstocks = EG190, EG195 and EG203; Tomato scions = Assila; Monica and Tengeru 97

4.2.2.4 Total yield

Grafting significantly influenced total yield per ha ($p = 0.001$) (Table 8). Results revealed enhanced total yield per ha for Tengeru 97. However, the technology markedly reduced yield per ha for Assila and Monica. Ungrafted Assila followed by ungrafted Monica had the highest total yield per ha. EG195/Tengeru 97 produced the next highest total yield which was significantly similar to ($p \leq 0.05$) to EG190/Tengeru 97 and EG203/Tengeru 97. The lowest total yield was observed in EG190/Monica. EG190/Monica, EG203/Assila, EG190/Assila and ungrafted Tengeru 97 were statistically similar ($p \leq 0.05$).

4.2.2.5 Marketable and nonmarketable tomato yield per ha

Marketable yield per ha was significantly (p = 0.001) influenced grafting (Table 8). The highest marketable yield per ha was observed in ungrafted Assila which did not significantly differ ($p \leq 0.05$) from ungrafted Monica. EG195/Tengeru 97 had the next highest marketable yield per ha. Rootstock/Tengeru 97, EG203/Monica, EG195/Monica and EG195/Assila did not significantly differ ($p \leq 0.05$). EG190/Monica, EG190/Assila and ungrafted Tengeru 97 had the lowest yield per ha and were statistically similar ($p \leq 0.05$) to EG203/Assila.

Grafting resulted in significant (p = 0.001) effect on nonmarketable yield per ha (Table 8). Ungrafted Assila yielded the greatest nonmarketable yield per ha followed by ungrafted Monica and EG195/Tengeru 97. The third highest nonmarketable yield was observed in EG203/Tengeru 97 and EG195/Monica which were statistically similar ($p \leq 0.05$) to EG195/Assila. The next highest nonmarketable yield was observed in EG190/Tengeru 97, which was statistically similar ($p \leq 0.05$) to both EG195/Assila and ungrafted Tengeru 97. The lowest nonmarketable yield was observed in EG203/Assila and EG190/ Monica which did not significantly differ from EG190/Assila and EG203/ Monica.

Table 8: Grafting effect on total yield, marketable yield and nonmarketable yield

Treatment	**Total yield ($t\ ha^{-1}$)**	**Marketable yield ($t\ ha^{-1}$)**	**Nonmarketable yield ($t\ ha^{-1}$)**
EG190/Assila	6.4ab	4.9a	1.5ab
EG195/Assila	12.9bc	9.5bc	3.4de
EG203/Assila	7.9ab	6.9ab	1.0a
Assila	33.8fg	17.6e	16.2g
EG190/ Monica	3.6a	2.9a	0.7a
EG195/Monica	13.6bc	9.4bc	4.2e
EG203/Monica	12.2bc	10.9bcd	1.3ab
Monica	23.3e	14.7de	8.6f
EG190/ Tengeru 97	14.4cd	11.7bcd	2.7cd
EG195/Tengeru 97	20.9de	13.0cd	7.7f
EG203/Tengeru 97	14.8cd	10.9bcd	3.9e
Tengeru 97	7.1ab	5.0a	2.1bc
Grand mean	14.2	9.8	4.4
sd±	9.0	4.341	4.356
CV (%)	31.9	14.7	7.6
P-Value	0.001	0.001	0.001

Means in the same column followed by the same letter are not significantly different ($p \leq 0.05$) based on Turkey's Honest Significant Difference. CV= coefficient of variation; sd = standard deviation; Eggplant rootstocks = EG190, EG195 and EG203; Tomato scions = Assila; Monica and Tengeru 97

4.2.3 Grafting effect on fruit quality

4.2.3.1 Fruit firmness and TSS

Grafting significantly ($p = 0.001$) impacted on fruit firmness. EG195/Assila scored the highest fruit firmness (Table 9). EG195/Assila, EG190/Assila, EG190/Tengeru 97, EG203/Assila, EG203/Monica, EG203/Tengeru 97, ungrafted Assila, Monica and Tengeru 97 did not significantly differ. ($p \leq 0.05$). EG190/Monica produced fruits with the lowest fruit firmness. Grafting culminated in a statistically significant ($p = 0.001$) influence on

TSS (Table 9). Grafting increased TSS in Assila and Monica but no effect on this parameter in Tengeru 97. EG190/Monica scored the highest TSS concentration. EG190/Monica, EG190/Assila, EG195/Monica and EG203/Monica were statistically similar ($p \leq 0.05$). Ungrafted Assila and Monica scored the lowest of TSS concentrations and these were statistically similar to rootstock/Tengeru 97 and ungrafted Tengeru 97.

