EVALUATION OF ROOTSTOCKS FOR BIOTIC STRESS MANAGEMENT IN TOMATO UNDER PROTECTED CONDITIONS

THESIS

By

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(A-2016-40-024)

Submitted to

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CERTIFICATE – I

This is to certify that the thesis entitled **"Evaluation of rootstocks for biotic stress management in tomato under protected conditions"** submitted in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy **(Agriculture)** in the discipline of **Vegetable Science** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Ms. Vibhuti Sharma (A-2016-40-024)** daughter of **Smt. Brinda Sharma** and **Dr. Ashok Sharma** under my supervision and that no part of this thesis has been submitted for any other degree or diploma

The assistance and help received during the course of this investigation have been fully acknowledged.

Place: Palampur
Dated: 14th May, 2019

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Major Advisor

CERTIFICATE- II

This is to certify that the thesis entitled **"Evaluation of rootstocks for biotic stress management in tomato under protected conditions"** Submitted by **Ms. Vibhuti Sharma(A-2016-40-024)** daughter of **Dr. Ashok Sharma** to the CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of Doctor of Philosophy **(Agriculture)** in the discipline of **Vegetable Science** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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Needless, to say, errors and omissions are mine.

Place: Palampur
Dated: 14th May, 2019 ***(Vibhuti Sharma)***

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LIST OF ABBREVIATIONS USED

Sr. no.	Abbreviation	Meaning
1.	et al.	et alia (and others)
2.	*i.e.*	Idest (that is)
3.	viz.	Videlicet (namely)
4.	p	Page
5.	°C	Degree Celsius
6.	g	Gram
7.	kg	Kilogram
8.	/	Per
9.	%	per cent
10.	fig.	Figure
11.	cm	Centimeter
12.	m	Meter
13.	FYM	Farmyard manure
14.	@	at the rate
15.	df	Degree of freedom
16.	MOP	Muriate of potash
17.	m^2	Per square metre
18.	mm	Millimeter
19.	ml	Milileter
20.	lt	Litre
21.	^{0}	Degree
22.	mg	Miligram
23.	N	Normality
24.	pH	Negative log of Hydrogen ion
25.	cfu	Colony forming unit
26.	?.	Rupees
27.	CV	Coefficient of variation
28.	CD	Critical difference
29.	sq m	Square metre

