INFLUENCE OF DIFFERENT ROOTSTOCKS ON GRAFTING COMPATIBILITY WITH SUMMER TOMATO

MD. MARUF HOSSAIN BHUIYAN

DEPARTMENT OF HORTICULTURE

SHER-E-BANGLA AGRICULTURAL UNIVERSITY

DHAKA-1207

DECEMBER, 2020

INFLUENCE OF DIFFERENT ROOTSTOCKS ON GRAFTING COMPATIBILITY WITH SUMMER TOMATO

BY

MD. MARUF HOSSAIN BHUIYAN

REGISTRATION NO. 18-09113

A Thesis
Submitted to the Faculty of Agriculture
Sher-e-Bangla Agricultural University, Dhaka
In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE (MS)

IN

HORTICULTURE

SEMESTER: JULY-DECEMBER, 2020

APPROVED BY:

Prof. Md. Hasanuzzaman Akand
Supervisor
Department of Horticulture
SAU, Dhaka

Dr. M. A. Goffar
Co-Supervisor
Principal Scientific Officer
Olericulture Division, HRC
BARI, Joydebpur, Gazipur

Prof. Dr. Md. Jahedur Rahman
Chairman
Examination Committee

DEPARTMENT OF HORTICULTURE

SHER-E-BANGLA AGRICULTURAL UNIVERSITY

Sher-e-Bangla Nagar, Dhaka-1207

Ref. Date: …………...

CERTIFICATE

*This is to certify that the thesis entitled **"INFLUENCE OF DIFFERENT ROOTSTOCKS ON GRAFTING COMPATIBILITY WITH SUMMER TOMATO"** submitted to the Department of Horticulture, Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (M.S.) IN HORTICULTURE**, embodies the result of a piece of bonafide research work carried out by **MD. MARUF HOSSAIN BHUIYAN**, Registration No. **18-09113** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that any help or source of information, received during the course of this investigation has been duly acknowledged.

Dated**:** December, 2020
Dhaka, Bangladesh

Supervisor

Md. Hasanuzzaman Akand

Professor

Department Of Horticulture,

Sher-e-Bangla Agricultural University,

Sher-e-Bangla Nagar, Dhaka-1207

Dedicated To

My Beloved Parents

ACKNOWLEDGEMENTS

All praises and thanks are due to the Supreme Ruler of the universe, the "Almighty Allah" who grace bestowed upon the author for accomplishment of this present piece of work.

*The author express his deepest sense of gratitude, sincere appreciation and heartfelt thanks to his respectable research supervisor, **Md. Hasanuzzaman Akand**, Professor, Department of Horticulture, Sher-e-Bangla Agricultural University, Dhaka for his scholastic guidance, innovative suggestion, constant supervision, valuable advice and helpful criticism in carrying out the research work and preparation of this manuscript.*

*The author feels proud to express his deepest respect, sincere appreciation, and immense indebtedness to his Co-supervisor **Dr. M. A. Goffar**, Principle Scientific Officer, Olericulture Division, HRC, BARI, Joydevpur, Gazipur, for his scholastic and continuous guidance, constructive criticism, and valuable suggestions during the entire period of the course and research work and preparation of this thesis.*

*The author expresses his sincere respect and heartfelt thanks to **all the teachers** of the Department of Horticulture, SAU, for their valuable teaching, suggestions, and encouragement during the period of study.*

*The author also expresses sincere gratitude to his younger sister's husband **Sultan Muhammad Shubuktagin**, well wishers and friends especially SafayetHossen, Md. Abu Hena, Md. Jalal uddin and Narayan Chakraborti for their inspiration, help and encouragement during the study period.*

*Finally, the author expresses his unfathomable tributes, sincere gratitude and heartfelt indebtedness from his core of heart to his mother **Dil Ara Jahan**, father **Md Abdul Mannan Bhuiyan** and sister **Israth Jahan Bhuiyan** whose immensurable sacrifice, blessings, continuous inspiration and moral support opened the gate and paved the way of his higher study.*

The Author

INFLUENCE OF DIFFERENT ROOTSTOCKS ON GRAFTING COMPATIBILITY WITH SUMMER TOMATO

ABSTRACT

A field experiment was carried out at the research field of Olericulture Division, Horticulture Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI), Gazipur during the period from April, 2019 to September, 2019 in order to study the resistance level of rootstocks and grafting compatibility with tomato on different rootstocks and their field performance during the summer season of 2019. The experiment was consisted of seven treatment combinations viz.- T_0 = Control (non-grafted tomato seedling of BARI hybrid tomato-10); T_1 = Grafted seedling (tomato grafted on *S. sisymbriifolium*); T_2 = Grafted seedling (tomato grafted on EG-203); T_3 = Grafted seedling (tomato grafted on Khag-1); T_4 = Grafted seedling (tomato grafted on khag-2); T_5 = Grafted seedling (tomato grafted on khag-3); T_6 = Grafted seedling (tomato grafted on BARI brinjal-8). The experiment was laid out in RCB design with three replications which was set under polytunnels. The results revealed that appropriate rootstock is the prerequisite for successful tomato production based on the grafting technique. The maximum grafting success (86.15%), plant survivability (94.64%), fruit length (7.23 cm), fruit width (5.81 cm), number of fruits plant^{-1} (33.33), average single fruit weight (48.83 g), total soluble solids (4.53%), days to first harvest (98 days) and longer harvesting duration (27.33 days), fruit yield plant^{-1} (1.39 kg), and yield ha^{-1} (44.02 tons) was obtained from T_6 (tomato grafted on BARI brinjal-8) treatment. Among the rootstocks, tomato seedling grafted on BARI brinjal-8 showed complete resistance against bacterial wilt and the minimum virus infestation 0.00%, 0.00%, 8.00% and 8.00% at 45 DAS, 60 DAS, 75 DAS and 90 DAS were observed respectively. Considering the growth, yield and yield contributing characters, and resistance potentiality against bacterial wilt and virus infection in field condition, it was revealed that seedling of BARI hybrid tomato-10 grafted on BARI brinjal-8 (T_6) was the most suitable rootstock than other rootstocks used in the present study for summer tomato production. Hence, tomato seedling grafted on BARI brinjal-8 may be a suitable option for successful summer tomato production avoiding bacterial wilt disease.

LIST OF CONTENTS

LIST OF CONTENTS (Cont'd)

LIST OF CONTENTS (Cont'd)

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ACRONYMS

ABBREVIATIONS	ELABORATIONS
AEZ	Agro Ecological Zone
AVRDC	Asian Vegetables Research and Development Centre
ANOVA	Analysis Of Variance
@	at the rate
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BBS	Bangladesh Bureau of Statistics
BW	Bacterial Wilt
CV%	Percentage of Coefficient of Variation
^{0}C	Degree Celsius
>	greater than
%	Percent
cm	Centimeter
DF	Degree of Freedom
et al.	and others
etc.	Et cetera
FAO	Food and Agriculture Organization
g	Gram
HRC	Horticulture Research Centre
kg	Kilogram
m	Meter
RCBD	Randomized Complete Block Design
SAU	Sher-e-Bangla Agricultural University
LSD	Least Significant Difference
TSS	Total Soluble Solids
TYLCV	Tomato Yellow Leaf Curl Virus
TMV	Tomato Mosaic Virus
VAR.	Variety
viz.	Namely

CHAPTER 1

INTRODUCTION

Tomato (*Solanum lycopersicum* L.), under solanaceae family is one of the most important and nutritious vegetables in Bangladesh and in the world wide too. It is the widely grown 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 the third ranked vegetable in the world level with a representation of 7.0% of the total vegetable production, behind potato and sweet potato (29.0% and 14.0%) respectively and it is cultivated on surface approximately 5.0 million hectares with an annual production of 170.0 million tons and an output of 34.0 tons ha^{-1}. China is the first tomato producer country; it produces 52.0 million tons on a surface of 1.0 million hectares (FAO, 2014).

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

In Bangladesh, Recent statistics showed that tomato was grown in 28206 ha of land and the total production was approximately 388 thousand metric tons in 2019 and about 6.10% area is under tomato cultivation both in winter and summer (BBS, 2019). However, the yield of the crop is very low compared to those obtained in some advanced country (Hossain *et al.,* 2019). In Bangladesh congenial atmosphere remains for tomato production during low temperature winter season that is early November is the best time for tomato planting in our country (Hossain *et al.,* 1986). Usually, it is sown in October- November and harvesting is mostly confined to the months from January to March. But, tomato cultivation during summer season (March-November) is constrained due to adverse weather along with absence of heat tolerant and wilt resistant varieties. Simultaneously its production is also severely limited by an important soil borne pathogen, *Ralstonia solanacearum*, and the causal organism of bacterial wilt (Mondal, 1992; Bhuyan and Haque, 1983). The disease causes severe yield loss of tomatoes in many tropical and sub-tropical countries (Kelman, 1953). Only a few specific bacterial wilt surveys have been done in Bangladesh. In Taiwan, on an average 29.0% of hybrid tomato varieties are affected by this disease (Hartmen *et al.*, 1991). The magnitude of wilt incidence is much higher in summer- humid compared to winter season. Once the plants are affected by wilting organisms, it dies invariably and this disease may attack the plants at any stage of development.

In Bangladesh, there is a great demand for summer tomato but its production is affected by bacterial wilt. Even at the flowering stage complete crop failure may occur due to bacterial wilt incidence (Rahman and Hoque, 1986). Hossain *et al.* (1999) observed that incidence or bacterial wilt ranged from 3.33 to 36.76% in tomato. The bacterium has wide host range and the extent of crop damage due to bacterial will varies greatly depending upon the bacterial strain, host variety, geographical region and the population of the bacteria in the soil (Hsu, 1991). High temperature and soil moisture are also the major factors for the development of bacterial wilt. It is found that problem of this disease is common in high lands which are not flooded and under continuous cultivation of *Solanaceous* crops without crop rotation. In case of tomato, this acute problem occurs commonly in kitchen gardens, which are usually non-flooded areas. It has been observed that due to wilt problems in some cases 100% of the tomato plants are died in kitchen gardens as has been stated by Ali (1993).

In controlling soil borne diseases (wilting), two traditional methods exist: i) soil sterilization by using chemicals or solarization, and ii) use of resistant varieties. Many efforts are being given worldwide to develop resistant varieties but such tomato varieties have not been developed yet. However, considering the increasing demand of summer tomato among the people of Bangladesh and to make available during summer, BARI has developed four heat tolerant hybrid tomato varieties so far. These varieties are being popularized day by day among the tomato growers. But, its production is severely constrained by several diseases, insect and mites. The major soil borne diseases are bacterial wilt, virus, root knot nematode and blights while pests include fruit borer armyworm, leaf miner etc. Among the diseases bacterial wilt considered to be number one threat for producing tomato during summer season in Bangladesh. It is also observed to be location specific. The location specificity may be due to the diversity of the pathogen strains, environments (temperature, soil property, or inoculum density etc.) and their interactions (Jaw, 1998). The yield of tomato is very low compared to other tomato growing countries that constrained by due to lack of good variety and pest and diseases problem as mentioned above. This poor yield may be increased by adding high yielding new tomato variety and by combating bacteria, insect, pest and diseases infestation problem. To protect the crop from insects and diseases during summer season production, growers are frequently and indiscriminately used toxic pesticide in their field which resulted poisonous tomato fruit that responsible for health hazard and wasting money. Only resistant variety is reliable tool to combat this problem but still such variety is not available in the world. Therefore, as alternate means or as an innovative technique- grafting technology (grafting of cultivable tomato variety onto wild rootstock) may be a good option considered to combat the problem caused by soil-borne diseases (Oda 1999; Hasna *et al*., 2009). It is also used to improve resistance to abiotic stresses such as salinity, drought, heat and low soil temperature, and enhance the uptake of nutrients and water (Mohammed *et al.,* 2009).

Different types of rootstocks have been used for performing grafting techniques. But, 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). The possibilities of these rootstocks in providing prospective benefits are enormous. For instance, a wide range of resistance or tolerance to diseases, abiotic stress, and high yielding and fruit quality with long shelf life may be obtained (Oda, 2002; Lee and Oda, 2003; Kubota *et al.,* 2008). In recent times, *S. melongena*, (eggplants) and its close relatives have been identified as potential and effective rootstocks for grafting tomatoes (Gisbert *et al.,* 2011). On the other hand, BARI has used *S. sysmbriifolium, S. torvum and S. melongena* as rootstocks for grafting purpose in tomato and brinjal. But due to degenerating trends of resistance level against bacterial wilt and root knot nematode diseases, it is prime need to find out alternate resistant rootstocks to control above problems. Therefore, the present study has been undertaken having six rootstocks to fulfill the following objectives:

- To assess grafting success and survivability of grafted seedlings;
- To assess grafting compatibility and field performance; and
- To select suitable rootstock for summer tomato grafting.

CHAPTER 2

REVIEW OF LITERATURE

According to Shankara *et al*. (2005) tomato originated from the South American Andes Region. Tomato is an herbaceous tropical perennial plant grown as an annual crop for its fruits, destined for both fresh and processing market. It is highly productive and economically valuable commodity worldwide. For all scales of commercial farmers it is an important cash crop (Shankara *et al*., 2005). Tomato has gained tremendous popularity over the last century, being cultivated practically in every country under greenhouse, nethouse and field conditions (Wener, 2016).

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

2.1 Grafting technology

2.1.1 Origin and evolution of grafting technology

According to Savvas *et al*. (2010), 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.

The part which provides the root system is called a rootstock. On the other hand the part which provides aerial part is called scion. The fusion permits the grower to combine a scion possessing desirable fruit producing traits with a rootstock that may be resistant to a multitude of abiotic and biotic stresses, resulting in a more productive plant (Petran and Hoover, 2014). Traditionally, grafting was limited to woody perennial species that did not root well from vegetative cuttings.

Grafting for vegetable production was first practiced in Japan and Korea 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).

Grafting was (Research on *Cucumis sativus* L.) started in the late 1920s, though wider commercial applications could only be realized in the 1960s (Sakata *et al*., 2008). Oda (1998) reported that the first grafting of Solanaceae family was recorded in eggplant (*Solanum melongena* L.) grafted on scarlet eggplant (*Solanum integrifolium* P.) in the 1950s. Furthermore, tomato grafting was introduced commercially in the 1960s (Lee and Oda, 2003; Bletsos and Olympios, 2008).

Turhan *et al.* (2011) observed that grafting in vegetable production systems has since been exploited to control such pathogens as other fungi, oomycetes, bacteria, nematodes and viruses in vegetable producing areas dominated by monocropping and intensive cultivation.

Grafting has been adopted as a major component of an integrated program in the Mediterranean regions to manage soilborne pathogens (Rivard and Louws, 2008). According to Lee *et al*. (2010), the technology was introduced to western countries in the early 1990s, initially in response to a need to grow residue free produce and due to the phasing out of Methyl bromide (Besri, 2003). Bletsos and Olympios (2008) stated that the other rationale for grafting was the increasing demand for produce grown under organic and Integrated Pest Management systems (IPM).

From a study carried by Lee (1994), the increasing advantages of grafting coupled with its possible application in commercial vegetable production have led to employment of this technology beyond disease management. That encloses grafting for tolerance against high and low temperatures, flood, (Black *et al*., 2003; King *et al*., 2010) salinity, drought, heavy metals, enhanced growth vigour, yield and quality, amongst others.

Now-a-days grafting is a common practice in many countries of Europe, the Middle East, Central America, Northern Africa, and other parts of Asia (Kubota *et al*., 2008). Today 59% and 81% of Japanese and Korean vegetables respectively are produced on grafted plants (Rivero *et al*., 2003). For many greenhouse operations, vegetable grafting has been a standard procedure (Rodriquez and Bosland, 2010). Meanwhile the technology has also gained popularity under open field conditions (Rodriquez and Bosland, 2010) and further research is still underway to evaluate its application there under (Kubota *et al.*, 2008).

2.1.2 Grafting techniques applicable to vegetables

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

Cleft 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) experimented and revealed, 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.

2.2 Grafting materials

According to Lee *et al*. (2010), a number of grafting tools to facilitate automated and manual grafting are available though most of them are not widely used by commercial growers. 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. Specially designed blade, knives, and hole insertion equipment have been manufactured for manual grafting (Bletsos and Olympios, 2008).

2.3 Sowing scheduling for grafting

Stem diameters of rootstocks and scions must be of comparable sizes for successful alignment of cambiums (Johnson *et al*., 2011b; Rivard and Louws, 2011; Miles *et al*., 2013), depending on the grafting method to be involved. This necessitates well thought out sowing scheduling of a scion and a rootstock involved. Black *et al*. (2003) stated that the relative duration to emergence and growth rate of rootstock and scion seedlings strongly influences sowing and grafting schedules. Most fresh market tomato lines germinate in two to three days while eggplant needs up to six days at 21 to 24ºC. As such AVRDC generally sows eggplant seeds three days before sowing tomato scions. Seed of the scions and rootstocks are sown on the same day, when tomato is to be grafted onto tomato rootstocks.

Miles *et al*. (2013) suggested that 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). Plants are ready for grafting when they attain two to four true leaves (Black *et al*., 2003; Johnson *et al*., 2011b).

2.4 Grafting process

Bletsos and Olympios (2008) noticed that 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; (Lee *et al*., 2010).

2.4.1 Rootstock selection

It was reported that 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 abiotic and biotic stresses, enhances scion growth, yield and fruit quality (Bletsos and Olympios, 2008; Savvas *et al*., 2009). According to Bumgarner and Kleinhenz (2015), selection of rootstocks should also be based on suitability for growing seasons, climate and growing conditions.

2.4.2 Application of grafting technique

Both scion and rootstock seedlings must be watered 12–24 hours before grafting (Johnson *et al*., 2011b; Miles *et al*., 2013). The inside surfaces of the healing chamber should be misted with water a day before grafting to raise relative humidity to 95% before grafts are placed inside (Johnson *et al*., 2011a; Ozores-Hampton and Frasca, 2013).

Rivard and Louws, (2011) suggested that grafting should be done in a shady, wind free place and during the cooler part of a day to reduce wilting of grafts. Hands and working places should be cleaned with anti-microbial detergents and hand latex gloves and sterile tools should be used to reduce exposure of plants to pathogenic viruses, bacteria and fungi.

2.4.3 Healing of graft union

Ozores-Hampton and Frasca (2013) stated that the rootstock must establish vascular connection which is the most critical part of the healing process in grafted vegetable transplants.

In several experiments, it was noticed that 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 properly to check graft desiccation. As such grafts are adopted in a low light intensity healing chamber at 25-32°C and 85-100 % relative humidity for four to seven days (Black *et al*., 2003; Kubota *et al.,* 2008). For this purpose 95% relative humidity is considered optimum (Lee, 2007; Oda, 2007) and should be maintained throughout the whole healing process. For the healing process this stipulated temperature range stimulates cell division (Lee, 2007). Misting, instead of direct water application to grafts is involved to prevent diseases, necrotic tissue formation and graft failure (Johnson *et al*., 2011b).

2.4.4 Acclimatization of grafts

It was reported that approach to acclimatization depends on the prevailing environmental conditions. On the fifth day, the healing chamber should be opened for about 30 minutes, and chamber's surfaces and grafts misted if necessary (Miles *et al.*, 2013). The chamber should be opened on the sixth day for two to four hours. Grafts can be removed on the seventh day from the healing chamber (Ozores-Hampton and Frasca, 2013). Grafts should then be adopted in the greenhouse for five to 10 days and before transferring them outside for three to five days for further hardening off (Miles *et al.*, 2013). Five days after grafting the major hydraulic connections within the graft union of tomato becomes functional (Fernández-García *et al.*, 2004). Tamilselvi and Pugalendhi (2017) revealed that full healing and functioning takes 14 to 15 days thereafter.