4.2.3.2 TA and TSS/TA ratio

Grafting significantly ($p = 0.001$) influenced TA concentrations (Table 9). The highest TA concentration was observed in ungrafted Tengeru 97 and EG203/Tengeru 97 followed by EG190/Tengeru 97. The third highest TA was observed in EG190/Monica followed by EG203/Monica. EG203/Monica, EG195/Monica, EG195/Tengeru 97, rootstock/Assila and ungrafted Assila were statistically similar ($p \leq 0.05$). The lowest TA concentration was observed in ungrafted Monica. Ungrafted control Monica, Assila rootstock/Assila, EG195/Monica and EG195/Tengeru 97 were statistically similar ($p \leq 0.05$).

Grafting also resulted in significantly ($p = 0.008$) different effects on TSS/TA ratio, with EG190/Assila scoring the highest on this parameter. The latter did not significantly differ ($p \leq 0.05$) from EG190/ Monica, EG195/Assila, EG195/Monica and EG203/Assila. The next highest TSS/TA ratio was observed in EG203/Monica. EG203/Monica was statistically similar ($p \leq 0.05$) to EG190/Monica, EG190/Tengeru, EG195/Assila, ungrafted Monica, EG195/Monica, EG195/Tengeru 97, EG203/Assila ungrafted Assila. Ungrafted Tengeru 97 and EG203/Tengeru 97 yielded the lowest TSS/TA ratios.

Table 9: Grafting effect on fruit quality of tomato

Treatment	Firmness (kg cm^2)	TSS (%)	TA (%)	TSS/TA
EG190/Assila	1.82bc	6.65cd	0.44abc	15.11c
EG195/Assila	2.10c	5.65bc	0.48abc	11.77bc
EG203/Assila	2.0bc	5.59bc	0.46abc	12.15bc
Assila	1.98bc	3.90a	0.41ab	9.51ab
EG190/ Monica	1.30a	7.02d	0.53de	13.24bc
EG195/Monica	1.76b	5.77bcd	0.49abc	11.77bc
EG203/Monica	1.87bc	5.89bcd	0.52bc	11.33b
Monica	1.87bc	4.15a	0.38a	10.92ab
EG190/Tengeru 97	1.93bc	4.67ab	0.64fg	7.30ab
EG195/Tengeru 97	1.76b	4.90ab	0.47abc	10.43ab
EG203/Tengeru 97	1.91bc	4.68ab	0.65h	7.20a
Tengeru 97	1.91bc	4.67ab	0.65h	7.18a
Grand mean	1.85	5.30	0.5	10.62
sd±	0.22	1.00	0.09	2.66
CV (%)	5.7	8.3	7.4	12.5
P-Value	0.001	0.001	0.001	0.008

Means in the same column followed by the same letter are not significantly different ($p \leq 0.05$) based on Turkey’s Honest Significant Difference. CV= coefficient of variation; sd = standard deviation; Eggplant rootstocks = EG190, EG195 and EG203; Tomato scions = Assila; Monica and Tengeru 97

4.3 Profitability Analysis of Grafted F1 Hybrid Tomato Cultivars

The results indicate higher total variable costs in grafted treatments than in ungrafted treatments (Table 10). Grafted Monica had the highest total variable costs followed by grafted Assila and Tengeru 97 in that order. Ungrafted Assila and Monica yielded higher profit margins in comparison to grafted Assila and Monica. On the other hand, grafted Tengeru 97 had higher profit margins than ungrafted Tengeru 97.