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ABSTRACT

Tomato is one of the principle vegetables grown under protected conditions worldwide. Biotic stresses are among major constraints which are affecting vegetable crops. Bacterial wilt of tomato (*Ralstonia solanacearum*) is one of the devastating bacterial diseases affecting vascular bundles of plants. Plant-parasitic nematodes are economic pests of agriculture importance and tomato is regarded as the favourable host for root knot nematode. Vegetable production and productivity is very high under protected environments as compared to open field conditions. But production under protected conditions has suffered a great setback due to biotic stresses such as bacterial wilt caused by *Ralstonia solanceraum* and nematode infestation (*Meliodogyne* sp.) Both these problems are not easy to manage and there is no effective chemical treatment to manage these biotic stresses under polyhouses. The chemical control measures and manipulation of agronomical practices are not effective to control the disease. Hence, identification and development of new improved disease resistant cultivars is very important to boost up the production and productivity of crop in wilt prone areas of H.P. In order to combine various desirable horticultural traits in tomato along with resistance to diseases, the most appropriate approach is grafting of desirable scion on resistant rootstocks. Therefore, keeping above mentioned facts, the present investigation entitled "Evaluation of rootstocks for biotic stress management in tomato under protected conditions" was carried out in a Randomized Block Design with three replications and cleft grafting method was used to graft desirable scion on resistant rootstocks. The treatments comprised of sixteen different rootstocks and one commercial hybrid GS-600 which was horticulturally superior and was used as a scion. The data were recorded on various growth parameters, horticultural and quality traits. All rootstocks used in the study were found resistant to bacterial wilt. For nematode incidence rootstocks Green Gourd (Tomato), Brinjal (VI-34845), Chilli rootstocks (PI-201232 and AVPP0205) were found to be resistant. Whereas, Brinjal rootstock VI-47335 (EG-195) was found moderately resistant. Rootstock Green Gourd and VI-34845 were found resistant for bacterial wilt as well as for nematode incidence. Therefore, these rootstocks can be used for countering biotic stresses such as (bacterial wilt and nematodes) efficiently under protected conditions. For early production to fetch higher returns plants grafted on rootstock LS-89 proved best as it was found superior to other rootstocks for days to first flowering (28.00) and days to first harvest (75.50). To get higher yield in terms of number of marketable fruits per plant (23.67), average fruit weight (91.50 g), marketable fruit yield per plant (2.16 kg) and marketable fruit yield per square metre (25.92 kg/m^2) as well as for prolonged harvest duration (72.62 days) plants grafted on tomato rootstock Green Gourd found superior. The rootstock Hawaii-7998 showed higher success rate (97.00 %) when scion GS-600 was grafted on it. Grafted plants on various rootstocks excelled in quality over non-grafted plants and were high-caliber for TSS (5.48 ^{0} Brix) which was found higher in plants grafted on rootstock Arka Nidhi. Lycopene content (6.75 mg/100 g) was recorded maximum in plants grafted on rootstock Back Attack. Whereas, titrable acidity an important quality trait was detected in plants grafted on rootstock VI-47335 (0.67%). Fruit firmness hold great significance for enhanced shelf life as well as maintaining quality during transit was recorded highest in plants grafted on rootstock Palam Pink (4.34 kg/cm^2). Ascorbic acid content which has exceptional importance in human health was also adjudged highest in plants grafted on rootstock Palam Pink (21.94 mg/100g). This rootstock also recorded maximum fruit length (5.49 cm) as well as fruit width (5.99cm). Pericarp thickness which plays remarkable role in long distance transportation was recorded highest in plants grafted on rootstock Palam Pride (5.81mm). Benefit cost ratio is a critical factor in crop production to determine the expenses incurred and returns received in any crop production. Higher Benefit: cost ratio (10.76) was found in plants grafted on rootstock Green Gourd.

(Vibhuti Sharma)	**(Dr. Pardeep Kumar)**
Student	**Major Advisor**
Date: 14^{th} May, 2019	**Date: 14^{th} May, 2019**

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1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable owing to its wider adaptability, higher yielding potential and suitability both in fresh and processed food industries (He *et al*. 2003 and Nwosu *et al*. 2014). It ranks second in importance to potato in many countries and is also one of the principle vegetable grown under protected conditions worldwide. It is an economically important cash crop with high demand in the international market (Solieman *et al*. 2013). Globally tomato is grown in area of 5.02 million hectares, production of 170.75 million tones and productivity of 33.99 tonnes per hectare (Anonymous, 2017 a). In India, tomato occupies an area of 797 thousand hectares with the production of 20708 thousand metric tonnes and productivity of 25.98 metric ton per hectare (Anonymous, 2017 b). Tomatoes also occupy an important position in Himachal Pradesh as it is a major cash crop grown under mid hills in 11.04 thousand hectare area with an annual production of 485.54 metric tonnes and the productivity of 43.99 metric tonnes per hectare (Anonymous, 2017c). In H.P. with state funding schemes the area under polyhouse technology is increasing day by day. In Himachal Pradesh there are approximately 30,000 polyhouses, occupying an area of approximately 350 hectares.(Kumar *et al*. 2018).

Biotic stresses occur due to damage caused by living organisms (bacteria, viruses, fungi, parasites, beneficial and harmful insects, weeds and cultivated or native plants). The nature and type of biotic stresses depend on the climatic conditions and inherent ability of the plant to resist or tolerate the stress. Biotic stresses are difficult to mitigate in comparison to abiotic stresses due to many reasons like change in the physiology of the pathogen or pest, or changes in the race of the pathogen with passage of time or due to breakdown of the resistance after sometime. Polyhouse technology has gained importance due to its manifold benefits in terms of increased yield and quality of produce. But certain biotic stresses like bacterial wilt and nematodes have become serious threat to the vegetables particularly solanaceous vegetables like tomato, bell pepper and brinjal.