2.4.5 Grafting success

According to Fernández-García *et al*. (2004), grafting is considered successful when a complete union of the vascular system of a rootstock and a scion is achieved. This permits continued 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).

An experiment was conducted by Lee *et al.* (2010) and suggested that grafting success rate is improved when seedlings are grafted at three weeks of age. Tomato 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.

Rivard and Louws (2008) stated that tube grafting has a success rate of 85 to 95% attributed to a complete fusion of all vascular bundles of both parts. Similarly, 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).

Tamilselvi and Pugalendhi (2017) mentioned that grafting success also requires proper alignment of the vascular systems at the graft union. Thus, stem diameters of a rootstock and a scion seedling must be of comparable size at the time of grafting. Tai *et al*. (2004) revealed that reduced survival rate of grafts due to differences in stem diameter between *Cucurbita* spp and *Cucumis melo.*

Kubota *et al*. (2008) suggested that 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 before these conditions are gradually reversed during acclimatization. Misting should be employed but direct application of water should be avoided (Johnson *et al*., 2011b). It was reported that 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).

Msogoya and Mamiro (2016) observed that intraspecific grafting between rootstock Hawaii 7996 and Tanzania's local tomato cultivars terminated in lower graft success of 30-50% at healing stage

2.5 Transplanting and field management of a grafted vegetable crop

The graft interface should remain well above the soil line when transplanting. Rivard and Louws (2011) mentioned that 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. Adventitious roots should be removed routinely before reaching the soil (Johnson, 2011a; Miles *et al*., 2013). Similarly, suckers that developed on the rootstock near the cotyledons should be removed (Rivard and Louws, 2011). Plants should be staked and pruned to two main stems, two to three weeks after transplanting (Black *et al.*, 2003).

2.6 Benefits of vegetable grafting

From a study carried by Wills *et al.* (1996), vegetables are high value commodities, they are also subject to grave losses, both pre and post-harvest particularly in tropical regions. These losses undertake considerable economic and social significance. The main causes of such losses are disease outbreaks of bacterial, fungal, and viral pathogens. Research has revealed that grafting has a potential to prevent some of these diseases (Rivard and Louws, 2011).

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

2.6.1 Grafting to manage biotic stresses

An experiment was conducted by Davis *et al*. (2008) where they revealed that the earliest prime purpose for commercial grafting efforts was to manage fusarium wilt in watermelon production (Sakata *et al*., 2008; Louws *et al*., 2010). Vegetable grafting systems has since then rapidly extended to control other pathogens in other cucurbit and solanaceous vegetables (Davis *et al*., 2008; Louws *et al*., 2010). Khah *et al.* (2006) stated that the accelerated expansion was necessitated by increased pathogen inoculum densities due to intensification of production practices and reliance on susceptible cultivars to meet specific market demands. Louws *et al*. (2010) reported that 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, thus seeking alternative approaches.

2.6.1.1 Diseases commonly managed by grafting in solanaceae vegetables

Several experiment showed that some of the diseases successfully controlled by grafting in solanaceous and cucurbitaceous crops are bacterial wilt (*Ralstonia solanacearum*), fusarium wilt (*F. oxyporum)*, RKN (*Meloidogyne* spp.), verticillium wilt (*Verticillium dahlia*), monosporascus sudden wilt (*Monosporascus cannonballus*) and phytophthora blight (*Phytophthora capsici*) (Bletsos and Olympios, 2008; Davis *et al*., 2008; Guan *et al*., 2012).

Islam (1992) has made an experiment In Bangladesh, where five species of wild *Solanum* were evaluated for their resistance to root knot nematode (*Melodogyne incognita*) and their susceptibility was graded on the development of gall and nematode in root systems. It was observed that *S. sisymbriifolium* was found as resistant, *S. indicum* and *S. suranthense* as susceptible an *S. integrifoliumand, S. insanum* as highly susceptible. The compatibility of cultivated eggplant varieties for grafting on *S. sisymbriifolium* was studied and it was found to be an effective rootstock for grafting with susceptible eggplant to reduce the severity of root knot disease.

A study was conducted on bacterial wilt in sick bed to assess the reaction of rootstocks of wild *Solanum* spp. and cultivated eggplant variety against bacterial wilt. *Solanum torvum, S. sisymbriifolium, S. melongena* (Var. Khotkhotia long) and *S. melongena* (Var. Sufala) showed 0.00, 0.00, 19.44 and 100.00% wilt incidence, respectively (Rashid *et al.,* 2000).

In several researches it was reported that wild *Solanum* species were susceptible to complete resistance against bacterial wilt (Yamakawa and Mochizuki, 1978). Almost all the wild *Solanum* species were resistant to Fusarium wilt (Yamakawa and Mochizuki, 1979) and *S. torvum* was resistant to Verticillium wilt (McCammon and Honma, 1983). *S. foxicarium, S. sisymbriifolium and S. torvum* were reported to have resistance against nematodes along with resistance to other soil borne diseases, especially in the latter two species (Fassuliotis and Bhatt, 1982). It was also reported that many of the wild relatives have not yet been investigated for their resistance against these pests.

Hossain *et al.* (1999) investigated and revealed that *Solanum torvum* and *S. sisymbriifolium* were identified as resistant to bacterial wilt. It was also mentioned that between these two species; *S. torvum* was more suitable for grafting as it contains few numbers of spines on leaves and stems compared to *S. sisymbriifolium.*

According to Bletsos and Olympios (2008), In Morocco, 95% of greenhouse tomato is produced on grafted plants due to resistance against *Ralstonia solanacearum, F. oxyporum* f. sp. *lycopersici, and F. oxyporum* f. sp. *Radices lycopersici* assured by selected rootstocks and therefore ensuring higher yield. AVRDC recommends tomato line rootstock Hawaii 7996. Because it gives 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). King *et al*. (2008) reported that grafting against diseases in vegetable production is also becoming a common practice in open field conditions and is considered as an important IPM package (Besri, 2003; Rivard and Louws 2008; Louws *et al*., 2010).

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

Louws *et al*. (2010) stated that grafting to defy diseases may either be intraspecific or interspecific. Intraspecific grafting defines as grafting plants of the same species, for instance grafting tomato onto tomato. On the other hand, interspecific grafting involves grafting plants of different species, as for example eggplant and tomato. However, Intraspecific grafting often depends on use of specific major resistance genes that maybe overcome by indigenous or novel races of a compatible pathogen.

Intraspecific grafting may be preferred because of its less negative effects on crop productivity, fruit quality or graft compatibility (Louws *et al*., 2010).

Guan *et al*. (2012) suggested that single gene-mediated host resistance has been an important mechanism to manage fusarium diseases in solanaceous crops. However, interspecific and intergeneric rootstock offers multigenic resistance or nonhost reactions rendering them broader spectrum and durable. Intergeneric grafting has proven to be an effective management approach, mainly in cucurbit crops (Louws *et al*., 2010).

An investigation was carried out by Michel *et al*. (2010) and revealed, 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. Hence, 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*., 2002 cited by King *et al*., 2008; Louws *et al*., 2010). Rivard *et al*. (2010) reported that over-reliance on specific rootstocks also leads to shifts in host specificity of the pathogen population. Dependence on rootstocks in the absence of fumigation led to resurgence problems with tomato brown root rot caused by *Colletotrichum coccodes* and other pathogens.

2.6.2 Grafting to manage abiotic stresses

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

A study was conducted by Ahmed *et al.* (1996) and mentioned that high temperature had a depressing effect on auxin content and its activity in the reproductive process. Therefore, the exogenous application of growth regulating substance had been found to influence the endogenous hormones and thus improving the fruit setting process under unfavorable temperature. It was also suggested that a commercial crop of summer tomato could successfully be produced by spraying tomatotone (2% solution using 20 ml tomatotone per liter of water) on the open flowers of heat resistant varieties when grown on raised beds under polytunnels.

Several experiment suggested that 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). Wang *et al*. (2007) mentioned that eggplant rootstock CV. “Yuanqie” grafted onto a heat-tolerant rootstock CV. “Nianmaoquie” leading a prolonged growth stage and yield increase of up to 10%.

According to Ahn *et al*. (1999), 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. This arises from limited water and essential mineral nutrients uptake resulting slower leaf initiation and expansion rate as well as late crop productivity (Schwarz *et al*., 2010). On the other hand cold-tolerant rootstocks enhance root hydraulic conductance, shrink 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 reduced root-zone temperature (Schwarz *et al*., 2010).

2.6.3 Grafting to improve vegetable growth and yield

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

It was suggested that a vigorous and larger rootstock on a vigorous scion promotes absorption and translocation of water and nutrients, encouraging plant growth and yield (Davis *et al.*, 2008; Lee *et al.*, 2010; Martinez-Ballesta *et al*., 2010). Grafting vegetables onto vigorous rootstocks under deficit irrigation improve N, K and Mg uptake efficiency and use (Rouphael *et al*., 2008). Colla *et al*. (2014) reported that eggplant rootstocks are more efficient for water uptake than their tomato counterparts (because of their dense and extensive root systems) (Bletsos and Olympios, 2008). Palada and Wu (2008) mentioned that 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) suggests rootstocks EG195 and EG203 for these circumstances. Tomato grafted onto eggplant has a better leaf surface area, greater root and shoot dry weight and yield higher at higher temperature (Bletsos and Olympios, 2008). Similarly, Al-Harbi *et al.* (2016) observed 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) also reported an increase in height and yield for open field grafted tomato plant.

Harmful agrochemical application can be significantly reduced by using vigorous rootstocks, increasing successful production of organically grown fruit set (Lee *et al*., 2010; Martinez-Ballesta *et al*., 2010).

Pogonyi *et al*. (2005) stated that higher yield in a grafted crop as opposed to a non-grafted one results from larger and many fruits per plant. From a study by Turhan *et al*. (2011) mentioned that a higher number of fruit index, fruits per truss, fruit weight and fruits per plant of grafted tomato in comparison to controls. Again, grafting has also been reported to confer deleterious effects on growth and yield. Turhan *et al*. (2011) and Khah *et al.* (2006) revealed that grafting tomato onto a suitable rootstock has a positive effect on cultivation performance and yield. On the other hand, some rootstocks can reduce scion growth and production. For instance, tomato and eggplant grafted onto *Datura patula* show less growth, lower production and smaller fruit size in contrast to self-rooted plants (Bletsos and Olympios, 2008).

Grafting is also responsible for delay flowering in vegetable crops. Khah *et al*. (2006) also noticed this phenomenon in both greenhouse and open field grafted tomato in comparison to controls. Similarly, Ibrahim *et al*. (2001) stated that more days are required for first flowering, first fruit set, and first fruit maturity of grafted tomato plants in comparison to ungrafted ones. Ibrahim *et al*. (2001) also revealed that non-grafted plants had the maximum plant height at both first and last harvest.

Hossain *et al.* (2019) directed an experiment at Hajee Mohammad Danesh Science and Technology University, Dinajpur to look at the yield performance of some grafted and non-grafted plants. The experiment was consisted based on the four scion-rootstock combinations such as T_0= Tomato-4 (Non-grafted plant), T_1 = Tomato-4 grafted on the *Sunchalo* rootstock, T_2= Tomato-4 grafted on the brinjal rootstock and T_3 = Tomato-4 grafted on the wild tomato rootstock. The results of the grafted plants showed significant variations in all properties compared to non-grafted one except for plant height. The grafted plants on the *Sunchalo* rootstock was found better for a number of branches, clusters, fruits per plant, fruit length, diameter and weight rather than the other grafted and the non-grafted ones. The individual fruit weight ranges from 44.84 (non-grafted) to 57.88 g (grafted with *Sunchalo*) and the total yield (60.87 tons/ha) were found maximum in *Sunchalo* rootstock. Fruit quality properties (i.e. vitamin C, protein, lycopene, and β-carotene contents) were found better with *Sunchalo* rootstock rather than the other treatments. But fruit color, TSS (total soluble solids) and phenols content were not affected by the treatments.

A study was carried by Matsuzoc *et al.* (1990) noticed that the yield and quality of tomato fruits of grafted plants on the amphidiploid rootstocks were equivalent to or higher than those of non-grafted plants. Maync (1999) also revealed that tomato grafted on vigorous rootstocks and cultivated under tunnel was economic for high quality and yield because of longer harvesting period.

According to Lu *et al.* (1992), grafting of the main local tomato varieties with wild one gave 100% control of tomato bacterial wilt. Again, it was reported, yields were increased by 120.9, 80.5 and 78.6% when three wild rootstocks (CH-2-26, CH-2-25 and CH-2-21) were used in tomato grafting.

A field experiment was done in Turky to evaluate the effects of different grafting methods on the success of grafting and yield of eggplant/tomato graft combination. It was reported that grafting success was obtained 43.7%, 69.7%, and 83.3% from lateral perforation, tongue and cleft grafts, respectively. It was also noticed that grafting increased yield by 39-67% and total number of fruits was increased by 58-28% compared to control (Vuruskan and Yanmaz, 1991).

Granges *et al.* (1998) have made a research work in green house to assess the effect of soil steaming and grafted plants in a soil infected with corky root. It was observed that grafted tomato showed 65% increased yield. Tomatoes from grafted plants had higher mineral salt contents but had slightly lower dry matter. However, grafting had no influence on vitamin C content. It was also observed that soil steaming enhanced the yield of non- grafted plants by 48%, while increasing plant vigor, but did not reduce the infection rate, by corky root.

2.6.4 Grafting to improve quality of vegetable produce

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

An experiment was carried by Gisbert *et al*. (2011) and reported that the noticeable quality characteristics and composition of a final product of grafted plants should remain unchanged or be improved with respect to non-grafted plants. But, 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) and this may be attributed in part to different production environments (air temperature and light intensity), 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 was reported 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).

CHAPTER 3

MATERIALS AND METHODS

The present research work was conducted at the Olericulture Division of Horticulture Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur, during the period of April, 2019 to September, 2019 to study the effect of tomato grafting compatibility with different rootstock and their field performance during summer season. This chapter deals with the materials and methods in conducting the experiment and has been described under the following sub-heading:

3.1 Experimental site

The experiment was conducted at the field of Horticulture Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI), Gazipur-1702, Bangladesh. The experiment was carried out during summer season (April to September, 2019). The experimental field was located at $24^0$26 N latitude and $90^0$26 E longitudes at a height of 8.4 m above the mean sea level.

3.2 Climate

The area is characterized by hot and humid climate. The average rainfall of the locality during the experiment was 345.83 mm. The average minimum and maximum temperatures were 24.4 and 35.2 °C respectively. The average relative humidity was 84.1% during April to September, 2019. The detail meteorological data in respect of monthly temperature, rainfall and relative humidity recorded during the period of the present study have been presented in Appendix-II.

3.3 Soil

The land was medium high with good drainage facilities. The soil of the experimental area belongs to the Gray Terrace Soil Tract. The texture of the soil was silt loam having pH 6.4 with an organic matter content of 1.88%.

3.4 Planting materials

Bangladesh Agricultural Research Institute (BARI), Joydebpur developed BARI hybrid tomato-10 was used as scion and six rootstocks of solanaceous species viz. *S. sisymbriifolium*; *S. melongena* (BARI brinjal-8); EG 203 and three others newly collected rootstocks were considered as rootstock. Tomato and rootstock seeds were collected from Olericulture Division, Horticulture Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI), Gazipur.

3.5 Treatments of the experiment

The experiment consisted of following treatments that are represented as below:

T_0= Non-grafted tomato seedling of BARI hybrid tomato-10 (Control);

T_1= Grafted seedling (tomato grafted on *Solanum sisymbriifolium*);

T_2= Grafted seedling (tomato grafted on EG- 203);

T_3= Grafted seedling (tomato grafted on Khag-1);

T_4= Grafted seedling (tomato grafted on Khag-2);

T_5 = Grafted seedling (tomato grafted on Khag-3); and

T_6 = Grafted seedling (tomato grafted on BARI brinjal-8)

3.6 Design and layout of the experiment

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. A block consisted of 7 unit plots each receiving a treatment combination of the experiment. Treatment combinations of the experiment were assigned randomly in each block. Thus, the total number of unit plot was 21. The number of plant per unit plot was 20. The area of unit plot was 9.15 m^2 (3 m x 3.05 m) which was set under polytunnels. The polytunnels were raised up to 30 cm from the ground level and 2.3 m in width and 20 m in length having 30 cm space in between two beds for providing irrigation and cultural operations.

3.7 Seedling raising

3.7.1 Raising of rootstock seedling

Seeds of rootstocks (*S. sisymbriifolium*, EG-203, Khag-1, Khag-2, Khag-3 and BARI brinjal-8) were sown directly in the seedbed on April 10, 2019. Seedlings at 2-3 true leaf stage were transplanted individually in polyethylene bag (9 cm in diameter) containing a mixture of 3 parts well- decomposed cow dung and 1 part soil (plate-1) .

The rootstock seedlings of was ready for grafting at 30-35 days when four to six fully opened leaves were developed and the plants were 8 to 10 cm tall.

3.7.2 Raising of scion seedling

Seeds of tomato (BARI hybrid tomato-10) were sown directly in the seedbed on April 28, 2019. The scion seedlings (plate-1) were ready for grafting when they were 5-8 cm in height with 4-5 leaves. Adjustment was made with sowing date of scion and stock so that the seedlings were ready for grafting at the same time. Watering, mulching, weeding and shading were done as and when necessary.

3.8 Procedure for grafting

3.8.1 Rootstock preparation

- Rootstock in polyethylene bag was held tightly between knees (plate-2a).
- The top of the rootstock was removed by a sharp horizontal cut using a razor blade retaining 1-3 leaves with the stock plant.
- About 1 cm depth vertical cut was made so that the tip of the rootstock becomes two equal parts (plate-2b).
- Slightly open and wide slit was made to facilitate the insertion of scion (plate-2c).

3.8.2 Scion Preparation

- Four to five cm long shoot with growing point from the scion seedling was cut with the help of a sharp razor blade.
- Lower leaves were removed from the scion to reduce transpiration. The first slanting cut about one cm long on the basal end of the scion was made.
- A similar cut to the opposite side at the basal end was made such that a ‘ V' or ‘wedge’ shape was formed at the base of the scion.

3.8.3 Making the graft and nursing

- Grafting was performed on May 23, 2019 to May 26, 2019 in a grafting house when rootstock and scion seedlings were 28 and 21 days old, respectively.
- BARI hybrid tomato-10 seedlings were each cleft grafted on rootstocks *S. sisymbriifolium*, EG-203, Khag-1, Khag-2, Khag-3 and BARI brinjal-8 (plate-3).
- To make the joint tight and strong a plastic clip was used (plate-2d).
- After grafting, water was sprayed on the scion using a hand sprayer (plate-2e).
- Grafted plants were put in a small healing house (plate-4) covered with a sheet of polyethylene and a black sheet of curtain under the polyethylene cover so that high humidity can be maintained and no sunlight can directly enter into the healing house. When there was no rain the house was kept uncovered at night but covered again during the day time. Water was sprayed on the grafted plants 3-4 times a day for a period of 7- 10 days.
- Polyethylene sheet was removed from the top of the house after above mentioned times keeping the black cover for another few days until the graft union was established. After 10-12 days the scion started to grow. Emerged twig from the rootstock was removed immediately.

For better success house was prepared in a shady place and grafting was done in the afternoon.

3.9 Land preparation

Selected land was opened on June 19, 2019 by a disc plough to open direct sunshine to kill soil borne pathogens and soil inhabitant insects. The land was prepared by ploughing and cross ploughing followed by laddering. The land was leveled, corners were shaped and the clods were broken into pieces. The weeds and stubbles were removed and the land was prepared through addition of the basal doses of manures and fertilizers.