Table 10: Costs, revenue and profit margin of grafted and ungrafted tomato

Treatment	Total variable cost (TSh/ha)	Revenue (TSh/ha)	Profit margin (TSh/ha)
EG190/Assila	3 764 600	2 455 000	-309 600
EG195/Assila	3 764 600	4 750 000	985 400
EG203/Assila	3 764 600	3 450 000	-314 600
Assila	2 808 600	8 800 000	5 991 400
EG190/ Monica	4 084 600	1 450 000	-2 634 600
EG195/Monica	4 084 600	4 700 000	615 400
EG203/Monica	4 084 600	5 450 000	1 365 400
Monica	3 158 600	7 350 000	4 191 400
EG190/Tengeru 97	3 239 600	5 850 000	2 610 400
EG195/Tengeru 97	3 239 600	6600 000	3 360 400
EG203/Tengeru 97	3 239 600	5 450 000	2 210 400
Tengeru 97	2 308 600	2 500 000	191 400

Eggplant rootstocks = EG190, EG195 and EG203; Tomato scions = Assila; Monica and Tengeru 97

CHAPTER FIVE

5.0 DISCUSSION

5.1 Determination of Grafting Success between Selected Eggplant Rootstocks and Selected F1 Hybrid Tomato Cultivars

5.1.1 Grafting success at nursery level

The results unveiled a high grafting success among all treatments, ranging from 83 to 100 % after hardening off. Grafting success decreased as grafts moved from one healing environment to the next. By the end of hardening off only EG190/Monica retained the 100 % grafting success trend. The rest of the treatments achieved a grafting success range of 83 to 97 %.

Grafting success is determined by such factors as grafting technique employed, seedling age at grafting, post-grafting environmental conditions and rootstock-scion compatibility. Other factors include comparability of stem diameters of rootstocks and scions during grafting, and craftsmanship of a grafter, amongst others (Andrews and Marquez 1993; Bletsos and Olympios, 2008; Bumgarner and Kleinhenz, 2015).

Cleft grafting which was employed in this study resulted in a grafting success rate ranging from 86 to 100 % between the same eggplant rootstocks and Tanzania’s local tomato cultivars. The high graft success observed in this experiment is supported by results from other studies including the study by Msogoya and Mamiro (2016). Likewise, Marsic and Osvald (2004) observed a 100% survival rate of tomato cv. “Monroe” grafted onto “Beaufort” and “PG 3” rootstocks and 92 % and 93 % with cv. “Belle” onto “Beaufort” and “PG 3,” respectively, using cleft grafting method.

The seedling stage (three weeks) at which grafting was performed may also have contributed to high grafting success. This observation is supported by Lee *et al.* (2010) who asserted that grafting success rate is improved when seedlings are grafted at three weeks of age. Martínez-Ballesta *et al.* (2010) emphasized that the seedling stage at grafting time is important for the efficiency of the rootstock/scion interaction. The grafting success was achieved at 22-25°C and 90-95 % relative humidity which are within recommended ranges of 25 to 32°C and >85% relative humidity (Black *et al.*, 2003; Kubota *et al.*, 2008).

5.1.2 Grafting success at field level

Despite significantly high graft success at nursery level, rootstock/Assila and rootstock/Monica expressed low graft success at field level. They had very high incidences of adventitious roots in comparison to ungrafted treatments. Adventitious roots at the graft union which were more apparent in EG190/Assila and EG190/Monica, are signs of graft incompatibility. Adventitious roots at the graft union are triggered by accumulation of carbohydrate and auxin at graft union (Kawaguchi *et al.*, 2008). The accumulation of carbohydrate and auxin at that point is due to lack of, or limited, vascular continuity (Ives *et al.*, 2012) which prevents free translocation of these materials along with water.

The accumulation of materials at the graft interface results in enlarged stem diameter at that point in comparison to rootstock stem diameter. Bletsos and Olympios (2008) reported incompatibility between tomato scion and *S. intergrifolium* rootstock, causing smaller stem diameter of rootstocks than scions.

Tamilselvi and Pugalendhi (2017) reported delayed incompatibility in bitter gourd (*Momordica charantia* L.)/cucurbit graft combinations owing to discontinuous xylem elements in the graft union. Ives *et al*. (2012) observed development of adventitious roots at the scion base of pepper/tomato heterografts due to incompatibility.