Bacterial wilt of tomato (*Ralstonia solanacearum*) is one of the devastating bacterial diseases affecting vascular bundles of plants. It is the most important disease in the mid-hills of H.P. and sub-humid areas of Kangra and Mandi districts of the state. The disease was first noticed in Kangra valley in 1981 and remained sporadic in nature till 1985, and now it has become endemic in Kangra and Mandi districts (Sood and Singh, 1992). It was first observed in Kangra valley in 1981 and gradually spread to other districts like Kullu, Mandi (Sood and Singh, 1993), Solan (Gupta *et al*. 1998), Bilaspur and Hamirpur (Sood *et al*. 2002). It has since become endemic in these districts and causes 80-90% yield losses. The race 1 biovar III is prevalent under Himachal Pradesh (Kalha and Sood, 1994). The bacterium is host of many plants nearly 200 which includes all the solanaceaus vegetables (tomato, brinjal, chilli, potato and tobacco). The disease is aggravated in soils where there is combined infestation of the *Ralstonia solanacearum* and root knot nematodes. The chemical control measures and manipulation of agronomical practices are not effective to control the disease. Hence, identification and development of new improved disease resistant cultivars is very important to boost up the production and productivity of crop in wilt prone areas of H.P. In order to combine various desirable horticultural traits in tomato along with resistance to diseases, the most appropriate approach is grafting of desirable scion on resistant rootstocks.

Plant-parasitic nematodes are economic pests of agriculture importance. (Okorley *et al*. 2018). Root-Knot nematodes are one of the most important polyphagous pests and have great impact on health, yield and quality of the crop. Tomato is regarded as the most favourable host for root knot nematode. All four major species of nematode viz, *Meloidogyne incognita, Meloidogyne javanica, Meloidogyne arneria and Meloidogyne hapla* and their known races attack tomato crops in outdoor as well as in indoor conditions. The average crop yield losses due to root knot nematodes are thought to be 5 per cent. In India, losses vary from 20 to 80 per cent. Nematode-resistant plants or rootstocks can be successfully utilized as a source of resistance in reducing nematode infestations in solanceous crops (tomato, brinjal etc) grown in infested soils (Corbett *et al*.2011). Thus, grafting of susceptible tomato scions on resistant rootstocks has proven as an effective management strategy in combating RKNs (Ioannou, 2001), reducing cost of production besides improving yield (Clark and Moyer. 1988).

It is a fact that still farmers from remote parts of the country are unable to use various modern tools to manage biotic stress. Poor access to tools and products of modern tool box of crop management is retrogressive to ambitions of growth in agriculture.

Use of grafted seedlings had become a modern tool to counter biotic as well as abiotic stresses on their field, which creates more pressure to sustainability of resource poor, less knowledgeable farmers and is gaining popularity in case of cucurbits, tomato, eggplant and pepper. (Pogonyi *et al*. 2005) .This technology is gaining importance in areas where land is intensive and continuous cropping is practised (Khah *et al*. 2006). Commercial vegetable grafting is a new technique and the area under vegetable grafting is progressively increasing (Kumar *et al*. 2018). Vegetable grafting is one of the alternative tools to slow breeding procedures which is further used for development of resistant varieties. The use of resistant rootstocks reduces dependency on agrochemicals therefore, it is considered ecofriendly for sustainable vegetable production (Rivard and Louws, 2008). Grafting is used to improve both production, productivity besides improving resource use efficiency in crops under protected conditions.

Use of rootstocks can enhance plant biotic responses by improving plant vigour through vigorous attainment of soil nutrients, avoidance of soil pathogens and tolerance to low soil temperature and salinity. The type of rootstock affects scion growth, yield and quality of fruits. Besides improving productivity, it also helps to ensure better fruit set during off-season. Rootstocks are used to impart disease resistance in vegetable crops such as bacterial wilt, fusarium wilt and verticillium wilt. Changing rootsystem through grafting in vegetable crops is becoming an important tool not only to manage soil borne diseases but also to improve crop response to a variety of abiotic and biotic stresses.