3.10 Doses of manure and fertilizer and their methods of application

Manure and fertilizers were applied uniformly in all the experimental plots as per following doses:

Manure/Fertilizer	**Dose ha^{-1}**	**Dose plot^{-1}**
Well decomposed cowdung	10 tons	4 kg
Urea	550 kg	0.22 kg
TSP	450 kg	0.18 kg
MoP	250 kg	0.10 kg
Gypsum	120 kg	0.04 kg

The whole amount of cowdung and TSP were applied as basal dose during land preparation. Urea and MoP were applied as side dressing in two equal splits at 21 and 35 days after transplanting.

3.11 Tunnel setting

Polytunnels were set on the plot that was made with bamboo frame and covered with transparent polythene sheet as suggested by Ahmed *et al.* (1996). The tunnels were used to protect plant from heavy rain and water logging condition of soil.

3.12 Transplanting and establishment of seedlings

Seedlings were transplanted in the main field after fifteen days of grafting on June 26, 2019. Non-grafted seedlings (control) of similar age were also transplanted in the field on the same date. Grafted seedlings were watered 3-4 hours before transplanting in the main field. Before transplanting undesired emerging shoots and twigs of stocks (below grafted point) were removed. During transplanting the polythene bag was cut and removed with care to keep the soil intact with the root system of the rootstock plant. A spacing of 60 x 40 cm was used. Irrigation was provided after transplanting of seedlings.

3.13 Intercultural operations

Intercultural practices were made to confirm the normal growth of the crop. The following intercultural operations were done timely.

3.13.1 Staking and pruning practices

Plants were supported by ‘A’ shaped bamboo stick to keep the branch upright. The plants were pruned twice 21 and 35 days after transplanting respectively.

3.13.2 Weeding and mulching

Weeding and mulching were done as and when necessary to keep the plot free from weeds.

3.13.3 Irrigation

The plants were initially irrigated by watering can and as they grew older flood irrigation was provided whenever required.

3.13.4 Application of tomatotone

Tomatotone (consisting of 4-para chlorophenoxy acetic acid) solution @ 2 ml/l water was sprayed on plants having flower cluster at full bloom stage. Plants were received two sprays at 7 days interval and only flower clusters were sprayed as recommended by Chandha *et al.* (1992) who reported that tomatotone improves exogenous auxin which reduces flower drop and increases fruit-set.

3.13.5 Pest and disease control

White flies were controlled by spraying Bimecron 50 EC @ 2ml/L at 15 days interval as suggested by Khurshed *et al.* (1987). There were no other major insects pests found in the crop and the bacterial wilt affected plant whenever found was uprooted and destroyed.

3.14 Harvesting

Fruits were harvested at 3 day intervals during early ripe stage when they attained slightly red color. Harvest of mature fruits was started on August 24, 2019 and it was continued up to September 20, 2019.

3.15 Data collection:

Data were recorded on the following parameters from the sample plants to assess the result. The sampling was done randomly. The plants in the outer two rows and at the extreme end of the middle rows were excluded during randomization. Ten plants were randomly selected from each plot. The data on following parameters were recorded.

3.15.1 Grafting success at healing house (%)

The number of grafts that survived at the end of stay in each healing. Grafting success was then arrived at by the following equation:

.

$$\text{Grafting success (\%)} = \frac{\text{Number of successful grafts x 100}}{\text{Total number of grafts}}$$

Percent success of grafting was determined 15 days after grafting when the scion started growing on the rootstock. Healthy and well established scions were counted as successful grafts.

3.15.2. Grafting success at field condition

3.15.2.1 Plant survivability (%)

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.

3.15.2.2 Plant height (cm)

Plant height at final harvest was measured from sample plants in centimeter (cm) from the ground level to the tip of the longest stem and the mean value for each treatment was calculated. This was measured by using a metallic meter rule (2m long) from the base of the plant to the apical growing point of the plant.

3.15.2.3 Number of leaves plant^{-1}

The numbers of leaves plant^{-1} were counted manually. The number of leaves of the sample plant was counted at the time of harvesting and the average number of leaves produced per plant was recorded.

3.15.2.4 Number of main branches plant^{-1}

The numbers of main branches plant^{-1} were measured from the randomly selected ten plants from each unit plot by counting and the mean value was calculated at the time of the final harvest.

3.15.2.5 Number of total branches plant^{-1}

The numbers of total branches plant^{-1} were measured from the randomly selected ten plants from each unit plot by counting and the mean value was calculated at the time of the final harvest.

3.15.2.6 Days to 1st flowering

The days to flowering was measured by counting the number of days after transplanting to first flowering.

3.15.2.7 Days to 50% flowering

The days to flowering was measured by counting the number of days after transplanting to 50% flowering.

3.15.2.8 Number of clusters plant^{-1}

The numbers of flower clusters plant^{-1} were counted from the sample plants and the average number of flower clusters produced per plant.

3.15.2.9 Number of flowers cluster^{-1}

The flowers cluster^{-1} was calculated by counting manually in the flowering stage of selected plants and data was recorded. It was calculated by the following formula:

$$\text{Number of flowers per cluster} = \frac{\text{Sample plant}}{\text{Total number of flower clusters from 10 sample plant}}$$

3.15.2.10 Days to 1st harvest

This was measured by counting the number of days after transplanting to the days of the first harvest at fully ripen stage.

3.15.2.11 Harvesting duration

This was measured by counting the number of days after first harvest to the days of the last harvest.

3.15.2.12 Number of fruits plant^{-1}

It was recorded by the following formula:

$$\text{Number of fruits per plant} = \frac{\begin{array}{c}\text{Total number of fruits from 10 sample}\\ \text{plants upto final harvest}\end{array}}{10}$$

3.15.2.13 Single fruit weight (g)

Among the total number of fruits during the period from first to final harvest of fruits, except the first and final harvests, were considered for determining the individual fruit weight by the following formula and expressed in gram.

$$\text{Average single fruit weight (g)} = \frac{\text{Total weight of fruits from 10 sample plants}}{\text{Total number of fruits from 10 sample plants}}$$

3.15.2.14 Fruit length (cm)

The length of fruit was measured with a digital slide caliper (Guanglu, China) from the neck of the fruit to the bottom of ten selected marketable fruits from each plant of each replication and their average was calculated in centimeter (cm).

3.15.2.15 Fruit diameter (cm)

The diameter of fruit was measured at the middle portion of ten selected marketable fruits from each treatment of each replication with digital slide calipers (Guanglu, China) and their average was calculated in centimeter (cm).

3.15.2.16 Total Soluble Solids (%)

Ten defect free tomato fruits at red stage of maturity were selected for TSS measurement. TSS content was determined by Refractometer. Tomato fruits of each variety were taken and a drop of juice squeezed from the sample was placed on the surface of the prism of the Refractometer and percent TSS was recorded from direct reading.

3.15.2.17 Fruit yield plant^{-1} (kg)

It was measured by the following formula:

$$\text{Weight of fruits per plant (Kg)} = \frac{\text{Total weight of fruits of 10 sample plants}}{10}$$

3.15.2.18 Fruit yield plot^{-1} (kg)

A per scale balance was used to take the weight of fruits per plot. It was measured by totaling the fruit yield of each unit plot separately during the period from first to final harvest and was recorded in kilogram (kg).

3.15.2.19 Fruit yield tunnel^{-1}

It was calculated from per plant yield and multiplied by number of plants survived per tunnel.

3.15.2.20 Fruit yield ha^{-1} (ton)

It was calculated from tunnel, considering 170 tunnels per hectare (Ahmed *et al.*, 1996).

3.15.2.21 Bacterial wilt infestation (%)

Incidence of wilting incidence of plants was recorded at 45, 60, 75 and 90 days after sowing (DAS).

3.15.2.22 Virus infestation (%)

Incidence of virus infection of plants was recorded at 45, 60, 75 and 90 days after sowing (DAS).

3.15.2.23 Pest and other diseases (%)

The percentage of pest and diseases were measured from 45, 60, 75 and 90 days after sowing (DAS) by counting and the mean value was calculated at the time of the final harvest.

3.16 Statistical analysis

The recorded data were statistically analyzed using STATISTIX 10 statistical package program. Test of significance for each character was performed by F-test. The difference between the treatments was judged by Least Significant Difference (LSD) test. Analysis of variance table has been presented in Appendix.

CHAPTER 4

RESULTS AND DISCUSSION

The present experiment was conducted to study the resistance level of rootstocks and tomato grafting compatibility with different rootstock and their field performance, seedling survivability, plant stand ability, growth, quality of fruits and yield of summer tomato. The results obtained from the study have been presented and discussed in this chapter with the following headings:

4.1 Grafting success at healing house

The effect of rootstock on the grafting success was found significant (Appendix-III). The results in this regard have been presented in figure-1. In the case of influence of rootstock on grafting success, it was revealed that the maximum grafting success (86.15%) was recorded from treatment T_6 (tomato grafted on BARI brinjal-8) which was statistically similar (83.95%) with T_1 (tomato grafted on *S. sisymbriifolium*). It might be occurred due to good grafting compatibility between tomato and rootstocks. The lowest grafting success was obtained (70.00%) from T_4 (tomato grafted on khag-2). Such poor success occurred due high number of mortality (30.00 %) caused by abiotic stress, while biotic and other cause were also responsible for mortality. The climatic condition indicted that average outside temperature was recorded 30.5°C and inside graft house was prevailed 31.6°C. In the case of humidity, it was 80.75 and 84.73% in outside and inside of grafting chamber respectively. One of the grafting researchers (Kubota *et al.,* 2008) reported that 27-28°C temperature with >85% humidity is suitable for successful grafting. Vuruskan and Yanmaz, (1991) obtained 83.33% grafting success when tomato was grafted on eggplant. Similar results also noted by Msogoya and Mamiro (2016) and Lee *et al.* (2010).

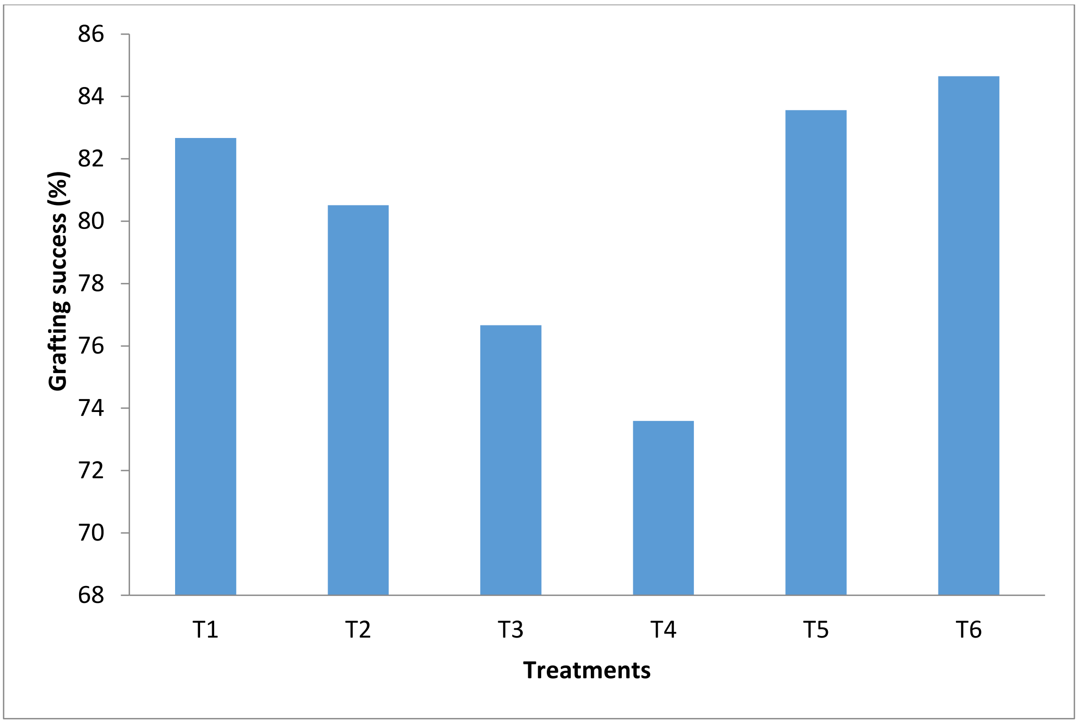


Figure 1. Effect of different grafted tomato seedlings on grafting success

Note: T_1= Grafted seedling (tomato grafted on *S. sisymbriifolium*); T_2= Grafted seedling (tomato grafted on EG-203); T_3= Grafted seedling (tomato grafted on Khag-1); T_4= Grafted seedling (tomato grafted on khag-2); T_5= Grafted seedling (tomato grafted on khag-3); T_6= Grafted seedling (tomato grafted on BARI brinjal-8)

4.2 Grafting success at field condition

4.2.1 Plant survivability plot^{-1}

The plant survivability percentage was found significant. The results in this regard have been presented in Table-1. Under the study, T_6 treatment (tomato grafted on BARI brinjal-8) showed the highest plant survivability percentage (94.67%) which was statistically similar to T_2 (93.67%) (tomato grafted on EG-203) and T_1 (93.00%) (tomato grafted on *S. sisymbriifolium*) treatments. It might be due to effect of resistance potentiality. The lowest (63.33%) plant survivability was observed from T_0 (non-grafted tomato seedling) treatment. It might occur due to susceptibility to bacterial wilt of tomato variety.

Among the grafted seedlings the minimum (81.00%) plant survived in T_5 (tomato grafted on khag-3) which is statistically similar (83.00%) with T_4 (tomato grafted on Khag-2). It was occurred due to they had very high incidences of adventitious roots in comparison to non-grafted treatments. Adventitious roots at the graft union are the signs of graft incompatibility. These result also supported by Kawaguchi *et al*. (2008), Ives *et al*. (2012) and Parkinson *et al*. (1987).

Table 1. Effect of different grafted and non-grafted tomato seedlings on plant survivability plot^{-1}

Treatments	Plant survivability plot^{-1} (%)
T_0	63.33d
T_1	93.00a
T_2	93.67a
T_3	88.33ab
T_4	83.00bc
T_5	81.00c
T_6	94.67a
$LSD_{(0.05)}$	6.81
Level of Significance	**
CV (%)	4.49

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly.

** : Significant at 1% level of probability

T_0= Control (non-grafted tomato seedling);

T_1= Grafted seedling (tomato grafted on *S. sisymbriifolium*);

T_2= Grafted seedling (tomato grafted on EG-203);

T_3= Grafted seedling (tomato grafted on Khag-1);

T_4= Grafted seedling (tomato grafted on khag-2);

T_5= Grafted seedling (tomato grafted on khag-3);

T_6= Grafted seedling (tomato grafted on BARI brinjal-8)

4.2.2 Plant height

From this experiment result, it was observed that there was significant (Appendix-IV) variation on plant height of grafted and non-grafted plants of summer tomato (Fig. 2). The tallest plant height (135.42 cm) was recorded from T_6 (tomato grafted on BARI brinjal-8) treatment which was statistically similar (130.17cm) to T_1 (tomato grafted on *S. sisymbriifolium*) treatment. The shortest plant height (92.62 cm) was counted from T_0 (non-grafted tomato seedling) treatment, which was statistically similar to T_2 (93.50 cm) treatment (tomato grafted on EG- 203). Similar results reported by Al-Harabi *et al*. (2016) who observed that plant height was significantly increased in grafted tomato as compared to ungrafted plants. These results also supported by Bletsos and Olympios (2008) and Colla *et al*. (2014).

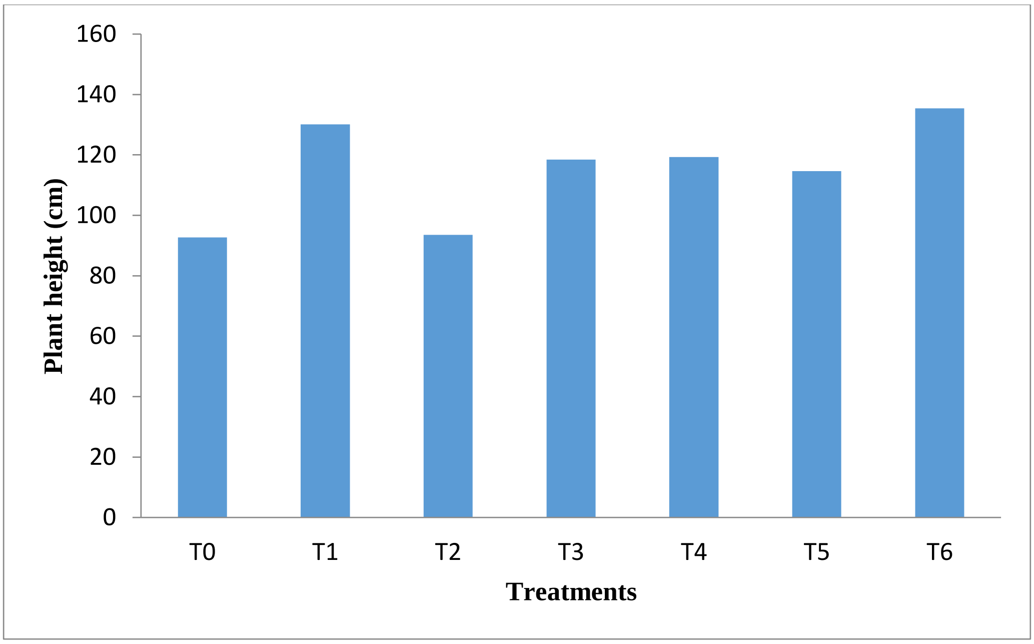


Figure 2. Effect of different grafted and non-grafted tomato seedlings on plant height

Note: T_0= Control (non-grafted tomato seedling); T_1= grafted seedling (tomato grafted on *S. sisymbriifolium*); T_2= grafted seedling (tomato grafted on EG- 203); T_3= grafted seedling (tomato grafted on Khag-1); T_4= grafted seedling (tomato grafted on Khag-2); T_5 = grafted seedling (tomato grafted on Khag-3) and T_6 = grafted seedling (tomato grafted on BARI brinjal-8).

4.2.3 Number of leaves plant^{-1}

Significant variation (Appendix-IV) was observed on number of leaves plant^{-1} for grafted and non-grafted plants of summer tomato (Fig. 3). This experiment results revealed that the number of leaves plant^{-1} was varied from 47.00 to 88.00 which indicated the growth and development variation among the treatments that may influence yield variation too. The maximum number of leaves plant^{-1} (88.50) was recorded from T_6 (tomato grafted on BARI brinjal-8) while, the minimum number of leaves plant^{-1} (47.00) was observed from T_0 (non-grafted tomato seedling) treatment. From the present results, it was revealed that the number of leaves increased in grafted seedlings compared to non-grafted seedling. Similar results also supported by the findings of Black *et al*. (2003).