Visual observation revealed that EG190/Monica and EG190/Assila also had far small root systems in comparison to ungrafted control Assila and Monica. The small root system and the limited vascular discontinuity cause low hydraulic conductance (Parkinson *et al*. 1987). This reduced water and nutrient transport to the scions, resulting in limited growth, wilting and subsequent death of severely affected treatments as in EG190/ Monica and EG190/Assila. Tai *et al*. (2004) observed stunted growth and subsequent death of all Capsicum/Solanum heterografts due to limited vascular continuity. These observations are also supported by Oda *et al*. (2005) who reported that the reduction of water and nutrient transport to the scion is due to low hydraulic conductance, causing graft failure.

EG195/Assila, EG195/Monica, and EG203/Monica and EG203/Assila attained more growth than EG190/Assila and EG190/Monica. This is indicative of more vascular bundles formed and the connections between them in comparison to EG190/Assila and EG190/Monica. These treatments may therefore be partially incompatible. Heterografts such as tomato scions/eggplant rootstocks usually exhibit partial incompatibility, which further impairs water and nutrient translocation from the rootstock to the scions in comparison to homografts (Kawaguchi *et al*., 2008; Goldschmidt, 2014).

The root systems for EG195/Assila, EG195/Monica, EG203/Monica and EG203/Assila were also more developed than those of EG190/Assila and EG190/Monica, though they were smaller than those for ungrafted Assila and Monica. The small root systems in rootstock/Assila and rootstock/Monica in comparison to the ungrafted treatments could imply that the rootstocks’ root systems are not vigorous enough to feed vigorous scions such as Assila and Monica. Moreover, Martinez-Ballesta *et al*. (2010) stressed that eggplant root systems are small, which restricts xylem hydraulic conductivity to absorb water and nutrients from the soil and translocate them towards the scions.

The negligible adventitious root incidences and severity, and comparatively well-developed root systems observed in rootstock/Tengeru 97 imply sufficient vascular bundles and continuity between them. This allowed free material translocation (Bletsos and Olympios, 2008) through the graft interface due to high hydraulic conductance. Tengeru 97 can then be pronounced compatible with the three rootstocks under study. This observation is supported by earlier work by Msogoya and Mamiro (2016), who successfully grafted Tengeru 97 onto the same rootstocks and evidenced higher yield than ungrafted treatments.

5.2 Effect of Rootstocks on Plant Growth, Yield and Fruit Quality of F1 Hybrid Tomato Cultivars

5.2.1 Plant growth

5.2.1.1 Days to first flowering and first harvest

Grafting, regardless of treatments, resulted in earlier flowering in comparison to ungrafted treatments. These findings concur with observations by Khah *et al*. (2011), who reported the same trend in both greenhouse and open field eggplant/tomato treatments. It is however contrary to findings by Ibrahim *et al*. (2001) and Khah *et al*. (2006), who observed more days to flowering in grafted tomato. The latter phenomenon is attributable to stress experienced by these plants following the grafting operation (Ibrahim *et al*., 2001; Khah *et al*., 2006). Because of early flowering grafted plants matured earlier than ungrafted treatments. Khah *et al*. (2011) also reported early fruit maturity in grafted tomato. Flowering date is an important aspect in vegetable production as it affects fruit harvest time, which can in turn have a direct bearing on fruit quality (Davis *et al*., 2008). Early fruit set is crucial for the early harvesting to secure good market prices (Lee *et al*., 2010).

5.2.1.2 Plant heights and stem diameters

Rootstock/Assila had significantly lower plant height at first flowering and first harvest in comparison to ungrafted Assila. However, at last harvest only EG190/Assila was shorter than ungrafted Assila, while rest of the treatments did not significantly differ from the latter. On the other hand, rootstock/Monica had significantly low plant heights in comparison to ungrafted Monica from first flower set to last harvest. Rootstock/Assila had small stem diameters at both first and last harvest in comparison to ungrafted Assila. Grafting also reduced stem diameters in rootstock/Monica at first harvest and EG190/Monica at last harvest. However, EG203/Monica and EG195/Monica did not significantly differ from ungrafted Monica at last harvest.