However, to make a specific change in plant rootsystem through grafting the performance of grafted plants depend on nature of rootsytem used as rootstocks. Most of rootstocks are selected through screening/evaluation. In general rootsytem are selected on the basis of tolerance to biotic and abiotic stresses and compatibility in scions. Recent literature reveals that grafted plants are more vigorous and tolerant to diseases in comparison to non-grafted ones. (King *et al*. 2010 and Khah. 2011).

The basic requirements of rootstock are that they are compatible with scion without contributing negative traits. Majority of rootstocks in tomato breeding are used for high value produce under greenhouse conditions. Therefore, traits to be focused on greenhouse system should be based on rootstock with strong rootsystem that can support long cropping system as the main priority alongwith with desired traits for greenhouse. The important traits imparting resistance are soil borne diseases, root knot nematodes, cold, heat, flooding and salinity.

Enhancing water, nutrient uptake, nutrient uptake efficiency, extending duration of harvest time and improving fruit quality are important traits required to be incorporated through grafting. The influence of rootstock on the mineral content in aerial plant parts is attributed to physical characteristics of rootstock such as vertical and lateral which resulted in nutrient uptake. This is one of the main motive for wide spread use of rootstock through grafting.

Proper rootstock and scion combinations should be carefully selected in accordance with the climatic and geographical conditions of the region to avoid soilborne diseases besides increasing the efficiency and the quality of fruits (Davis *et al*. 2008). This is considered as an important aspect for making grafted plants tolerant to biotic stresses. Use of vigorous rootstocks developed through breeding can be utilized to improve fruit yield and quality through improved vigour and better rootsystem of rootstocks. (King et al. 2010 and Lee *et al*. 2010).

Production under protected conditions has suffered a great setback due to biotic stresses such as bacterial wilt caused by *Ralstonia solanceraum* and nematode infestation (*Meliodogyne* sp.) Both these problems are not easy to manage and there is no effective chemical treatment to manage these biotic stresses under polyhouses. Therefore, keeping in view all the above mentioned facts, the present investigation was planned keeping in mind the following objectives:

1. To screen the rootstocks for their resistance to *Ralstonia solanacearum* and *Meloidogyne incognita*
2. To study the performance of promising rootstocks with respect to growth, yield and quality of tomato in polyhouse.
3. To work out the economics.

2. REVIEW OF LITERATURE

In this chapter an attempt has been made to review the available literature under various heads as below:

2.1 Effect of rootstocks on bacterial wilt incidence

2.2 Effect of rootstocks on nematode incidence

2.3 Effect of rootstocks on growth, yield and quality parameters

2.s1 Effect of rootstocks on bacterial wilt incidence

Hanson *et al* (1996) in their studies found out grafting as an effective tool to reduce yield losses caused by *Ralstonia solanacearum* in severely infested soils through use of efficient and resistant rootstocks.

Rivard (2006) reported ‘Hawaii-7996’ for conferring resistance to bacterial wilt and improving yield in grafted tomato plants.

Lin *et al*. (2008) studied that plants grafted on EG 203 rootstock exhibited 0 to 2.8% incidence of bacterial wilt while non-grafted ones showed 24.4-92.9% wilt incidence.

Rivard and Louws (2011) studied the effect of grafting on bacterial wilt incidence and found that rootstocks ‘CRA 66 ‘and ‘Hawaii-7996’ were resistant to disease. Moreover, yield was higher in Hawaii-7996 as compared to non-grafted plants.

Cardoso *et al*. (2012). Evaluated tomato rootstocks for the resistance to *Ralstonia solanacearum* in which H7996 was used as rootstock, and the cvs. Santa Clara, Santa Cruz Kada, and Debora Plus were used as the scion. They observed that rootstock H-7996 was resistance to bacterial wilt throughout the entire crop cycle. While, the cultivar ‘Santa Clara’ was the most susceptible genotype to bacterial wilt.

Rivard *et al*. (2012) studied the effectiveness of grafting for management of bacterial wilt in tomato. They found that tomato plants grafted on ‘Dai Honmei’ and ‘RST-04-105-T’ rootstocks had significantly lower incidence of bacterial wilt as compared to non-grafted plants.