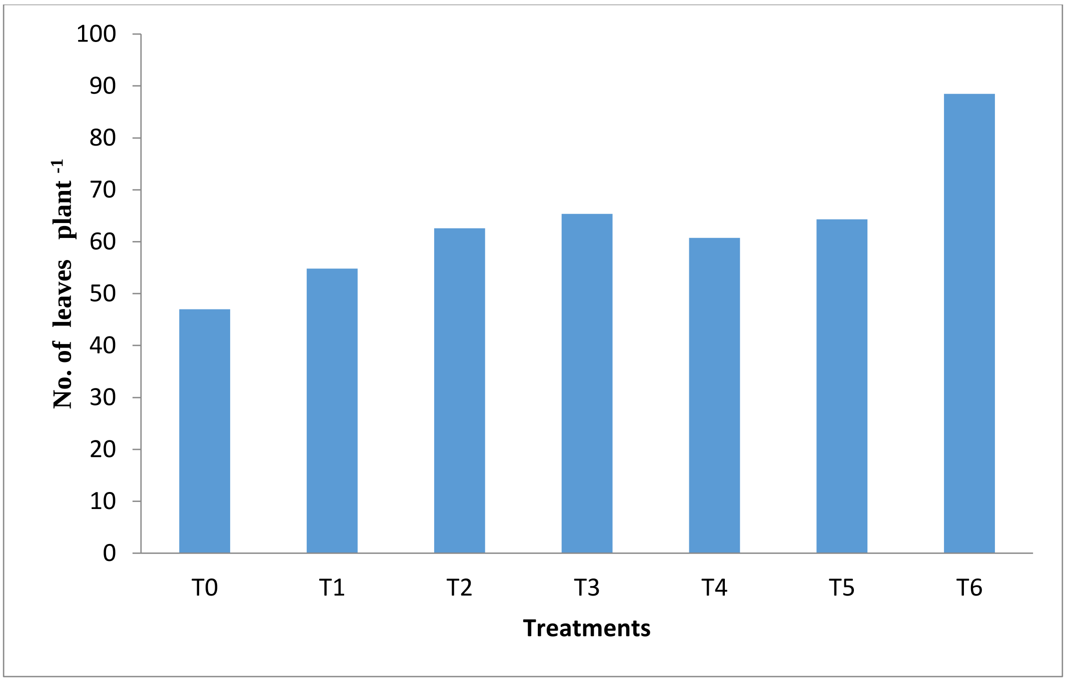


Figure 3. Effect of different grafted and non-grafted tomato seedlings on number of leaves plant^{-1}

Note: T_0= Control (non-grafted tomato seedling); T_1= grafted seedling (tomato grafted on *S. sisymbriifolium*); T_2= grafted seedling (tomato grafted on EG- 203); T_3= grafted seedling (tomato grafted on Khag-1); T_4= grafted seedling (tomato grafted on Khag-2); T_5 = grafted seedling (tomato grafted on Khag-3) and T_6 = grafted seedling (tomato grafted on BARI brinjal-8).

4.2.4 Number of main branches plant^{-1}

Significant variation observed on number of main branches plant^{-1} for grafted and non-grafted seedlings of summer tomato (Table 2). The main branches plant^{-1} differ from 2.17 to 3.17 among the treatments, while the highest number of main branch plant^{-1} (3.17) was counted from T_6 (tomato grafted on BARI brinjal-8) which was statistically similar to all other treatments except T_2 (tomato grafted on EG- 203) and T_4 (tomato grafted on Khag-2). The lowest number of main branch plant^{-1} (2.17) was observed from T_0 (non-grafted tomato seedling) treatment which was statistically similar to T_2 (tomato grafted on EG- 203) and T_4 (tomato grafted on Khag-2) treatments. From the experiment results, it was observed that number of main branches was significantly increased in grafted tomato as compared to ungrafted plants.

4.2.5 Number of total branches plant^{-1}

Different treatments showed significant variation for number of total branches plant^{-1} for grafted and non-grafted seedlings of summer tomato (Table 2). The results expressed that the total branches per plant differ from 6.17 to 10.17 among the treatments respectively while the highest number of total branch plant^{-1} (10.17) exhibited from the treatment T_6 (tomato grafted on BARI brinjal-8) and the lowest number of total branch plant^{-1} (6.17) was counted from T_0 (tomato grafted on Khag-2) which was statistically identical to T_5 (tomato grafted on Khag-3) treatment (6.67) and T_2 (tomato grafted on EG- 203) treatment (6.83). Numbers of total branches were significantly increased in grafted tomato as compared to ungrafted plants. These results agreed with the findings of Hossain *et al.* (2019) who reported that grafting produced maximum number of branches compared with non-grafted one.

Table 2. Effect of different grafted and non-grafted tomato seedlings on number of main and total branches plant^{-1}

Treatments	Number of main branch plant^{-1}	Number of total branches plant^{-1}
T_0	2.17b	6.17d
T_1	3.08a	8.33c
T_2	2.17b	6.83d
T_3	3.12a	9.33b
T_4	2.17b	7.83c
T_5	3.17a	6.67d
T_6	3.17a	10.17a
$LSD_{(0.05)}$	0.17	0.69
Level of Significance	**	**
CV%	3.48	4.94

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly.

** : Significant at 1% level of probability

T_0= Control (non-grafted tomato seedling);
T_1= Grafted seedling (tomato grafted on *S. sisymbriifolium*);
T_2= Grafted seedling (tomato grafted on EG-203);
T_3= Grafted seedling (tomato grafted on Khag-1);
T_4= Grafted seedling (tomato grafted on khag-2);
T_5= Grafted seedling (tomato grafted on khag-3);
T_6= Grafted seedling (tomato grafted on BARI brinjal-8)

4.2.6 Days to 1st flowering

Different treatments showed significant variation for first flowering (Table 3). From the experiment result, it was observed that the maximum days for first flowering (54.33 days) were counted from T_2 (tomato grafted on EG- 203) treatment which was statistically identical (53.00 days) to T_4 (tomato grafted on Khag-2), where the minimum days for first flowering (50.00 days) were counted from T_0 (non-grafted tomato seedling) treatment. It was revealed that the grafted seedlings attained late first flowering compared to non-grafted one and likewise early fruiting or harvesting was made from non-grafted seedlings too. The delayed flowering in grafted plants might be due to grafting shock of the scion, which resulted in disruption of growth. The present results also supported the findings of Ibrahim *et al*. (2001) and Khah *et al*. (2006), who observed more days to flowering in grafted tomato.

4.2.7 Days to 50% flowering

Significant effect was observed on 50% flowering on grafted and non-grafted plants of summer tomato (Table 3). From the experiment result, it was observed that the maximum days for 50% flowering (57.33 days) were observed from T_2 treatment which was statistically similar to other grafted plants except T_4 (55.53 days) treatment (tomato grafted on Khag-2). The minimum days for 50% flowering (54.00 days) were recorded from T_0 (non-grafted tomato seedling) treatment. As evident from the results, it was found that non-grafted plants took minimum time for 50% flowering. On the other hand, the grafted plants took more days for 50% flowering. Matsuzoe *et al.* (1990) and Ali (1994) also mentioned similar trend of delayed flowering in grafted plants.

4.2.8 Number of clusters plant^{-1}

Significant variation was found on number of clusters plant^{-1} for grafted and non-grafted summer tomato plants (Table 3). From the experiment results, it was observed that the maximum number of clusters plant^{-1} (27.00) was recorded from T_6 (tomato grafted on BARI brinjal-8) treatment. And the minimum number of flower clusters plant^{-1} (21.00) was counted from T_0 (non-grafted tomato seedling) treatment which was statistically similar (21.00) to T_5 (tomato grafted on Khag-3) treatment. The grafted plant produced more flowering clusters than the non-grafted one. That might occur probably due to the variation in rootstocks (Hossain *et al.*, 2019).

4.2.9 Number of flowers cluster^{-1}

The number of flowers cluster^{-1} differed significantly between the grafted and non-grafted plants of summer tomato (Table 3). It was highest (7.07) in T_3 (tomato grafted on Khag-1) which was statistically similar (6.45) to T_2 (tomato grafted on EG- 203) while the least was in the non-grafted one (5.17). It might be the effects of different rootstocks. Khah *et al.* (2006) reported that the grafted plants generally showed to have a larger number of flowers. This observation is in agreement with Ibrahim *et al*. (2001), who found a higher number of fruits per cluster in grafted tomato, in comparison to the ungrafted treatment. Pogonyi *et al*. (2005) also observed the same trend.

Table 3. Effect of different grafted and non-grafted tomato seedlings on clusters plant^{-1} and flowers cluster^{-1}

Treatments	Days to 1st flowering	Days to 50% flowering	Number of clusters plant^{-1}	Number of flowers cluster^{-1}
T_0	50.00d	54.00c	21.00d	5.17c
T_1	52.67b	56.00ab	23.33c	6.08b
T_2	54.33a	57.33a	24.33b	6.45ab
T_3	52.67b	56.00ab	22.67c	7.07a
T_4	53.00ab	55.33bc	23.00c	5.17c
T_5	51.67bc	56.33ab	21.00d	6.20b
T_6	51.00cd	56.00ab	27.00a	6.26b
$LSD_{(0.05)}$	1.55	1.55	0.99	0.73
Level of Significance	**	*	**	**
CV (%)	1.67	1.56	2.40	6.73

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly.

** : Significant at 1% level of probability * : Significant at 5% level of probability

T_0= Control (non-grafted tomato seedling);
T_1= Grafted seedling (tomato grafted on *S. sisymbriifolium*);
T_2= Grafted seedling (tomato grafted on EG-203);
T_3= Grafted seedling (tomato grafted on Khag-1);
T_4= Grafted seedling (tomato grafted on khag-2);
T_5= Grafted seedling (tomato grafted on khag-3);
T_6= Grafted seedling (tomato grafted on BARI brinjal-8)

4.2.10 Days to 1st harvest

Significant effect was observed on days to first harvesting for grafted and non-grafted summer tomato plants (Table 4). Fruit harvest was started from 91.00 to 98 DAS. From the experiment, the results expressed that maximum days require for first harvest (98.00 days) was recorded from T_6 (tomato grafted on BARI brinjal-8) treatment which was statistically similar (98.00 days) to T_5 (tomato grafted on Khag-3) treatment followed by T_4 (tomato grafted on Khag-2) (96.00 days) treatment, while the minimum days to first harvesting (90.67 days) was observed from T_0 (non-grafted tomato seedling) treatment. Normally, grafted plants had a tendency of delay flowering, fruit set and harvesting. This may occurred due to transplanting shocks during grafting process. Matsuzoe *et al.,* (1990) and Ali (1994) also mentioned the same observation.

4.2.11 Harvesting duration

The harvesting duration was observed from first harvest to last harvest. Significant effect was observed on harvesting duration (Table 4). The highest harvesting duration (27.33 days) was recorded from T_6 (tomato grafted on BARI brinjal-8) treatment followed by T_1 (tomato grafted on *S. sisymbriifolium*) (25.67 days). And the lowest harvesting duration (17.33 days) was counted from T_0 (non-grafted tomato seedling) treatment. The longer period of harvesting in grafted plants compared to non-grafted plants might be due to use of *Solanum* rootstock, which possesses stronger root system compared to cultivated tomato scion. Hence, there was a relationship among the treatments in increasing harvesting duration, which consequently contributed higher yield. The result was agreed by Maync (1999) who stated that tomato grafted on vigorous rootstocks give higher yield due to longer harvesting duration. Similar result was also reported by Mazollier (1999) and Hossain *et al.* (2019).

Table 4. Effect of different grafted and non-grafted tomato seedlings on first harvest and harvesting duration

Treatments	Days to 1st harvest	Harvesting duration
T_0	90.67c	17.33d
T_1	95.33ab	25.67b
T_2	94.00bc	20.33c
T_3	95.67ab	20.67c
T_4	96.00ab	20.33c
T_5	98.00a	21.00c
T_6	98.00a	27.33a
$LSD_{(0.05)}$	3.72	1.55
Level of Significance	*	**
CV (%)	2.19	4.00

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly.

**: Significant at 1% level of probability *: Significant at 5% of probability

T_0= Control (non-grafted tomato seedling);
T_1= Grafted seedling (tomato grafted on *S. sisymbriifolium*);
T_2= Grafted seedling (tomato grafted on EG-203);
T_3= Grafted seedling (tomato grafted on Khag-1);
T_4= Grafted seedling (tomato grafted on khag-2);
T_5= Grafted seedling (tomato grafted on khag-3);
T_6= Grafted seedling (tomato grafted on BARI brinjal-8)

4.2.12 Number of fruits plant^{-1}

The number of fruits plant^{-1} at different treatments exhibited significant variation (Appendix-VII). The maximum number of fruits plant^{-1} (33.33) was recorded from T_6 (tomato grafted on BARI brinjal-8) treatment which was statistically identical to T_1 (32.67) (tomato grafted on *S. sisymbriifolium*) treatment (Fig. 4). It might be due to prolonged harvesting duration. The lowest number of fruits plant^{-1} (25.67) was counted from T_0 (non-grafted tomato seedling) treatment. Among the grafted plants the lowest number of fruits per plant (26.67) was recorded from T_3 (tomato grafted on Khag-1). This might be due to impaired growth performance emanating from constricted graft unions and possibly low rootstock vigour. These results supported the findings of Turhan *et al.* (2011) who stated that the number of fruits per plant increased by grafting than without grafting of tomato.

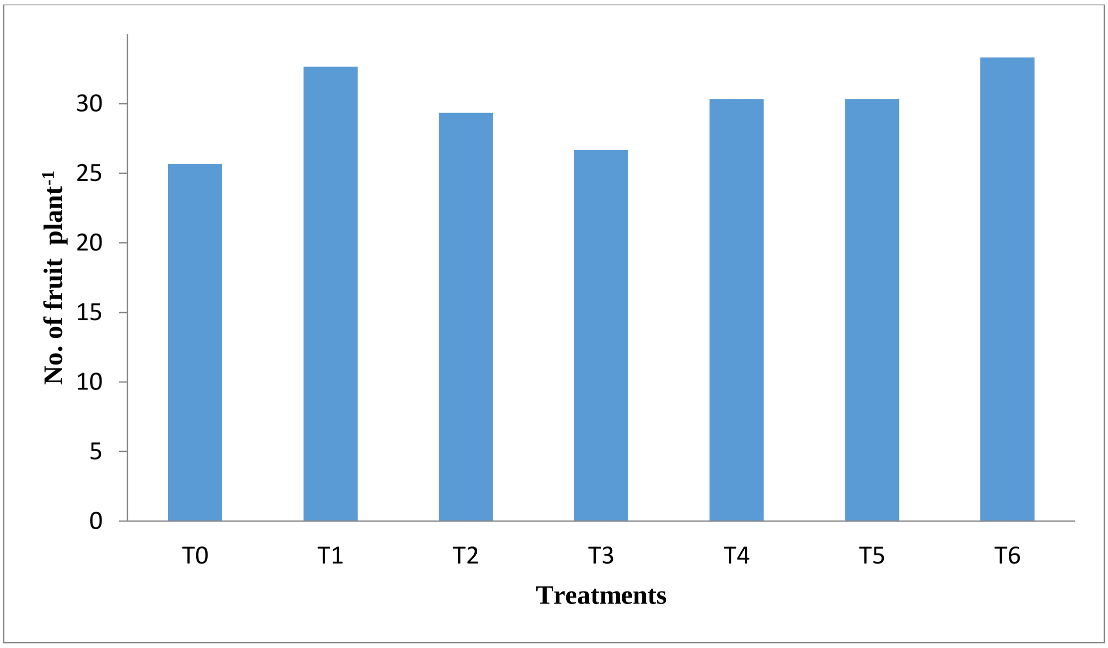


Figure 4. Effect of different grafted and non-grafted tomato seedlings on fruit number plant^{-1}

Note: T_0= Control (non-grafted tomato seedling); T_1= grafted seedling (tomato grafted on *S. sisymbriifolium*); T_2= grafted seedling (tomato grafted on EG- 203); T_3= grafted seedling (tomato grafted on Khag-1); T_4= grafted seedling (tomato grafted on Khag-2); T_5 = grafted seedling (tomato grafted on Khag-3) and T_6 = grafted seedling (tomato grafted on BARI brinjal-8).

4.2.13 Weight of single fruit

The variation in weight of single fruit was found significant (Appendix-VII) in different treatments (Fig. 5).The average weight of individual fruit varied from 36.00 to 48.83 g. The highest fruit weight (48.83 g) was recorded from T_6 (tomato grafted on BARI brinjal-8) treatment which was statistically similar (46.32 g) to T_1 (tomato grafted on *S. sisymbriifolium*) and the lowest single fruit weight (36.00 g) was counted from T_0 (non-grafted tomato seedling) treatment followed by (38.57 g) T_4 (tomato grafted on Khag-2) treatment. It was reported that heavier fruits were produced from grafted plants. The heavier fruits which produced from grafted plants might be due to the suitability of the rootstock. For this reason, fruits weight was increased proportionally. The similar result was agreed by Hossain *et al.* (2019) who revealed that the fruit weight was meaningfully influenced by grafting. Khah *et al.* (2006) also reported that fruit weight of grafted plants was higher than with the non-grafted plants.

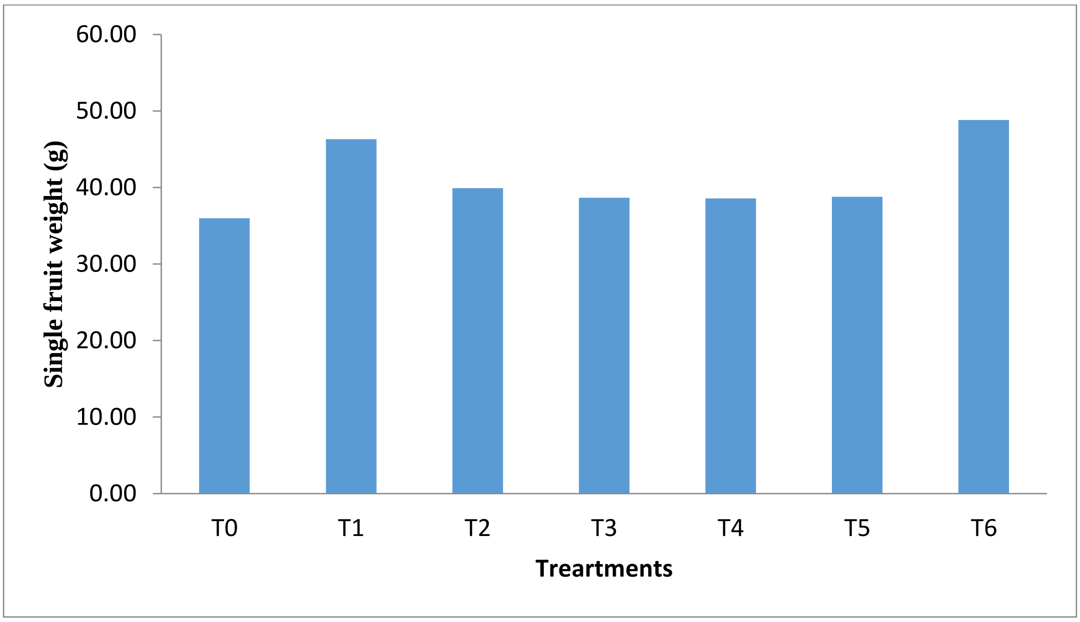


Figure 5. Effect of different grafted and non-grafted tomato seedlings on weight of single fruit

Note: T_0= Control (non-grafted tomato seedling); T_1= grafted seedling (tomato grafted on *S. sisymbriifolium*); T_2= grafted seedling (tomato grafted on EG- 203); T_3= grafted seedling (tomato grafted on Khag-1); T_4= grafted seedling (tomato grafted on Khag-2); T_5 = grafted seedling (tomato grafted on Khag-3) and T_6 = grafted seedling (tomato grafted on BARI brinjal-8).

4.2.14 Fruit length

The length of fruit varied from 4.10 to 7.23 cm and exerted statistically significant variation among the treatments (Table 5). The maximum fruit length (7.23 cm) was counted from T_6 (tomato grafted on BARI brinjal-8) treatment followed by (6.77 cm) T_1 (tomato grafted on *S. sisymbriifolium*). That may happen due to the fact that these rootstocks were more compatible than the other rootstocks investigated, while the minimum fruit length (4.10 cm) was recorded from T_0 (non-grafted tomato seedling) treatment. That variation might be due to grafting effect resulting in the variations in enhancing the nutrient and water uptake. Similar results also found by Hossain *et al.* (2019) and Turhan *et al.* (2011) who reported that, in tomato, the fruit length was significantly influenced by grafting.