Ungrafted Tengeru 97 led rootstock/Tengeru 97 in terms of plant heights at first flowering. However, at first harvest rootstock/Tengeru 97 was taller and had larger stem diameters than ungrafted Tengeru 97. Grafting also enhanced plant heights at last harvest in Tengeru 97, however EG203/Tengeru 97 did not significantly differ from ungrafted Tengeru 97. Likewise, stem diameters at last harvest were enhanced in EG195/Tengeru 97, however there were no significant differences between ungrafted Tengeru 97, EG190/Tengeru 97 and EG203/Tengeru 97.

Both lower and greater plant heights observed in this study have been reported in other studies. Ibrahim *et al*. (2001) reported that tomato cv. “BARI tomato 3” grafted onto wild solanum was shorter than the ungrafted one. On the other hand, Khah *et al*. (2006)

observed that “Big Red” tomato scion grafted onto “He-man” rootstock was taller than non-grafted plants in open-field cultivation. A decrease in stem diameters of grafted plants observed in this study is contrary to findings by Al-Harbi *et al.* (2016) who reported a significant increase in stem diameter and plant height of grafted tomato as compared to ungrafted plants.

Low plant height and small stem diameter in grafted Assila and Monica could be attributed to limited vascular system continuity (Tai *et al*., 2004) and few vascular bundles regenerated at the graft union. This limited sufficient and free translocation of minerals, photoynthates and water (Ives *et al*., 2012), impacting negatively on plant growth. Low plant growth might also have resulted from rootstocks that may not be vigorous enough to support vigorous scions such as Assila and Monica. This observation is supported by Rivero *et al*. (2003); Louws *et al*. (2010); Rivard and Louws (2011) and Schwarz *et al*. (2010), who asserted that growth, yield and quality are improved when a crop is grafted onto a vigorous rootstock. Bletsos and Olympios, (2008) observed that some rootstocks reduce growth and production of scions. In addition, Abdelhafeez *et al*. (1975) found that tomato grafted onto eggplant exhibits limited growth and lower yield than self-rooted plants.

The low plant heights of rootstock/Tengeru 97 at flowering as compared to ungrafted Tengeru 97 could be due to stress the plants were still braving as a result of grafting (Ibrahim *et al*. 2001; Khah *et al*., 2006). On the other hand, the greater plant heights and stem diameters and first and last harvest of some of grafted Tengeru 97 may be due to sufficient vascular regeneration and continuity across the graft interface (Ives *et al*., 2012), and enhanced vigour of the scions by the rootstocks. Some eggplant rootstocks are more efficient at water uptake than their tomato counterparts (Colla *et al*., 2014) due to their dense, extensive root systems (Bletsos and Olympios, 2008). This indicates that rootstock variety may play a key role in the extent to which grafted plant respond in terms of plant growth.

5.2.2 Grafting effect on yield and yield components

5.2.2.1 Number of flowers and fruits per truss

Grafting markedly impacted negatively on number of flowers per truss and number of fruits per truss for Assila and Monica, in comparison to ungrafted treatments. Few flowers and fruits per truss could have emanated from limited growth expressed due to impaired water and nutrient flow through the graft unions. These results demonstrated that grafting a scion on an unsuitable rootstock can have deleterious effects on growth and yield.

Grafting had no significant effect on the number of flowers per truss for Tengeru 97. In a similar study, Khah *et al.* (2006) found no significant differences between treatments regarding the total number of flowers per plant in tomato. Bletsos and Olympios (2008) arrived at the same conclusion, reporting that grafting did not affect flowering in tomato. Contrariwise, the technology led to a higher number of fruits per truss in grafted Tengeru 97 in comparison to ungrafted Tengeru 97. This observation is in agreement with Ibrahim *et al*. (2001), who found a higher number of fruits per truss in grafted tomato, in comparison to the ungrafted treatment. Pogonyi *et al*. (2005) observed the same trend in “Beaufort”/”Lemance F1.”

The increased number of fruits per truss in rootstock/Tengeru 97 may be ascribed to improved vigour as compared to ungrafted Tengeru 97. It has been separately established that grafting onto a vigorous and larger rootstock increases absorption and translocation of water and nutrients (Davis *et al.*, 2008; Lee, 2010; Martinez-Ballesta *et al.*, 2010), thereby improving growth, yield and quality (Davis *et al.*, 2008; Martinez-Ballesta *et al*., 2010; Rivard and Louws, 2011).

5.2.2.2 Number of fruits per plant, yield per plant and yield per ha

Grafting reduced yield in terms of number of fruits per plant, yield per plant and total yield per ha for Assila and Monica. However, grafting increased the same parameters for Tengeru 97 except for EG203/Tengeru 97 whose number of fruits per plant did not significantly differ from that for ungrafted Tengeru 97. Yield reduction due to grafting has been reported by Msogoya (Msogoya, T. J. personal communication, 2016) for EG219/Tanya and EG203/Tanya graft combinations during both rainy and dry season. The low total yield in rootstock/ Assila and rootstock/Monica was sure to follow due to their impaired growth performance emanating from constricted graft unions and possibly low rootstock vigour. In addition, the few numbers of flowers and fruits per truss translated in fewer fruits per plant and in turn lower total yield. Abdelhafeez *et al*. (1975) observed limited growth and lower yields in eggplant/tomato as compared to self-rooted plants.

The higher total yield observed in rootstock/Tengeru 97 is supported by findings from other studies. Huitron- Ramirez *et al*. (2009) observed a yield increase of 66% and 115% for watermelon cv. Tri-X 313 grafted onto RS841. Ibrahim *et al*. (2001); Khah *et al*. 2006; Gisbert *et al*. (2011); Turhan *et al*. (2011) and Wahb-Alah (2014) have also reported increased yield in grafted tomato. These findings demonstrate that grafting tomato onto a suitable rootstock has a positive effect on cultivation performance and yield (Khah *et al.*, 2006; Turhan *et al*., 2011). Grafting possibly enhanced Tengeru 97 vigour, leading to increased absorption and translocation of water and nutrients, thereby enhancing plant growth and yield (Davis *et al.*, 2008; Lee *et al*., 2010; Martinez-Ballesta *et al*., 2010).

The higher total yield in grafted Tengeru 97 is attributable to larger and many fruits per plant. This concurs with findings by Pogonyi *et al*. (2005) who stated that higher yield in “Beaufort”/”Lemance” F1 as opposed to control “Lemance F1,” arose from higher average fruit weight per plant. Miguel *et al*. (2004) reported an increase in fruit size by an average of 90% and 26% in watermelon grafted onto squash interspecific hybrid rootstocks.

5.2.3 Grafting effect on fruit quality

5.2.3.1 Fruit diameters

Grafting in this study culminated in increased fruit diameter for rootstock/Tengeru 97 and EG195/Monica. However, the technology significantly reduced this parameter in rootstock/Assila and EG190/Monica while causing a nonsignificant difference between ungrafted Monica and EG203/Monica. The enhanced fruit diameter observed in this study concur with observations by Yetisir *et al*. (2007) who reported that watermelon grafted onto interspecific squash hybrid had increased fruit size by 52%. Turhan *et al*. (2011) indicated that fruit index and fruit weights of grafted plants were significantly higher than for control plants. Larger fruit diameter in grafted plants could be credited to enhanced water and nutrient uptake when vigorous rootstocks are used.

The small fruit diameters observed in rootstock/Assila and EG190/Monica in this study is supported by other findings. For instance, Bletsos and Olympios (2008) found that tomato and eggplant grafted onto *Datura patula* exhibit less growth, lower production and smaller fruit size in comparison to self-rooted plants. The small fruit diameters could be due to limited water and nutrient uptake as a result of small rootstock root systems and impaired vascular systems. Khah *et al.* (2006) for example, indicated that grafting does not improve the yield when the selection of the rootstock is not suitable. Fruit size is an important parameter in vegetable fruit production as it determines the final yield and quality.

5.2.3.2 Fruit marketability

The grafting technology increased marketable yield for Tengeru 97 while reducing it in Assila and Monica. Rootstock/Tengeru 97 also had higher nonmarketable fruits in comparison to ungrafted Tengeru 97. However, the latter did not significantly differ from EG190/Tengeru 97. Nonmarketable yield was lower in rootstock/Assila and rootstock/Monica than in ungrafted Assila and Monica. The increase in marketable fruits in grafted treatments in this study has also been observed in other works. Lee *et al*. (2010) emphasized that grafting can increase tomato marketable yield by up to 54%. The enhanced marketable yield in rootstock/Tengeru 97 can be ascribed to rootstock enhanced plant vigour as compared to ungrafted Tengeru 97, leading to improved water and nutrient uptake. This is supported by Di Gioia *et al*. (2010); Schwartz *et al*. (2010) and Turhan *et al*. (2011) who stressed that higher marketable yield in grafted plants is mainly due to improved water and nutrient uptake by vigorous rootstocks. The increase in marketable fruits maybe related to changes in fruit water content and mechanical properties, which ultimately inhibit fruit softening, cracking and decays. This concurs with Rouphael *et al*. (2010) who reported on variation in cell turgidity and cell wall properties in grafted tomato.