4.2.15 Fruit width

The diameter of fruit was varied from 4.21 to 5.81 cm and the variation was statistically significant among the treatments (Table 5).The maximum fruit width (5.81cm) was observed from T_6 (tomato grafted on BARI brinjal-8) treatment which was statistically similar (5.72cm) to T_1 (tomato grafted on *S. sisymbriifolium*) treatment. That variation was probably due to the fact that these rootstocks are more compatible than other rootstocks, while the minimum fruit width (4.21 cm) was observed from T_0 (non-grafted tomato seedling) treatment. That variation might be due to grafting effect enhancing the water and nutrient uptake by the respective plants. The improved fruit diameter observed in this study agree with observations by Yetisir *et al*. (2007) who reported that the grafted seedlings had increased fruit size by 52%. Turhan *et al*. (2011) also observed that the 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.

Table 5. Effect of different grafted and non-grafted tomato seedlings on fruit length and fruit width

Treatments	Fruit length (cm)	Fruit width (cm)
T_0	4.10d	4.21e
T_1	6.77b	5.72a
T_2	4.43cd	5.48b
T_3	4.45c	4.81d
T_4	4.32cd	5.24c
T_5	4.24cd	5.07c
T_6	7.23a	5.81a
$LSD_{(0.05)}$	0.34	0.20
Level of Significance	**	**
CV (%)	3.73	2.20

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly.

**: Significant at 1% level of probability

T_0= Control (non-grafted tomato seedling);
T_1= Grafted seedling (tomato grafted on *S. sisymbriifolium*);
T_2= Grafted seedling (tomato grafted on EG-203);
T_3= Grafted seedling (tomato grafted on Khag-1);
T_4= Grafted seedling (tomato grafted on khag-2);
T_5= Grafted seedling (tomato grafted on khag-3);
T_6= Grafted seedling (tomato grafted on BARI brinjal-8)

4.2.16 Total Soluble Solids (TSS)

There was a significant variation (Appendix-VII) for the TSS contents among the treatments. Grafted and non-grafted plants also showed a more or less similar trend of TSS content in their fruits (Fig. 6). The maximum total soluble solids content (4.53%) was observed from T_6 (tomato grafted on BARI brinjal-8) treatment which was statistically similar (4.47%) to T_1 (tomato grafted on *S. sisymbriifolium*), while the minimum total soluble solids content (4.33%) was counted from T_0 (non-grafted tomato seedling) treatment followed (4.40%) by T_5 (tomato grafted on Khag-3) treatment. It may be due to the grafting effect of the *Solanum* rootstocks.

The grafted tomato plants contributed higher TSS content compared to control one, which might be due to the combined effects of the variety and root stocks. The findings of Khah *et al.* (2006) also supported the present findings.

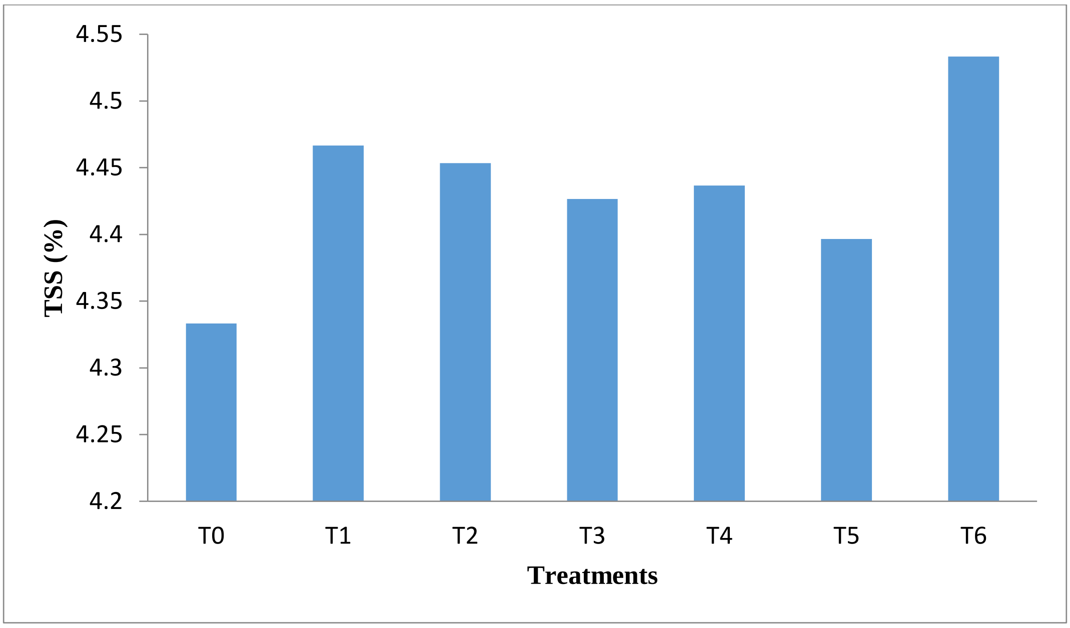


Figure 6. Effect of different grafted and non-grafted tomato seedlings on Total Soluble Solids

Note: T_0= Control (non-grafted tomato seedling); T_1= grafted seedling (tomato grafted on *S. sisymbriifolium*); T_2= grafted seedling (tomato grafted on EG- 203); T_3= grafted seedling (tomato grafted on Khag-1); T_4= grafted seedling (tomato grafted on Khag-2); T_5 = grafted seedling (tomato grafted on Khag-3) and T_6 = grafted seedling (tomato grafted on BARI brinjal-8).

4.2.17 Fruit yield plant^{-1}

Significant variation (Appendix-VIII) was observed on yield plant^{-1} on grafted and non-grafted plants of summer tomato (Fig. 7). The maximum fruit yield plant^{-1} (1.39 kg) was recorded from T_6 (tomato grafted on BARI brinjal-8) treatment followed by (1.30 kg) to T_1 (tomato grafted on *S. sisymbriifolium*) treatment. It might be occurred due to effect of resistance potentiality and good compatibility between scion and rootstocks. On the other hand, the minimum yield plant^{-1} (0.90 kg) was observed from T_0 (non-grafted tomato seedling) treatment. It might be occurred due to susceptibility to bacterial wilt (BW). The yield variation may be the effect of rootstocks.

Marsic and Osvald (2004) and Ibrahim *et al.* (2014) had also claimed the same type of results in grafted and non-grafted tomato plants; they concluded that the higher yield of fruit from grafted tomato plants was most likely an effect of the vigorous root system of the rootstock. The results of the present experiment showed that tomato plants grafted on suitable rootstocks exerted positive effects on the fruit yield.

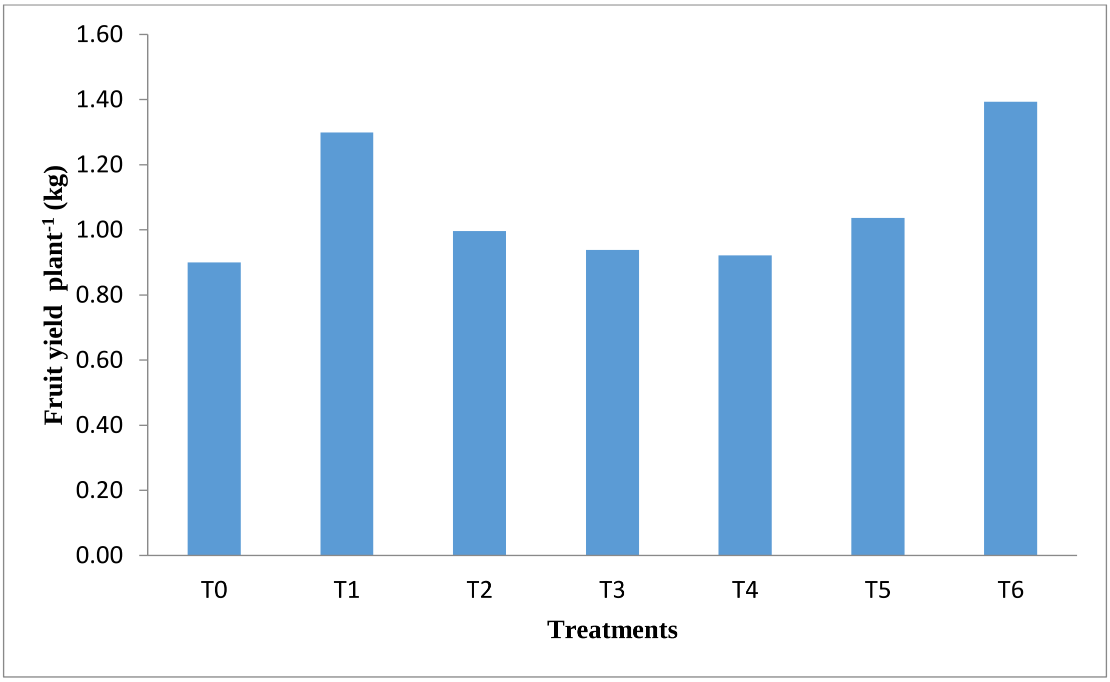


Figure 7. Effect of different grafted and non-grafted tomato seedlings on fruit yield plant^{-1}

Note: T_0= Control (non-grafted tomato seedling); T_1= grafted seedling (tomato grafted on *S. sisymbriifolium*); T_2= grafted seedling (tomato grafted on EG- 203); T_3= grafted seedling (tomato grafted on Khag-1); T_4= grafted seedling (tomato grafted on Khag-2); T_5 = grafted seedling (tomato grafted on Khag-3) and T_6 = grafted seedling (tomato grafted on BARI brinjal-8).

4.2.18 Fruit yield plot^{-1}

In respect of fruit yield plot^{-1} indicated that there was significant yield variation observed among the treatments which were varied from 15.01 to 28.50 kg (Table 6). The maximum fruit yield plot^{-1} (28.50 kg) was recorded from T_6 (tomato grafted on BARI brinjal-8) treatment followed (24.91 kg) by T_1 (tomato grafted on *S. sisymbriifolium*). This might be due to high resistance potentiality against soil borne diseases of these rootstocks, while the minimum fruit yield plot^{-1} (15.01 kg) was counted from T_0 (non-grafted tomato seedling) treatment followed by T_4 (tomato grafted on Khag-2). Such variations had occurred due to number of tomato plants survived per plot.

4.2.19 Fruit yield tunnel^{-1}

Significant effect was observed on yield per tunnel on grafted and non-grafted plants of summer tomato (Table 6). The maximum yield tunnel^{-1} (258.91 kg) was observed from T_6 (tomato grafted on BARI brinjal-8) treatment followed (245.09 kg) by T_1 (tomato grafted on *S. sisymbriifolium*) treatment. It was might be due to high survival rate per plot of tomato seedlings, while the minimum yield tunnel^{-1} (152.87 kg) was counted from T_0 (non-grafted tomato seedling) treatment followed by (159.62 kg) T_4 (tomato grafted on Khag-2) treatment. Such variations had occurred due to number of tomato plants survived per plot.

Table 6. Effect of different grafted and non-grafted tomato seedlings on yield plot^{-1} and yield tunnel^{-1}

Treatments	Yield plot^{-1} (kg)	Yield tunnel^{-1} (kg)
T_0	15.01e	152.87c
T_1	24.91b	245.09a
T_2	20.98c	186.38b
T_3	18.52d	165.95c
T_4	18.04d	159.62c
T_5	20.67c	167.83c
T_6	28.50a	258.91a
$LSD_{(0.05)}$	1.98	15.53
Level of Significance	**	**
CV (%)	5.31	4.57

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly.

**: Significant at 1% level of probability

T_0= Control (non-grafted tomato seedling);
T_1= Grafted seedling (tomato grafted on *S. sisymbriifolium*);
T_2= Grafted seedling (tomato grafted on EG-203);
T_3= Grafted seedling (tomato grafted on Khag-1);
T_4= Grafted seedling (tomato grafted on khag-2);
T_5= Grafted seedling (tomato grafted on khag-3);
T_6= Grafted seedling (tomato grafted on BARI brinjal-8)

4.2.20 Fruit yield ha^{-1}

The yield of tomato per hectare was significantly (Appendix-VIII) influenced by the treatments. The fruit yield per ha ranged from 25.99 to 43.00 tons and that varied between the grafted and non-grafted plants (Fig. 8). The maximum fruit yield ha^{-1} (44.02 tons) was recorded from the treatment T_6 (tomato grafted on BARI brinjal-8) treatment followed by (41.67 tons) T_1 (tomato grafted on *S. sisymbriifolium*) treatment, while the minimum yield ha^{-1} (25.99 tons) was observed from T_0 (non-grafted tomato seedling) treatment which was statistically similar to (27.14 tons) T_4 (tomato grafted on Khag-2) treatment. So, such variations in the yield might be due to the effects of rootstocks and survivability of plants per unit area. Al-Harbi *et al.* (2018), Milenkovic *et al.* (2018), Ibrahim *et al.* (2014) and Marsic and Osvald (2004) claimed the similar type of results in grafted and non-grafted tomato plants; they noticed that the higher yield of fruit from grafted tomato plants was most likely due to the effects of the vigorous root system of the rootstock used. The results of the present experiment reveal that tomato plants grafted on suitable rootstocks had positive effects on the fruit yield. Again, within the six rootstocks used, T_6 (tomato grafted on BARI brinjal-8) had the highest fruit yield per ha (44.02 tons) and T_4 (tomato grafted on Khag-2) had the lowest fruit yield ha^{-1} (27.14 tons). T_2 (tomato grafted on EG- 203) gave the medium amount of fruit ha^{-1} (31.68 tons). Those variations could be due to the fact that the effects of grafting were positive in BARI brinjal-8 and *S. Sissymbriifolium* than other brinjal rootstocks. Lee (1994) noted that the increased yield of grafted plants was probably due to the enhanced water and mineral uptake by the various rootstocks. Ibrahim *et al*. (2001); Khah *et al*. (2006); Gisbert *et al*. (2011); Turhan *et al*. (2011) and Wahb-Allah (2014) have also reported increased yield in grafted tomato. These findings demonstrate that grafting tomato on a suitable rootstock has a positive effect on cultivation performance and yield.

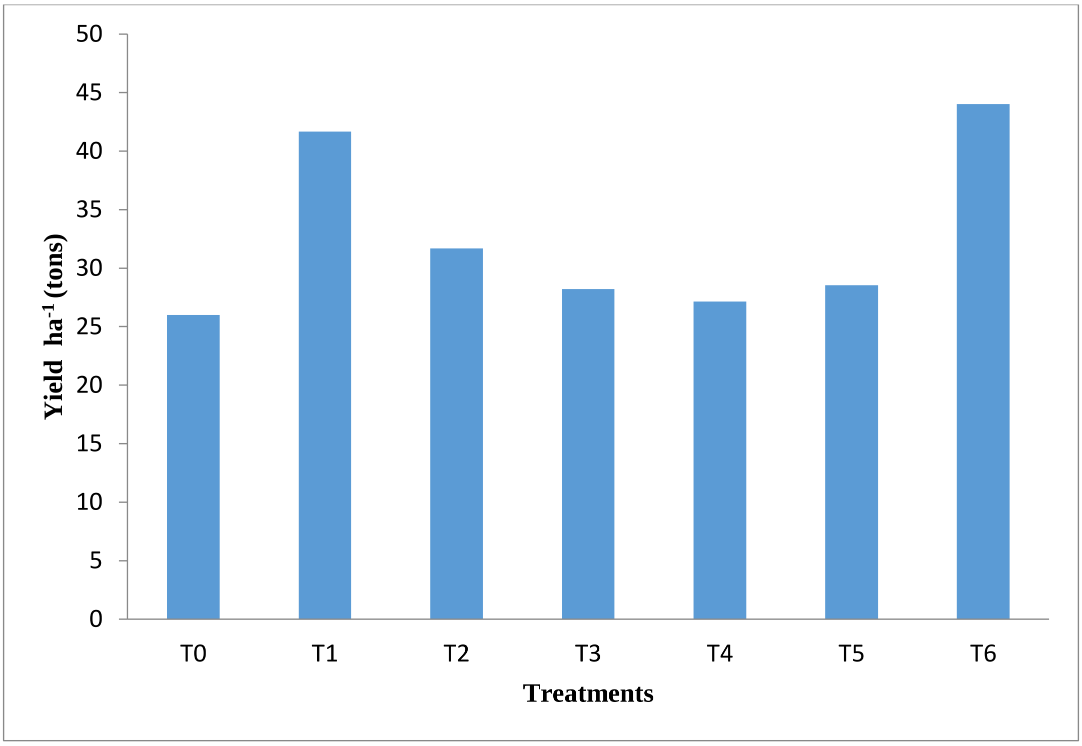


Figure 8. Effect of different grafted and non-grafted tomato seedlings on yield ha^{-1} of summer tomato

Note: T_0= Control (non-grafted tomato seedling); T_1= grafted seedling (tomato grafted on *S. sisymbriifolium*); T_2= grafted seedling (tomato grafted on EG- 203); T_3= grafted seedling (tomato grafted on Khag-1); T_4= grafted seedling (tomato grafted on Khag-2); T_5 = grafted seedling (tomato grafted on Khag-3) and T_6 = grafted seedling (tomato grafted on BARI brinjal-8).

4.2.21 Bacterial wilt infestation

Significant difference was observed on Bacterial wilt infestation on grafted and non-grafted summer tomato seedling at 45 to 90 days after sowing (DAS) (Table 7). The highest percent (28.00%) bacterial wilt (BW) infection was occurred in control (T_0) plot at 75 DAS and total infected plant was 50.00% in later stage. It was occurred due to existence of bacterial strain in the soil and susceptibility to bacterial wilt of tomato variety, where except T_6 (tomato grafted on BARI brinjal-8) and T_1 (tomato grafted on *S. sisymbriifolium*) treatments all other grafted seedlings were infected by bacterial wilt (BW) which was ranged up to 12.00% only. From the present study results, it revealed that tomato seedling grafted on BARI brinjal-8 and *S. sisymbriifolium* showed complete resistance to bacterial wilt while other rootstock showed different magnitude of wilt incidence. Similar opinion was put forward by Ali (1991), Mondal *et al.* (1991), Yamakawa and Mochizuki (1979), Fassuliotis and Bhatt (1982) and Guan *et al.* (2012), they reported that wild *Solanum* species showed complete resistance against bacterial wilt. This finding agrees with the results of the present investigation.

Table 7. Incidence bacterial wilt diseases on summer tomato production grafted with different rootstock under field condition

Treatments	Bacterial wilt infestation (%)			
	45 DAS	**60 DAS**	**75 DAS**	**90 DAS**
T_0	0.0000b	12.000a	28.000a	12.000a
T_1	0.0000b	0.0000c	0.0000c	0.0000c
T_2	0.0000b	0.0000c	0.0000c	0.0000c
T_3	0.0000b	8.0000b	0.0000c	12.000a
T_4	0.4000a	0.0000c	12.000b	8.0000b
T_5	0.0000b	8.0000b	12.000b	12.000a
T_6	0.0000b	0.0000c	0.0000c	0.0000c
$LSD_{(0.05)}$	0.0006724	0.9897	0.9897	0.9897
Level of Significance	**	**	**	**
CV (%)	6.61	13.91	7.49	8.85

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly.

**: Significant at 1% level of probability

T_0= Control (non-grafted tomato seedling);
T_1= Grafted seedling (tomato grafted on *S. sisymbriifolium*);
T_2= Grafted seedling (tomato grafted on EG-203);
T_3= Grafted seedling (tomato grafted on Khag-1);
T_4= Grafted seedling (tomato grafted on khag-2);
T_5= Grafted seedling (tomato grafted on khag-3);
T_6= Grafted seedling (tomato grafted on BARI brinjal-8)

4.2.22 Virus Infestation

There was significant effect was observed on percent virus infection on summer tomato at various days after sowing (DAS) (Table 8). Virus infection was observed irrespective of grafted and non-grafted plants. Seedling at the 60 to 90 DAS except control, virus infecting magnitude was higher at later stage of tomato plant which was ranged from 5.00 to 26.00% while the highest degree of virus infestation (26.00%) was recorded from T_0 (non-grafted seedling) at 90 DAS. It was occurred due to susceptibility of tomato variety to virus, while the minimum virus infestation (0.00%, 0.00%, 8.00% and 8.00%) at 45 DAS, 60 DAS, 75 DAS and 90 DAS was recorded from the treatment T_6 (tomato grafted on BARI brinjal-8) respectively. However, in, general, all the treatments in both grafted and non-grafted conditions were infected by Tomato Yellow Leaf Curl Virus (TYLCV) and Tomato Mosaic Virus (TMV) with various degrees. Kallo *et al.* (1945) and Alam *et al.* (1995) also agreed with the argument of the present study and stated that virus infestation was found to occur irrespective of different growing stages as per severity of white flies.

Table 8. Incidence of virus infestation on summer tomato production grafted with different rootstock under field condition

Treatments	Virus Infestation (%)			
	45 DAS	60 DAS	75 DAS	90 DAS
T_0	21.000a	23.000a	17.000a	26.000a
T_1	0.0000b	5.0000d	8.000c	8.000d
T_2	0.0000b	8.0000c	8.000c	8.000d
T_3	0.0000b	8.0000c	12.000b	18.000b
T_4	0.0000b	11.000b	8.000c	8.000d
T_5	0.0000b	8.0000c	12.000b	16.000c
T_6	0.0000b	0.0000e	8.000c	8.000d
$LSD_{(0.05)}$	0.6724	0.9897	1.5528	1.9795
Level of Significance	**	**	**	**
CV (%)	12.60	6.18	8.37	8.47

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly.

**: Significant at 1% level of probability

T_0= Control (non-grafted tomato seedling);
T_1= Grafted seedling (tomato grafted on *S. sisymbriifolium*);
T_2= Grafted seedling (tomato grafted on EG-203);
T_3= Grafted seedling (tomato grafted on Khag-1);
T_4= Grafted seedling (tomato grafted on khag-2);
T_5= Grafted seedling (tomato grafted on khag-3);
T_6= Grafted seedling (tomato grafted on BARI brinjal-8)

4.2.23 Pest and other diseases

In refer to other pest and diseases, southern blight infection was recorded from 8.00 to 22.00% (Fig. 9). The maximum (22.00%) southern blight infection was counted from T_0 (non-grafted seedling) and T_5 (tomato grafted on Khag-3) while the minimum (8.00%) was recorded from T_2 (tomato grafted on EG-203). The black leaf mold was severely infected the tomato plants irrespective grafted and non-grafted plants at later stage, in which highest (38.00%) infection was counted from T_4 (tomato grafted on Khag-2), while minimum (22.00%) from T_1 (tomato grafted on *S. sisymbriifolium*). Another devastating insect-mealy bug infested the all plants in all treatments in the magnitude up to 41.00%.the maximum (41.00%) mealy bug infestation was observed from T_3 (tomato grafted on Khag-1) and minimum (31.00%) from T_1 (tomato grafted on *S. sisymbriifolium*). Finally, maximum (11.00%) fruit borer attack was counted from T_4 (tomato grafted on Khag-2) and minimum (4.00%) one was from T_2 (tomato grafted on EG-203)

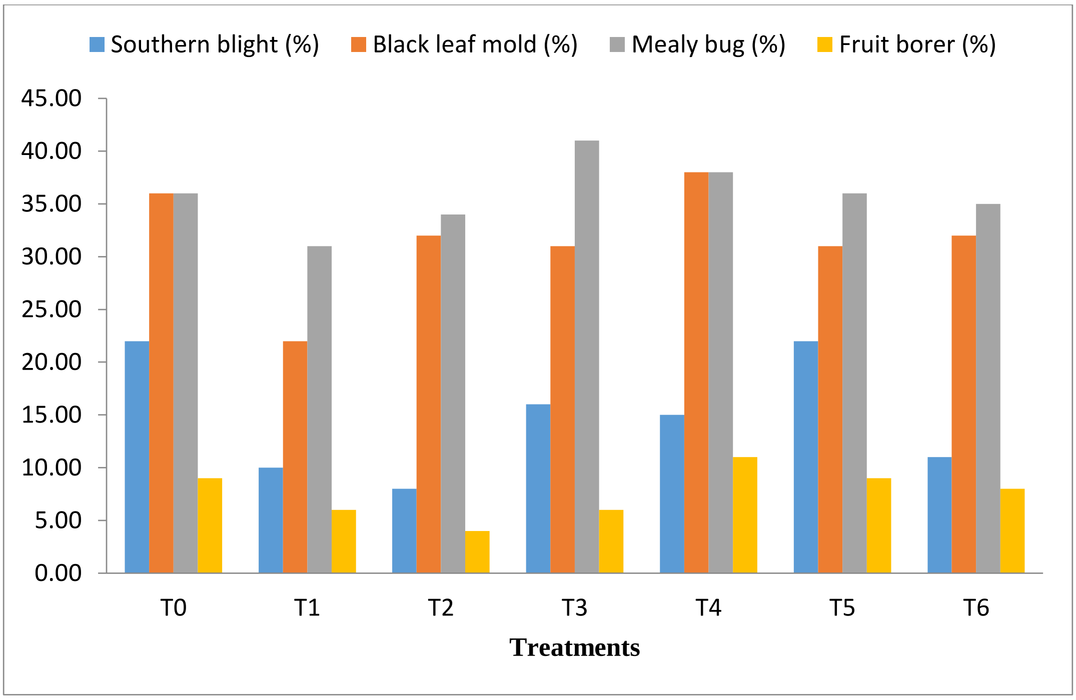


Figure 9. Incidence of pest and diseases on summer tomato production grafted with different rootstock under field condition

Note: T_0= Control (non-grafted tomato seedling); T_1= grafted seedling (tomato grafted on *S. sisymbriifolium*); T_2= grafted seedling (tomato grafted on EG- 203); T_3= grafted seedling (tomato grafted on Khag-1); T_4= grafted seedling (tomato grafted on Khag-2); T_5 = grafted seedling (tomato grafted on Khag-3) and T_6 = grafted seedling (tomato grafted on BARI brinjal-8).

CHAPTER 5

SUMMARY AND CONCLUSION

The present study was conducted at the Olericulture Division of Horticulture Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI), Gazipur to study the resistance level of rootstocks and tomato grafting compatibility with different rootstock and their field performance during the summer season of 2019. Grafted seedling was prepared with BARI hybrid tomato-10 on six rootstocks viz.- *S. sisymbriifolium*; *S. melongena* (BARI brinjal-8); EG 203 and three others newly collected rootstocks. The treatment combinations were as follows: T_0= Control (non-grafted tomato seedling); T_1=Grafted seedling (tomato grafted on *S. sisymbriifolium*); T_2= Grafted seedling(tomato grafted on EG-203); T_3=Grafted seedling(tomato grafted on Khag-1); T_4=Grafted seedling(tomato grafted on khag-2); T_5=Grafted seedling(tomato grafted on khag-3); T_6= Grafted seedling(tomato grafted on BARI brinjal-8).The experiment was laid out RCB design with three replications. Data on different parameters were recorded and statistically analyzed.

Data were collected for grafting success (%), number of plants survived plot^{-1} (%), plant height (cm), number of leaves plant^{-1}, number of main branches and total branches plant^{-1}, days to 1st and 50% flowering, number of flower clusters plant^{-1}, number of flowers cluster^{-1}, days to first harvest, harvesting duration, bacterial wilt incidence (%), virus infestation (%), number of fruits per plant, single fruit weight (g), fruit yield plant^{-1} (kg), yield plot^{-1} (kg), yield ha^{-1} (tons), pest and other diseases (%), fruit length (cm), fruit width (cm) and TSS (%). Data were analyzed using STATISTIX 10 package program. The mean differences among the treatments were compared by Least Significant Difference (LSD) test at 5% level of significance.

Tomato grafting with different rootstocks showed significant effect on growth characters of summer tomato. The effect of tomato seedling on different rootstocks on grafting success was found significant. The highest percentage of grafting success (86.15%) was recorded when tomato seedling was grafted on BARI brinjal-8 (T_6) followed by tomato grafted on *S. sisymbriifolium* (83.95%). The poorest success (70.00%) was observed when tomato seedling grafted on khag-2 (T_4) rootstock.

Results also revealed that the highest plant survivability plot^{-1} (94.67%) was recorded from T_6 (tomato grafted on BARI brinjal-8) followed by (93.00%) T_1 (tomato grafted on *S. sisymbriifolium*), where the lowest (63.33%) was counted from T_0 (non-grafted tomato seedling) treatment and among the grafted seedlings the poorest (81.00%) survivability was counted from T_5 (tomato grafted on khag-3). The longest plant height (135.42 cm) was recorded from T_6 (tomato grafted on BARI brinjal-8) followed by (130.17 cm) T_1 (tomato grafted on *S. sisymbriifolium*), while the shortest plant (92.67 cm) was observed from T_0 (non-grafted tomato seedling) which was statistically similar (93.50 cm) to T_2 (tomato grafted on EG-203) treatment.

The maximum number of leaves plant^{-1} (88.5) was observed from T_6 (tomato grafted on BARI brinjal-8), where the minimum was counted from T_0 (non-grafted tomato seedling) treatment. The highest number of main and total branches plant^{-1} (3.17) and (10.17) was recorded from T_6 (tomato grafted on BARI brinjal-8) treatment respectively, where the minimum number of main and total branches (2.17) and (6.17) were counted from T_0 (non-grafted tomato seedling) followed by (2.17) and (7.83) T_4 (tomato grafted on Khag-2) treatment.

Tomato grafting with different rootstock also showed significant effect on yield contributing characters and yield characters of summer tomato. For yield contributing characters the maximum number of flower clusters plant^{-1} (27.00) was recorded from T_6 (tomato grafted on BARI brinjal-8) treatment, where the minimum (21.00) was counted from T_0 (non-grafted tomato seedling) which was statistically similar (21.00) to T_5 (tomato grafted on Khag-3) treatment. The maximum number of flowers cluster^{-1} (7.07) was observed from T_3 (tomato grafted on Khag-1), where the minimum flowers (5.17) recorded from T_0 (non-grafted tomato seedling) which is statistically similar to (5.17) T_4 (tomato grafted on Khag-2) treatment.

In case of days to 1st and 50% flowering, it was found that non-grafted plant bloomed earlier than grafted ones. The maximum first flowering (54.33 days) and 50% flowering (57.33 days) was recorded from T_2 (tomato grafted on EG-203) treatment. And the minimum first flowering (50.00 days) and 50% flowering (54.00 days) was observed from T_0 (non-grafted tomato seedling) treatment.

In the grafted plants, first harvest was delayed and also harvesting duration was prolonged compared to non-grafted plant. The maximum days for first harvest

(98.00 days) and harvesting duration (27.33 days) were recorded from T_6 (tomato grafted on BARI brinjal-8) treatment, where the minimum days for first harvest (90.67 days) and harvesting duration were counted from T_0 (non-grafted tomato seedling) treatment. Among the grafted seedlings T_2 (tomato grafted on EG-203) required minimum days for first harvest (94.00 days) and harvesting duration (20.33 days).

For yield data, the results revealed that the maximum fruits (33.33) were obtained from T_6 (tomato grafted on BARI brinjal-8) treatment, where minimum fruits (36.00) were produced from T_0 (non-grafted tomato seedling) treatment. Among the grafted seedlings T_3 (tomato grafted on Khag-1) produced the lowest (26.67) fruits. The maximum individual weight of a single fruit (48.83 g) was recorded in T_6 (tomato grafted on BARI brinjal-8) treatment followed (46.32 g) by T_1 (tomato grafted on *S. sisymbriifolium*), where the minimum one (36.00 g) was counted from T_0 (non-grafted tomato seedling) treatment followed by (38.57 g) T_4 (tomato grafted on Khag-2).

The maximum (7.23 cm) fruit length was observed from T_6 (tomato grafted on BARI brinjal-8) treatment. The minimum fruit length (4.10 cm) was counted from T_0 (non-grafted tomato seedling) followed by (4.24 cm) T_5 (tomato grafted on Khag-3) treatment. Again the maximum fruit width (5.81 cm) was recorded from T_6 (tomato grafted on BARI brinjal-8) followed by (5.72 cm) T_1 (tomato grafted on *S. sisymbriifolium*) treatment, while minimum fruit width (4.21 cm) was observed from T_0 (non-grafted tomato seedling) which was statistically similar (4.81 cm) to T_3 (tomato grafted on Khag-1) treatment. In case of total soluable solids, the maximum (4.53%) TSS was recorded from T_6 (tomato grafted on BARI brinjal-8) treatment. And the minimum TSS (4.33%) was counted from T_0 (non-grafted tomato seedling) followed by (4.40%) T_5 (tomato grafted on Khag-3) treatment.

The maximum (1.39 kg) fruit yield plant^{-1} was recorded from T_6 (tomato grafted on BARI brinjal-8) followed by (1.30 kg) T_1 (tomato grafted on *S. sisymbriifolium*) treatment, where minimum (0.90 kg) fruit yield was observed from T_0 (non-grafted tomato seedling) treatment which is statistically similar (0.92 kg) to the grafted seedling T_4 (tomato grafted on Khag-2) treatment.

The highest (28.50 kg) fruit yield plot^{-1} and fruit yield tunnel^{-1} (258.91 kg) were recorded from T_6 (tomato grafted on BARI brinjal-8) treatment, while the lowest

(15.01 kg) yield plot^{-1} and yield tunnel^{-1} (152.87 kg) were recorded from T_0 (non-grafted tomato seedling) followed by (18.04 kg) and (159.62 kg) T_4 (tomato grafted on Khag-2) treatment respectively.

The maximum (44.02 tons ha^{-1}) yield was recorded from T_6 (tomato grafted on BARI brinjal-8) followed by (41.67 tons ha^{-1}) T_1 (tomato grafted on *S. sisymbriifolium*) treatment. And the minimum (25.99 tons ha^{-1}) was counted from T_0 (non-grafted tomato seedling) treatment. Among the grafted seedlings, the lowest (27.14 tons ha^{-1}) yield was observed from T_4 (tomato grafted on Khag-2) treatment.

The reaction of grafted and non-grafted plants against bacterial wilt was tested in field condition. The tomato seedling grafted on BARI brijal-8 and *S. sisymbriifolium* showed complete resistant against bacterial wilt where non-grafted seedling showed vulnerability against this disease at different level. The highest percentage of wilt incidence (0.00%, 12.00%, 28.00% and 12.00%) was recorded from T_0 (non-grafted tomato seedling) at 45 DAS, 60 DAS, 75 DAS and 90 DAS respectively.

From the experiment results, it was expressed that the maximum virus infestation (21.00%, 23.00%, 17.00% and 26.00%) at 45 DAS, 60 DAS, 75 DAS and 90 DAS were observed from T_0 (non-grafted tomato seedling) treatment respectively. And the minimum virus infestation (0.00%, 0.00%, 8.00% and 8.00%) and (0.00%), 5.00%, 8.00% and 8.00%) at 45 DAS, 60 DAS, 75 DAS and 90 DAS were observed from T_6 (tomato grafted on BARI brinjal-8) and T_1 (tomato grafted on *S. sisymbriifolium*) treatment respectively.

In case of pest and other diseases, the maximum southern blight (22.00%) and black leaf mold (36.00%) incidence was found in T_0 (non-grafted tomato seedling) treatment. The minimum infection of southern blight (8.00%) was recorded from T_2 (tomato grafted on EG-203) and the minimum (22.00%) incidence of black mold was found in T_1 (tomato grafted on *S. sisymbriifolium*) treatment. On the other hand, the highest (36.00%) mealy bug infestation was recorded in T_0 (non-grafted tomato seedling), where the lowest (31.00%) was from T_1 (tomato grafted on *S. sisymbriifolium*) treatment. And the highest infestation of fruit borer (11.00%) was counted in T_4 (tomato grafted on Khag-2), where lowest one (4.00%) was observed from T_2 (tomato grafted on EG-203) treatment.

Conclusion

In case of grafting, the grafted plant showed maximum grafting success, maximum survivability at field, delayed flowering days to harvest, fruit length, fruit diameter, fruits per plant and yield per plant compare to non grafted planted . The grafted plants had prolonged harvesting period and gave higher yield. Among the treatments, the results revealed that T_6 treatment (tomato grafted on BARI brinjal-8) showed the best performance than others treatment due to maximum grafting success (86.15%), plant survivability (94.64%), fruit length (7.23 cm), fruit width (5.81 cm), number of fruits plant^{-1} (33.33), average single fruit weight (48.83 g), Total Soluble Solids (4.53%), days to first harvesting (98 days) and longer harvesting duration (27.33days), fruit yield plant^{-1} (1.39 kg), and yield ha^{-1} (44.02 tons) which was also differed significantly from the grafted plants of other rootstocks and plants of control treatment. So, among the treatments, tomato seedling grafted on BARI brinjal-8 was found to the best for growing during summer through grafting technique. Hence, it could be concluded that tomato seedling grafted on BARI brinjal-8 has highest grafting compatibility than other treatments.

Among the rootstocks, tomato seedling grafted on BARI brinjal-8 and *S. sisymbriifolium* showed complete resistance against bacterial wilt and minimum virus infestation (0.00%, 0.00%, 8.00% and 8.00%) at 45 DAS, 60 DAS, 75 DAS and 90 DAS were observed respectively. The remaining rootstocks showed susceptible performance to bacterial wilt and virus infestation at varying levels. The non-grafted tomato seedling also showed susceptible performance to bacterial wilt and virus infestation in field condition. Considering the growth, yield and yield contributing characters, and resistance potentiality to bacterial wilt and virus in field condition, it was revealed that tomato seedling of BARI hybrid tomato-10 grafted on BARI brinjal-8 was the most suitable rootstocks than other rootstocks used in the present study for summer tomato production. Tomato seedling grafted on *S. sisymbriifolium* could be the second choice.

Therefore, the following recommendations can be made from the present study:

1. Tomato can be grafted on BARI brinjal-8 for controlling bacterial wilt and getting higher yield for summer tomato production.
2. This technique could be explored in the nurseries for commercialization so that the growers of rural and urban areas could have the required number of grafted seedling with an affordable price.
3. Further refine technology is required to find out more suitable rootstocks for summer tomato production.

REFERENCES

Abdelmageed, A.H.A. and Gruda, N. (2009). Influence of Grafting on Growth, Development and some Physiological Parameters of Tomatoes under Controlled Heat Stress Conditions. *European J. Hortic. Sci*. **74**(1):16-20.

Ahmed, S., Chadha, M. L., Monowar, S., Hossain, M. and Quasem, A. (1996). Summer tomato production using tomatotone in Bangladesh. Abstr. : 2nd *Intl. Crops Science Congress*, New-Delhi, India. p. 89.

Ahn, S. J., Im, Y. J., Chung, G. C., Cho, B. H. and Suh, S. R. (1999). Physiological responses of grafted-cucumber leaves and rootstock roots as affected by low root temperature. *Sci. Hortic.* **81**: 397 - 408.

Alam, M. Z., Hossain,M. M., Choudhury, D. A. M.,Uddin,M. J. and Haque, N. M. N.(1995). Effect of grafting technology on suppression of white fly *(Bemisiatabaci* gannadius) disseminating virus diseases in tomato. *Ann. Bangladesh Agric.* **5**(2): 91-98.

Al-Harbi, A. R., Al-Omran, A. M., Alqardaeai, T. A., Abdel-Rassak, H. S., Alharbi, K. R., Obadi, A. and Saad, M. A. (2018). Grafting affects tomato growth, productivity, and water use efficiency under different water regimes. *J. Agric. Sci. Tech*. **20**:1227–1241.