The low marketable fruits in rootstock/Assila and rootstock/Monica as compared to ungrafted Assila and Monica may be due reduced plant vigour. Reduced plant vigour limits sufficient water and nutrient uptake which can boost plant health. This could lead to small fruits, blossom end rot, fruit softening and decay. Oda *et al*. (1996) reported an enhanced incidence of fruit blossom end rot in tomato grafted onto *S. integrifolium* rootstocks.

5.2.3.3 Fruit firmness

Grafting significantly reduced fruit firmness in EG190/Monica, however, the rest of the treatments did not significantly differ from ungrafted treatments. Contradictory reports regarding vegetable fruit firmness as observed in this study have surfaced elsewhere. Khah *et al*. (2006) observed a non-significant difference between treatments with respect to tomato fruit firmness. The influence of rootstocks on vegetable fruit firmness may be ascribed to a variation on cellular morphology, cell turgor, chemical and mechanical properties of cell walls of fruit as a result of increasing synthesis of endogenous hormones, changing water relationships and nutritional status of scion (Rouphael *et al*., 2010).

5.2.3.4 TSS, TA and TSS/TA

Grafting enhanced TSS in rootstock/Assila and rootstock/Monica while inducing a non-significant effect on rootstock/Tengeru 97. Likewise, grafting did not alter TA in EG203/Tengeru 97, rootstock/Assila, EG195/Monica, however the technology reduced TA in EG190/Tengeru 97 and EG195/Tengeru 97. On the other hand, grafting led to an increase in TA concentration in EG190/Monica and EG203/Monica. Grafting did not influence TSS/TA ratios except for EG190/Assila in which it was enhanced.

Reduced TA concentration in EG190/Tengeru 97 and EG195/Tengeru 97 could be credited to enhanced water supply to the plants which led to a dilution effect on this parameter. Turhan *et al*. (2011) observed that fruits of grafted tomato plants can have higher water content, resulting in a dilution effect of compounds such as TSS, total sugar, and vitamin C content. In addition, Krumbein and Schwarz (2012) stressed that grafting onto vigorous rootstocks such as “Maxifort” can result in lowest sugar concentration.

Grafting a vigorous scion onto a nonvigorous rootstock would lead to limited water uptake. As such the increase in TSS concentration in rootstock/Assila and rootstock/Monica and the increases in TA concentration in EG190/Monica and EG203/Monica due to grafting could be attributed to limited water uptake as a result of low vigour of the rootstocks. Bletsos and Olympios (2008) reported that graft incompatibility between a tomato cultivar and *S. intergrifolium* resulted in high TSS concentration due to impaired water flow through the graft interface. In a study by Turhan *et al*. (2011), TA content was improved by grafting. A decrease or non-alteration of flavour compounds as observed in this work has also been observed elsewhere. Khah *et al*. (2006) observed that TSS, TA, concentrations and TSS/TA ratios in tomato fruits were not altered by grafting under field and greenhouse conditions.

These findings have demonstrated that an increase, a decrease or no change in quality parameters of fruits from grafted plants can occur. This concurs with Davis *et al*. (2008); Flores *et al*. (2010) and Gisbert *et al*. (2011) who reported on conflicting reports on changes in fruit quality parameters resulting from grafting. The inconsistency can emanate from different production environments (e.g. light intensity, air temperature), methods (e.g. soilless vs. soil culture, irrigation, and fertilization), rootstock-scion combinations used, and harvest date (Davis *et al*., 2008; Rouphael *et al*., 2010). Changes in the scion are controlled by the rootstock through controlled uptake and translocation of water, minerals, and plant hormones (Lee and Oda, 2003). However, it is important that the apparent quality characteristics and composition of a final product of grafted plants remain unchanged or be improved with respect to non-grafted plants (Gisbert *et al*., 2011).