Al-Harbi, A., Hejazi, A. and Al-Omran, A. (2016). Responses of grafted tomato (*Solanum lycopersiocon* L.) to abiotic stresses in Saudi Arabia. *Saudi J. Bio. Sci.* **14**:124-129.

Ali, M. (1993). Control of wilt and nematode diseases of tomato and eggplant through grafting on non-tuberous wild *Solanum.* Paper presented in the workshop on “Research and Development of Vegetable Crops”. March 9-10. IPSA, Gazipur. p. 68-73.

Ali, M. (1991). Breeding eggplant rootstock for multiple disease resistance. Ph. D. thesis, Laboratory of Horticulture Science, Kyushu University, Fukuoka, Japan. p. 240.

Ali, M., Alam, M. Z. and Akanda, A. M. (1994). Grafting: A technique to control soilborne diseases of tomato and eggplant. 1PSA-JAICA publication No. 4. Institute of Postgraduate Studies in Agriculture (IPSA), Salna, Gazipur, Bangladesh. p. l0.

Andrews, P.K. and Marquez C.S. (1993). Graft incompatibility. *Hort. Rev.* **15**:183-232.

Bawa, I. (2016). Management strategies of fusarium wilt disease of tomato incited by *Fusarium oxysporum* f. sp. *Lycopersici* (Sacc.). *Int. J. Adv. Acad. Res.* **2**(5): 32-42.

BBS, (2019). Yearbook of Agricultural Statistics of Bangladesh. Planning Division, Ministry of Planning, Govt. of the People's Republic of Bangladesh, Dhaka. p. 341.

Besri, M. (2003). Tomato grafting as an alternative to methyl bromide in Morocco, (2003).Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. San Diego, CA USA. November 3-6, 2003.

Bhuyan, M. A. J. and Haque, M. M. (1983). Selection of tomato varieties for winter and summer production. *Bangladesh Hort.* **11**:41-43.

Black, L., Wu, D., Wang, J., Kalb, T., Abbass, D. and Chen, J. H. (2003). Grafting Tomatoes for Production in the Hot-wet Season. *Asian Veg. Res. Devel. Ctr.*, Taiwan. p. 6.

Bletsos, F. A. and Olympios, C. M. (2008). Rootstocks and grafting of tomatoes, peppers and eggplants for soil borne disease resistance, improved yield and quality. *European J. Plant Sci. Biotech.* **2**(1): 63-73.

Bloom, A. J., Zwieniecki, M. A., Passioura, J. B., Randall, L. B., Holbrook, N. M. and St. Clair, D. A. (2004). Water relations under root chilling in a sensitive and tolerant tomato species. *Plant Cell Environ.* **27**(8): 971-979.

Bumgarner, N. R. and Kleinhenz, M. D. (2015). Grafting guide. A pictorial guide to cleft and splice graft methods as applied to tomato and pepper. The Ohio State University, Columbus. p. 18.

Chadha, M. L., Mondal, S. N., Monowar, S., Hossain, M., Ahmed, S. and Amzad, A. K. M. (1992). Techniques for growing tomato under stress conditions. In: George kuo, C. (ed.) Proc. Intl. Symp. Adaptation of Pood Crops, to Temperature and water stress. *Asian Veg. Res. Devel. Ctr.,* Taiwan. p. 461-465.

Cohen, S. and Naor, A. (2002). The effect of three rootstocks on water use, canopy conductance and hydraulic parameters of apple trees and predicting canopy from hydraulic conductance. *Plant Cell Environ.* **25**: 17-28.

Colla, G., Fiorillo, A., Cardarelli, M. and Rouphael, Y. (2014). Grafting to improve abiotic stress tolerance of fruit vegetables. University of Tuscia, Viterbo, Italy. p. 7.

Colla, G., Rouphael1, Y., Cardarelli, M., Salerno, A. and Rea, E. (2010). The effectiveness of grafting to improve alkalinity tolerance in watermelon. *Environ. Exp. Bot.* **68**(3): 283–291.

Dagade, S. B., Dhaduk, L. K., Hariprasanna, K., Mehata, D. R., Bhatt, V. M. and Barad, A. V. (2015). Parent offspring relations of nutritional quality traits in 8 x 8 partial diallel cross of fresh tomatoes. *Int. J. Appl. Biol. Pharm.* **6**(2): 45-55.

Davis, A. R., Perkins-Veazie, P., Hassell, R., Levi, A., Stephen R., King, S. R. and Zhang, X. (2008). Grafting effects on vegetable quality. *Hort. Sci.* **43**(6): 1670 - 1672.

Deloire, A. and Hebant, C. (1982). Peroxidase activity and lignification at the interface between stock and scion of compatible and incompatible grafts of *capsicums* on *lycopersicum*. *Ann. Bot.* **49**(6): 887-891.

Edelstein, M. (2004). Grafting vegetable-crop plants: Pros and cons. *Acta Hort.* **659:** 235-238.

Eurofresh Distribution (2016). Around the World: Tomatoes. [https:// www. eurofresh-distribution.com/news/around-world-tomatoes] site visited on 20/12/2019.

FAO (2014). Food and Agriculture Organisation of the United Nations. http://faostat.fao.org/ FAOSTAT: 2014

Fassuliotis, G. and Bhatt, D.P. (1982). Potential of tissue culture for breeding of root-knot nematode resistance into vegetables. *J.Nematol*. **14**: 10-14.

Fernández-García, N., Carvajal, M. and Olmos, E. (2004). Graft union formation in tomato plants: Peroxidase and catalase involvement. *Ann. Bot.* **93**(1): 53-60.

Flores, F.B., Sanchez-Bel, P., Estan, M.T., Martinez-Rodriguez, M. M., Moyano, E., Morales, B., Campos, J. F., Garcia-Abellan, J. O., Egea, M. I., Fernández-Garcia, N., Romojaro, F., Bolarin, M. C. (2010). The effectiveness of grafting to improve tomato fruit quality. *Sci. Hortic.* **125**: 211–217.

García-Sánchez, F., Syvertsen, J. P., Gimeno, V., Botia, P. and Perez-Perez, J. G. (2007). Responses to flooding and drought stress by two citrus rootstock seedlings with different water-use efficiency. *Physiol. Plant.* **130**: 532-542.

Gisbert, C., Prohens, J., Raigón, M. D., Stommel, J. R. and Nuez, F. (2011). Eggplant relatives as sources of variation for developing new rootstocks: Effects of grafting on eggplant yield and fruit apparent quality and composition. *Sci. Hortic.* **128**(1): 14-22.

Goldschmidt, E. E. (2014). Plant grafting: New mechanisms, evolutionary implications. *Front. Plant. Sci.* **5**(72): 1-9.

Granges-A., Pucheu-Plante,G., Leger, A. and Produit, V. (1998). Greenhouse tomato cultivation: effect of soil steaming and grafted plants in soil infected with corky root. *Sci. Hortic.* **30**(4): 233-236.

Guan, W., Zhao, X., Hassell, R. and Thies, J. (2012). Defense mechanisms involved in disease resistance of grafted vegetables. *Hort. Sci.* **47**(2): 164-170.

Hartman, G.L., Hong, W. F. and Wang, T. C. (1991). Survey of bacterial wilt on fresh market hybrid tomatoes in Taiwan. *Plant Proc. Bull.* **33**: 197-203.

Hasna, M. K., Ögren, E., Persson, P., Mårtensson, A. and Rämert, B. (2009). Management of corky root disease of tomato in participation with organic tomato growers. *Crop Prot.* **28**(2):155–161.

Hossain, M. A., Goffer, M. A., Chowdhury, J. C. S., Rahman, M. S. and Hossain, M. I. (1999). A Study on Postharvest Practices and Loss of Tomato in Some Selected Areas of Bangladesh. *Bangladesh J. Agril. Res.* **24**(2): 299.

Hossain, M. M., Karim, M. K., Haque, M. M. and Hassain, A. K. M. A. (1986). Performance of Some Promising Tomato Lines Planted at Different Dates. Annual Report, Vegetable Section, Division of Horticulture, Bangladesh Agricultural Research Institute, Gazipur. p. 9-12.

Hossain, Md., Ali, Md., Ripa, R., Subrina, A. and Shareef, M. (2019). Influence of Rootstocks on Yield and Quality of Summer Tomato cv. 'BARI Tomato-4'. *Earth Sys. Environ.* **3**:10.1007/s41748-019-00101-4.

Hsu, S. T. (1991). Ecology and control of *Pseudomonas solanacearum* in Taiwan. *Plant Proc. Bull.* **33**: 72-79.

Huitrón-Ramírez, M. V., Ricárdez-Salinas, M. and Camacho-Ferre, F. (2009). Influence of grafted watermelon plant density on yield and quality in soil infested with melon necrotic spot virus. *Hort. Sci.* **44**(7): 1838-1841.

Ibrahim, A., Wahb-Allah, M., Abdel-Razzak, H. and Alsadon, A. (2014). Growth, yield, quality and water use efficiency of grafted tomato plants grown in greenhouse under different irrigation levels. *Life Sci. J.* **11**(2):118–126

Ibrahim, M., Munira, M. K., Kabir, M. S., Islam, A. K. M. S. and Miah, M. M. U. (2001). Seed germination and graft compatibility of wild *solanum* as rootstock of tomato. *J. Bio. Sci.* **1**(8): 701-703.

Islam, N. (1992). Resistance in *Solanum* species to *Melodogyne incognita* and pathogenicity and control of the nematode. A thesis submitted to the faculty of Agriculture, Bangladesh Agricultural University, Mymensingh. p. 40.

Ives, L., Brathwaite, R., Barclay, G., Isaac, W. A., Bowen-O'Connor, C. and Bekele, I. (2012). Graft Compatibility of Scotch Bonnet (*Capsicum chinense*) with selected salt-tolerant solanaceous. *J. Agric. Sci. Technol.* **2**: 81-92.

Jaw-Fen W. (1998). Resistance to bacterial wilt in tomato. Paper presented in the seminar on "Advances in Tomato Research in Bangladesh". HRC, BARI, Gazipur.

.

Johkan, M., Mitukuri, K., Yamasaki, S. and Oda, M. (2009). Causes of defoliation and low survival rate of grafted sweet pepper plants. *Sci. Hortic.* **119**: 103-107.

Johnson, S., Kreider, P. and Miles, C. (2011a). Vegetable grafting - The healing chamber. Washington State University, Mount Vernon. p. 3.

Johnson, S., Kreider, P. and Miles, C. (2011b). Vegetable grafting - Eggplants and tomatoes. Washington State University, Mount Vernon. p. 4.

Kallo. (1985). Tomato. Allied Pub. Pvt. Ltd.., New-Delhi. p. 32-246.

Kawaguchi, M., Taji, A., Backhouse, D. and Oda, M. (2008). Anatomy and physiology of graft incompatibility in solanaceous plants. *J. Hortic. Sci. Biotechnol*. **83**: 581-588.

Kelman, A. (1953). The bacterial wilt caused by *Ralstonia solanacearum*. North, Carolin. *Agric. Expt. Sta. Tech. Bull.* **99**: 194.

Khah, E. M. (2011). Effect of grafting on growth, performance and yield of aubergine (*Solanum melongena* L.) in greenhouse and open-field. *Int. J. Plant Prod.* **5**(4): 1735-8043.

Khah, E. M., Kakava, E., Mavromatis, A., Chachalis, D. and Goulas, C. (2006). Effect of grafting on growth and yield of tomato (*Lycopersicon esculentum,* Mill.) in greenhouse and open-field. *J. Appl. Hortic.* **8**(1): 3-7.

Khurshed, K. and Samiruddin, M. (1987). Pest and disease management of vegetables crops. In: Huda, N. and Samiruddin, M. (eds.). Vegetable Seed Technology in Bangladesh. BADC, Dhaka. p. 137.

King, S. R., Davis, A. R., Liu, W. and Levi, A. (2008). Grafting for disease resistance. *Hort. Sci.* **43**: 1673-1676.

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

Kubota, C., Mclure, M. A., Kokalis-Burelle, N., Bausher, M. G., Erin N. and Rosskopf, E. N. (2008). Vegetable grafting: History, use, and current technology status in North America. *Hortic. Sci.* **43**(6): 1664-1669.

Lee, J. M. (1994). Cultivation of grafted vegetables: Current status, grafting methods and benefits. *Hortic. Sci.* **29**(4): 235-239.

Lee, J. M. and Oda, M. (2003). Grafting of herbaceous vegetable and ornamental crops. *Hortic. Rev*. **28**: 61-124.

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

Lee, S. G. (2007). Production of high quality vegetable seedling grafts. *Acta Hort.* **759:** 169-174.

Louws, F. J., Rivard, C. L., and Kubota, C. (2010). Grafting fruiting vegetables to manage soilborne pathogens, foliar pathogens, arthropods and weeds. *Sci. Hortic.* **127**(2): 127-146.

Lu, M. Q., Chen, Y. H.,Lin, M. S. and Chen, H. P.(1992). An experiment using grafting for control of tomato bacterial wilt. *Int. J. Plant Prot.* **18**: 25.

Mamiro, D. P., Meya, A. I. and Kusolwa, P. (2015). Response of late blights disease resistant-variety to common occurring tomato diseases in the field. *Asian J. Plant Sci. Res.* **5**(6): 8-15.

Marsic, N. K. and Osvald, J. (2004). The influence of grafting on yield of two tomato cultivars (*Lycopersicon esculentum* Mill.) grown in a plastic house. *Acta Agric. Slov.* **83**(2): 243-249.

Martínez-Ballesta, M. C., Alcaraz-López, C., Muries, B., Mota-Cadenas, C. and Carvajal, M. (2010). Physiological aspects of rootstock–scion interactions. *Sci. Hortic.* **127**: 112-118.

Matsuzoe, N., Ali,M.,Okubo, V. and Fujieda, K.(1990). Growth behaviour of tomato plants grafted on wild relatives of *Solanum melongena. J. Japan Soc. Hort. Sci.* **59**: 358-359.

Maync, A. (1999). Tomato cultivation in the unheated plastic tunnel. Gemuse. Munchen, Germany. **35**(2): 113-115.

Mazollier, C. 1999. Grafting of tomato under protected cultivation. *Hortic. rev.* **404**: 44-48.

McCammon, R.K. and Honma, S. (1983). Morphological and cytogenetic analysis of an interspecific hybrid eggplant (*S. melongena x S. torvum*.) *Hort. Sci.* **18**: 894-895.

Meena, O. P. and Bahadur, V. (2015). Breeding potential of indeterminate tomato (*Solanum lycopersicum* L.) accessions using D2 analysis. *J. Plant Breed. Genet.* **47**(1): 49-59.

Michel, V., Verbeek, F. and Pugliese, M. (2010). Mini-paper - success and failures of grafting against soil-borne pathogens. [ec.europa.eu/ eip/agriculture/ sites/agri- eip/files/3_eip_sbd_mp_grafting_final.pdf] site visited on 20/5/2019.

Milenkovic, L., Mastilovic, J., Kevresan, Z., Jaksic, A., Gledic, A., Sunic, L. J., Stanojevic, L. J. and Ilic, S. Z. (2018). Tomato fruit yield and quality as affected by grafting and shading. *J Food SciNutr.* **4**(3): 42–50.

Miles, C., Hesnault, L., Johnson, S. and Kreider, P. (2013). Vegetable grafting : Watermelon. Washington State University, Mount Vernon. p. 7.

Mohammed, S. M. T., Humidan, M., Boras, M. and Abdullah, O. A. (2009). Effect of grafting tomato on different rootstocks on growth and productivity under glasshouse conditions. *Asian J Agric. Res.* **3**(2):47–54.

Mondal, S. N. (1992). Bacterial wilt resistance in tomato and chilli. Paper presented in the SAVERNET joint planning meeting, Dhaka. Bangladesh.

Mondal, S.N., Khan, M.A., Rahman,M.T., Rashid, M. A. and Nahar, S.(1991). Reaction of eggplant cultivars and wild species of Solanum to bacterial wilt (*Pseudomonas solanacearum*). *Ann. Bangladesh Agric.* **1**(2): 65-68.

Msogoya, T. J. and Mamiro, D. (2016). Grafting compatibility between selected rootstocks and Tanzanian local tomato cultivars. *J. Appl. Biosci.* **106**: 10274-10278.

Mudge, K., Janick, J., Scofield, S. and Goldschmidt, E. E. (2009). A history of grafting. *Hortic. Rev.* **35**: 437-493.

Oda, M. (1999). Grafting of vegetables to improve greenhouse production. Scientific report: agricultural and biological science, Osaka Prefecture University, Japan. **54**: 49–72.

Oda, M. (1998). Grafting of Vegetables to Improve Greenhouse Production. Osaka Prefecture University, Sakai Osaka, Japan. p. 11.

Oda, M. (2002). Grafting of vegetable crops. *Sci. Rep. Agr. Biol. Sci.* **54**: 49-72.

Oda, M. (2007). Vegetable seedling grafting in Japan. *Acta Hort.***759**: 175-180.

Oda, M., Maruyama, M. and Mori, G. (2005). Water transfer at graft union of tomato plants grafted onto *Solanum* rootstocks. *J. Japan Soc. Hort. Sci.***74**: 458-463.

Ozores-Hampton, M. and Frasca, A. C. (2013). Healing chamber for grafted vegetable seedlings in florida. University of Florida, Gainesville. p. 5.

Palada, M. C. and Wu, D. L. (2008). Evaluation of chili rootstocks for grafted sweet pepper production during the hot-wet and hot-dry seasons in Taiwan. *Acta Hort.* **767**: 167-174.

Parkinson, M., Jefferee, C. E. and Yeoman, M. M. (1987). Incompatibility in cultured explant-grafts between members of the solanaceae. *New Phytol.* **107**: 489-498.

Petran, A. and Hoover, E. (2014). *Solanum torvum* as a compatible rootstock in interspecific tomato grafting. *J. Hortic.* **1**(1): 1-4.

Pogonyi, A., Pek, Z., Helyes, L. and Lugasi, A. (2005). Effect of grafting on the tomato's yield, quality and main fruit components in spring forcing. *Acta aliment.* **34**(4): 453-462.

Rahman, M. .A. and Hoque, M. O. (1986). Screening of tomato varieties against bacterial wilt. *Bangladesh J. Plant Pathol.* **2**(1): 15-18.

Rashid, M.A., Rahman, M.A.,Raliman, A.K.M. and Hossain, M. M. (2000). Sereening of wild rootstocks, brinjal lines and tomato varieties against bacterial wilt. Review of Progress. Activity - II. IPM-CRSP (Integrated Pest Management- Collaborative Research Support Program), HRC, BARI, Gazipur. p. 17.

Rivard, C. L. and Louws, F. J. (2008). Grafting to manage soilborne diseases in heirloom tomato production. *Hort. Sci.* **43**(7): 2104-2111.

Rivard, C. L. and Louws, F. J. (2011). Tomato Grafting for Disease Resistance and Increased Productivity. Kansas State University, Kansas City. p. 8.

Rivard, C. L., Sydorovych, O., Connell, S. O., Peet, M. M. and Louws, F. J. (2010). Production and marketing reports. An economic analaysis of two gratfted tomato transplant production systems in the United States. *Hortechnol.* **20**(4): 794-803.

Rivero, R. M., Ruiz, J. M. and Romero, L. (2003). Role of grafting in horticultural plants under stress conditions. *Food Agric. Environ.* **1**(1): 70-74.

Rodriquez, M. M. and Bosland, P. W. (2010). Grafting Capsicum to Tomato Rootstocks. *J. Young Investig.* **20**(2): 1-6.

Rouphael, Y., Cardarelli, M., Colla, G. and Rea, E. (2008). Yield, mineral composition, water relations, and water use efficiency of grafted mini-watermelon plants under deficit irrigation. *Hort. Sci.* **43**(3): 730-736.

Rouphaela, Y., Schwarz, D., Angelika, K. and Colla, G. (2010). Impact of grafting on product quality of fruit vegetables. *Sci. Hortic.* **127**(2): 172-179.

Sakata, Y., Ohara, T. and Sugiyama, M. (2008). The history of melon and cucumber grafting in Japan. *Acta Hort.* **767**(2): 217-228.

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

Satisha, J., Prakash, G. S., Bhatt, R. M. and Kumar, P. S. (2007). Physiological mechanisms of water use efficiency in grape rootstocks under drought conditions. *Int. J. Agric. Res.* **2**(2): 159-164.

Savvas, D., Colla, G., Rouphael, Y. and Schwarz, D. (2010). Amelioration of heavy metal and nutrient stress in fruit vegetables by grafting. *Sci. Hortic.* **127**(2): 156-161.

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

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

Shankara, N., Lidt de Jeude, J., de Goffau, M., Hilmi, M. and van Dam, B. (2005). Cultivation of Tomato: Production, Processing and Marketing. Digigrafi, Wageningen. p. 92.

Sharfudin, A. F. M. and Siddique, M. A. (1985). Sabji Bigyan. 1st Edition, Bangladesh Agricultural University, Mymensingh. p. 4.

Solieman, T. H. I., El-Gabry, M . A. H. and Abido, A. I. (2013). Heterosis, potence ratio and correlation of some important characters in tomato (*Solanum lycopersicum* L.). *Sci. Hortic.***150**: 25-30.

Tai, S. F., Huang, H. Y., Lin, C. H., Tseng, M. J. and Chang, W. N. (2004). Studies on the graft compatibility for pepper scions grafted onto eggplant rootstock. [http://www.kdais.gov.tw/exper/exp15-2-2e.pdf] site visited on 7/7/2019.

Tamilselvi, N. A. and Pugalendhi, L. (2017). Graft compatibility and anatomical studies of bitter gourd (*Momordica charantia* L.) scions with cucurbitaceous rootstocks. *Int. J. Curr. Microbiol. Appl. Sci.* **6**(2): 1801-1810.

Tasnia, T., Harun. R., Shahanaz, P., Sarowar H. and Azadul, H. (2015). Selection strategies to choose better parents in tomato using genetics parameters. *Plant knowl. J.* **4**(1): 33-39.

Tomato world production statistics (2015). Growing tomatoes. [http://www. growtomatoes.com/tomato-world-production-statistics/] site visited on 26/4/2019.

Turhan, A., Ozmen, N., Serbeci, M. S. and Seniz, V. (2011). Effects of grafting on different rootstocks on tomato fruit yield and quality. *Hort. Sci.* **38**(4): 142-149.

Vuruskan, M.A. and Yanmaz, R.(1991). Effect of different grafting methods on the success of grafting and yield of eggplant, tomato graft combination. *Acta Hort.* **287**(4): 405-409.

Wahb-Allah, M. A. (2014). Effectiveness of grafting for the improvement of salinity and tolerance in tomato. *Asian J. Crop Sci.* **6**(2): 112-122.

Wang, S., Yang, R., Cheng, J. and Zhao, J. (2007). Effect of rootstocks on the tolerance to high temperature of eggplants under solar greenhouse during summer season. *Acta Hort.* **761**: 357-360.

Wener, Z. W. (2016). Importance of tomato. [http://www.agrisupportonline. com/Articles/importance_of_the_tomato.htm] site visited on 14/5/2019.

Wills, R. B. H., McGlasson, W. B., Graham, D., Lee, T. H. and Hall, E. G. (1996). Postharvest: An introduction to the physiology and handling of fruit and vegetables. New Delhi. p. 173.

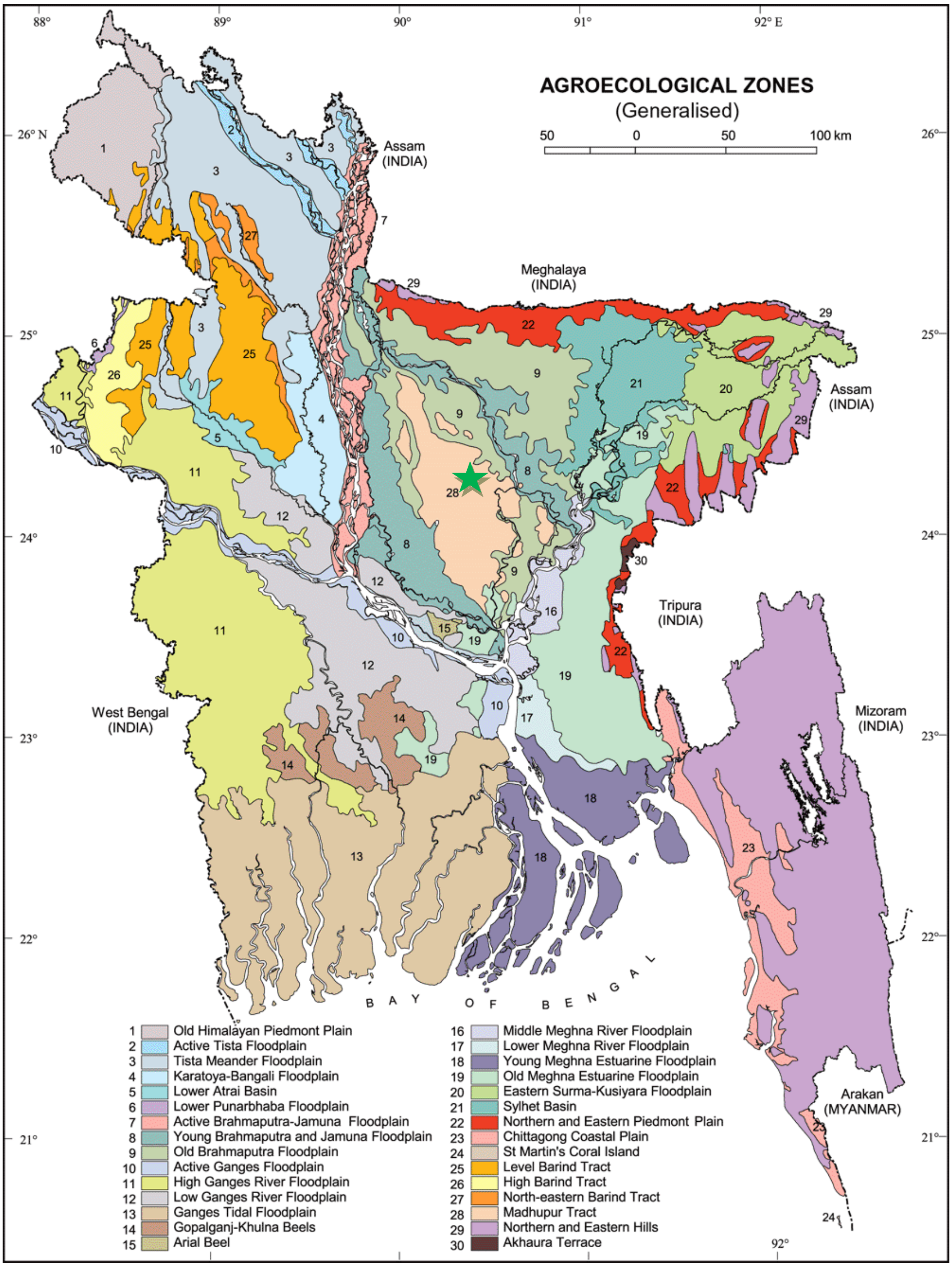
Yamakawa, K. and Mochizuki, H. (1978). Studies on the use of disease resistance of wild non-tuberous *Solanum* Species in the breeding of eggplants. Abstract No. 1674, 20th *Int. Cong. Hortic.* Meeting, Sydney, Australia.

Yamakawa, K. and Mochizuki,H.(1979). Nature and inheritance of *Fusarium* wilt resistance in eggplant cultivars and *Solanum* species. *Bull. Veg. Ornam. Crops Res. Sta.* **6**: 19-27.

Yetisir, H., Kurt, S., Sari, N. and Tok, F. M. (2007). Rootstock potential of Turkish *Lagenaria siceraria* germplasms for watermelon: plant growth, graft compatibility, and resistance to fusarium. *Turkish J. Agric. For.* **31**: 381-388.

APPENDICES

Appendix I. Map showing the experimental site under study



★ **The experimental site**

Appendix II. Monthly record of average soil temperature, relative humidity and rainfall of the experimental site during the period from April, 2019 to September, 2019.

Month	Air temperature (^{0}C)		Relative Humidity (%)	Rainfall (mm)
	Maximum	Minimum		
April	37.5	24.7	84.2	352
May	35.7	25.3	84.4	385
June	32.4	25.5	83.8	228
July	36.8	24.9	83.5	573
August	35.2	23.3	85.0	303
September	33.7	22.6	83.8	234

Source: Bangladesh Meteorological Department (Climate and Weather division) Agargaon, Dhaka.

Apendix III. Analysis of variance (ANOVA) of the data on grafting success of grafted tomato seedlings

Source of variation	Degree of freedom (DF)	Mean square of Grafting success (%)
Replication	2	5.0556
Treatment	5	92.5122**
Error	10	2.6556
Total	17	

** Significant at 1% level of probability

Appendix IV. Analysis of variance of the data on number of plant survived plot^{-1}, plant height, leaves plant^{-1}, main and total branches plant^{-1} of grafted and non grafted summer tomato seedlings

Source of variance	DF	Mean square of				
		No. of plant survived (%)	Plant height (cm)	No. of leaves Plant^{-1}	No. of main branches plant^{-1}	No. of total branches plant^{-1}
Replication	2	13.000	25.000	7.000	0.00413	0.22453
Treatment	6	366.39**	819.51**	492.31**	0.8010**	6.5191**
Error	12	14.667	37.500	13.667	0.00895	0.15221
Total	20					

** Significant at 1% level of probability

Appendix V. Analysis of variance (ANOVA) of the data on number of flower clusters plant^{-1}, flowers cluster^{-1}, first flowering and 50% flowering of grafted and non grafted summer tomato seedlings

Source of variance	DF	Mean square of			
		No. of clusters plant^{-1}	No. of flowers cluster^{-1}	1st flowering	50% flowering
Replication	2	0.1429	0.11127	0.42857	0.42857
Treatment	6	12.8670**	1.40817**	6.08954**	3.09049*
Error	12	0.3095	0.16627	0.76190	0.76190
Total	20				

** Significant at 1% level of probability
*Significant at 5% level of probability

Appendix VI: Analysis of variance (ANOVA) of the data on days to first harvest and harvesting duration of grafted and non grafted summer tomato seedlings

Source of variance	DF	Mean square of	
		Days to first harvest	Harvesting duration
Replication	2	2.7143	0.4286
Treatment	6	19.1441*	35.8884**
Error	12	4.3810	0.7619
Total	20		

** Significant at 1% level of probability
*Significant at 5% level of probability

Appendix VII. Analysis of variance (ANOVA) of the data on fruit length, fruit width, fruits plant^{-1}, single fruit weight and TSS of grafted and non grafted summer tomato seedlings

Source of variance	DF	Mean square of				
		Fruit length (cm)	Fruit width (cm)	No. of fruits plant^{-1}	Av. single fruit weight (g)	TSS (%)
Replication	2	0.01860	0.00601	1.0000	1.0000	0.00143
Treatment	6	5.26360**	0.93554**	24.1619**	66.0417**	0.01139**
Error	12	0.03580	0.01301	2.0000	2.0000	0.00143
Total	20					

** Significant at 1% level of probability

Appendix VIII. Analysis of variance (ANOVA) of the data on fruit yield plant^{-1}, yield plot^{-1}, yield tunnel^{-1} and yield ha^{-1} of grafted and non-grafted summer tomato seedlings

Source of variance	DF	Mean square of			
		Yield plant^{-1} (kg)	Yield Plot^{-1} (kg)	Yield tunnel^{-1} (kg)	Yield ha^{-1} (tons)
Replication	2	0.01330	0.5714	42.86	1.714
Treatment	6	0.11470**	61.2100**	5580.89**	161.368**
Error	12	0.01280	1.2381	76.19	3.048
Total	20				

** Significant at 1% level of probability

Appendix IX. Analysis of variance (ANOVA) of the data on incidence of bacterial wilt of grafted and non grafted summer tomato seedlings

Source of variance	DF	Mean square of bacterial wilt (%)			
		45DAS	60DAS	75DAS	90DAS
Replication	2	0.00001	0.1429	0.143	0.143
Treatment	6	0.06857**	80.0000**	342.857**	109.714**
Error	12	0.00001	0.3095	0.310	0.310
Total	20				

** Significant at 1% level of probability

Appendix X. Analysis of variance (ANOVA) of the data on virus infection of grafted and non grafted summer tomato seedlings

Source of variance	DF	Mean square of virus infestation (%)			
		45DAS	60DAS	75DAS	90DAS
Replication	2	0.143	0.143	0.4286	0.571
Treatment	6	189.000**	150.000**	35.8571**	151.429**
Error	12	0.143	0.310	0.7619	1.238
Total	20				

** Significant at 1% level of probability

Appendix XI . Analysis of variance (ANOVA) of the data on pest and diseases of grafted and non grafted summer tomato seedlings

Source of variance	DF	Mean square of			
		Southern blight (%)	Black leaf mold (%)	Mealy bug (%)	Fruit borer (%)
Replication	2	1.8571	1.7143	1.0000	0.1429
Treatment	6	94.4286**	76.7143**	29.4286**	16.8571**
Error	12	2.5238	3.0476	2.0000	0.3095
Total	20				

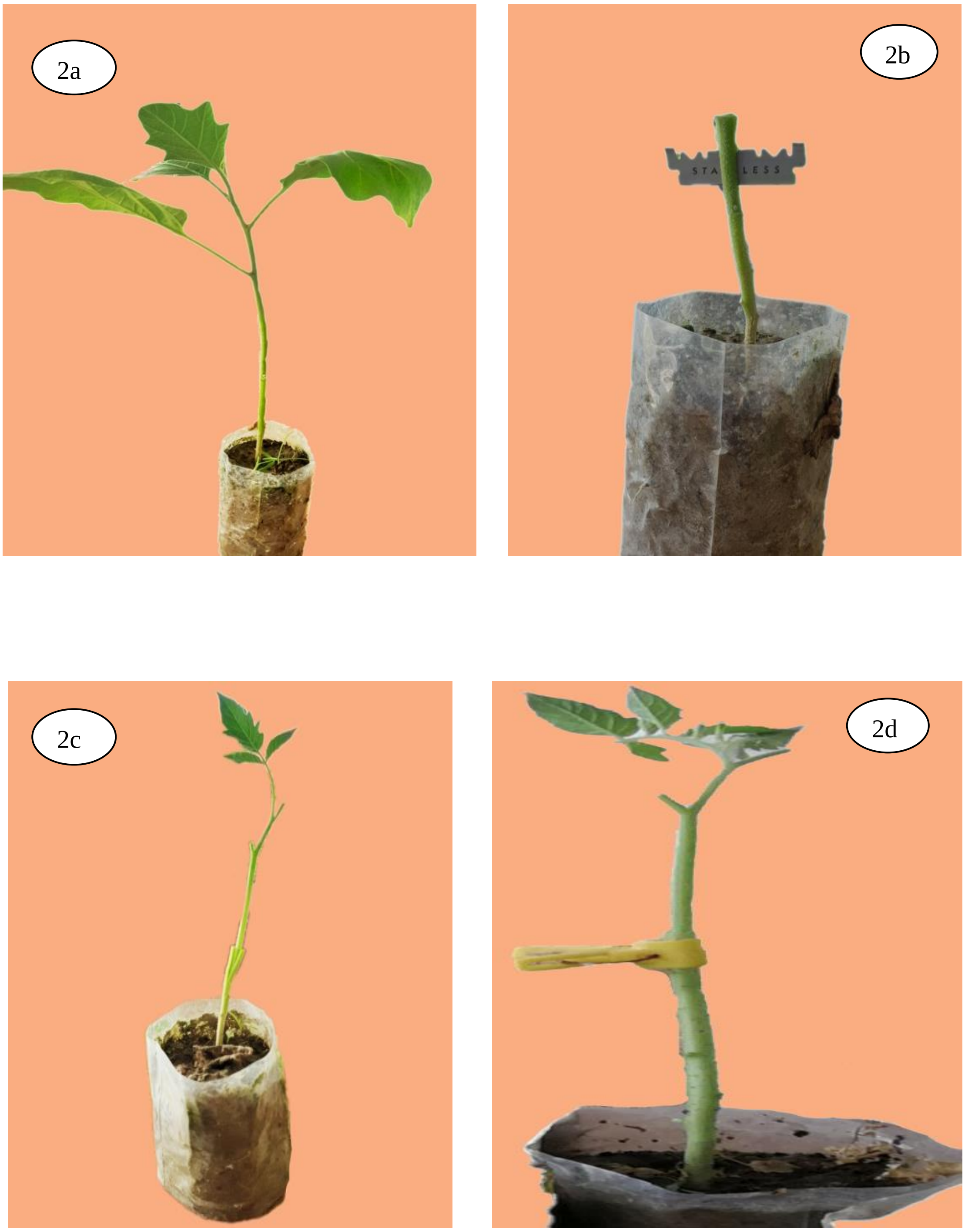
** Significant at 1% level of probability

LIST OF PLATES

A. Rootstock seedlings

B. Scion seedlings

Plate 1: Seedlings of rootstock and scion in seed bed



Different steps of grafting (continued)

Plate 2: Grafting procedure of tomato on rootstock

2.a) Seedling of rootstock ready for grafting.

2.b) Detopped the tip of the rootstock seedling and divided into two equal halves by a vertical cut about 1 cm deep using a razor blade.

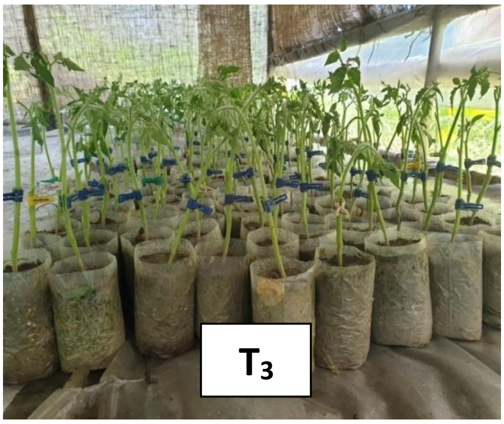
2.c) Insertion of "V" shaped end of the scion into the vertical cut of the rootstock.

2.d) Grafted tomato seedling on a rootstock attached with a grafting clip.

2.e) Spraying water on the grafted seedling.

2.f) Grafted seedling in a shade house house covered with a sheet of polythene and a black curtain.

A. Tomato seedling grafted on *S. sisymbriifolium*   B. Tomato seedling grafted on EG-203



C. Tomato seedling grafted on khag-1   D. Tomato seedling grafted on khag-2

E. Tomato seedling grafted on khag-3   F. Tomato seedling grafted on BARI brinjal-8

Plate 3: Grafted tomato seedlings

A. Outside of the healing house

B. Inside of the healing house

Plate 4: Healing house for grafted tomato seedlings

Plate 5. Polytunnels for summer tomato production

Plate 6. Transplantation of grafted and non-grafted tomato seedlings into the main field

A. Irrigation B. Pheromone trap C. Sticky trap D. Anti-bird netting

Plate 7. Crop management for grafted and non-grafted tomato at field condition

Plate 8. Vegetative stages of grafted and non-grafted summer tomato

Plate 9. Flowering stage of grafted and non-grafted summer tomato

Plate 10. Fruiting stage of grafted and non-grafted summer tomato