5.3 Profitability of Grafted F1 Hybrid Tomato Cultivars

Growing grafted tomato demonstrated higher production costs as compared to ungrafted tomato. The high total variable costs in graft combinations as compared to controls resulted from labour costs incurred in sowing and managing rootstock seeds and seedlings respectively, as well as labour charges for grafting, healing and acclimatization of grafts. De-suckering of shoots developing below the graft interface and removal of adventitious roots constituted other costs. These findings are in agreement with Djidonou *et al*. (2013) who observed that use of grafted tomato transplants results in additional costs inherent to materials, space, and labour needed for grafting. O'Connell *et al*. (2009) concluded that grafted tomato transplants have higher associated variable costs compared to non-grafted transplants due to increased seed costs, grafting materials, grafting labour, and the requirements of growing a rootstock and scion crop separately prior grafting.

These results indicate that although grafting increased the total costs of production in Tengeru 97, the increase in total and marketable yield generated significant profit margins to offset costs associated with the use of grafted plants. These observations concur with Djidonou *et al*. (2013) who reported that net returns were higher in the grafted system due to yield improvements. In another study, O'Connell *et al*. (2009) observed higher net profit from "RST-04-105-T"/"Celebrity" graft combination in comparison to ungrafted "Celebrity". Rivard and Louws (2011) observed that a grafted tomato crop yielded a per plant profit of 38% higher than ungrafted tomato. On the other hand, the low profit margin from rootstock/Assila, rootstock/Monica and ungrafted Tengeru 97 emanated from low total yield these treatments produced.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The objectives of this study were (1) to determine graft success between selected eggplant rootstocks and selected F1 hybrid tomato cultivars, (2) to evaluate the effect of selected eggplant rootstocks on plant growth, yield and fruit quality of F1 hybrid tomato cultivars and (3) to determine profitability of grafted F1 hybrid tomato cultivars. Results from this study unveiled low graft success between F1 hybrid tomato cultivars (Assila and Monica) and eggplant rootstocks (EG190, EG195 and EG203) after transplanting as manifested by low plant growth, wilting and death in comparison to ungrafted plants of the same cultivars. On the other hand, Tengeru 97 treatments maintained high graft success even at field level and also expressed good plant growth performance in comparison to ungrafted Tengeru 97. Results also indicate that grafting F1 hybrid tomato cv. Assila and Monica onto the eggplant rootstocks under question markedly reduces both total and marketable yield. However, grafting enhances these parameters in Tengeru 97 when grafted onto the same rootstocks.

Results from this experiment further suggest that grafting F hybrid tomato cv. Assila and Monica onto these rootstocks improves fruit taste based on high TSS but does not alter the parameter in tomato cv. Tengeru 97. Grafting between the scions and rootstocks under question increases production costs in comparison to ungrafted plants. As a consequence, grafting F1 hybrid tomato cv. Assila and Monica onto the rootstocks under consideration reduces profit margins in comparison to ungrafted cv. Assila and Monica. The low profit margin is further aggravated by reduced marketable yield. However, grafting Tengeru 97 onto the same rootstocks increases profit margins and offset the incurred costs in comparison to ungrafted Tengeru 97. Overall, it is inferred that grafting F1 hybrid tomato cv. Assila and Monica onto rootstocks EG190, EG195 and EG203 reduces graft success, plant growth, total yield, marketable yield and profitability.

6.2 Recommendations

It is recommended that F1 hybrid tomato cv. Assila and Monica should not be grafted onto rootstocks EG190, EG195 and EG203 due to low graft success, reduced plant growth, low total yield, low marketable yield and low profit margins. However, farmers are advised to graft Tengeru 97 onto these rootstocks for enhanced plant growth, high total yield, high marketable yield and high profit margins. Further studies are required in a quest to identify rootstocks that are compatible with, and vigorous enough to carry these, scions in order to improve yield, fruit quality and profit. It is further recommended that grafted F1 hybrid tomato cv. Assila and Monica should be evaluated for tolerance to tomato fusarium wilt and bacterial wilt in soils infested with these diseases.

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