Waiganjo *et al*. (2013) conducted trials to compare the effect of grafted with non-grafted tomato through use of high tunnels in relation to open fields on disease incidence, yield and fruit quality. They observed that use of high tunnels reduced disease and increased yield and quality of fruits. They further concluded reduced incidence under both high tunnel (15%) and open field (25%) non-grafted ones showed 88-90% disease incidence.

Ignotius *et al*. (2014) adopted different grafting techniques for management of bacterial wilt and found that tomato plants grafted on rootstocks viz., *Solanum melongena, Solanum incanum* were resistant to disease as compared to control plots.

2.2 Effect of rootstocks on nematode incidence

Dao-Feng *et al*. (2007) in their experiments studied the effect of resistant rootstocks on nematode growth and yield of tomato. They found 15-20% higher yield with high quality as compared to the non-grafted plants.

Sakata *et al*. (2007) reported that the use of resistant cultivars as rootstocks were more efficient in reducing nematode population as compared to susceptible cultivars on root-knot infested soils, especially when preferred nematode-resistant cultivars or nematicides were not available.

Tzortzakakis (2007) concluded that the use of grafted tomatoes on resistant rootstocks can manage nematode populations and rotation of resistant tomato with susceptible has been proved successful for reducing *M. javanica* infestations in greenhouse conditions.

Kaskavalci *et al*. (2009) reported reduced root galling when susceptible scion was grafted on resistant rootstock 'Beaufort'.

Burelle and Rosskopf (2011). Conducted experiments for two years and evaluated rootstocks of tomato for *Meloidogyne incognita* resistance in rootstocks. Three tomato rootstocks; 'TX301', 'Multifort', and 'Aloha' were used as scions. They found that all the rootstocks provided good reduced galling and J2 of *M. incognita* in soil and roots to some extent. They concluded that although *M. incognita* juvenile numbers in soil were similar, numbers in roots were higher in the non-grafted as compared to grafted tomato rootstocks.

Barrett *et al*. (2012) found from their studies that use of resistant rootstocks resulted in a greater reduction of root galls as compared to non-grafted plants. Grafting with appropriate rootstocks may play an effective role in RKN management.

Charles *et al*. (2012) reported reduced root galling in grafted plants as compared with the non-grafted and self-grafted scions by ’80.8% in organic field and by 97.1% in transitional field' when they were grafted on Survivor rootstock.

Jaiteh *et al*. (2012) revealed that increasing initial population of *Meloidogyne* spp. in the soil had a direct effect of increasing juvenile population in the tomato root.

Dhivya *et al*. (2014) conducted preliminary studies for reaction of wild Solanum rootstocks and two tomato hybrids against root-knot nematode utilizing following species viz., *Solanum torvum, Solanum xanthocarpum, Solanum incanum, Solanum aethiopicum, Solanum sisymbrifolium, Solanum viarum, Physalis peruviana* and *Solanum violaceum*. They found that *Solanum incanum* and *Solanum aethiopicum* were moderately resistant and can be used for grafting in tomato to reduce the deleterious effect of root knot nematodes. They concluded that grafting tomato with Solanum wild species can provide best solution for controlling root-knot nematodes.

Keatinge *et al*. (2014) found eggplant rootstocks VI046103 (EG 195) and VI045276 EG 203 resistant against bacterial wilt, root knot nematodes and other soilborne diseases.

Kunwar *et al*. (2015) studied the potential of grafting rootstocks as a sustainable and ecofriendly practice for bacterial wilt management. They evaluated three tomato rootstocks ‘RST-04-106-T’, ‘BHN 998’, and ‘BHN 1054’ for resistance to *Meloidogyne incognita* under field trials for two consecutive years. They concluded that grafting rootstocks on ‘BHN 602’ a tomato scion susceptible to bacterial wilt and RKNs, significantly reduced root galling caused by RKNs in all field trials and increased yield in two of the trials compared with the non-grafted treatment.

Burelle *et al*. (2016) in their studies observed less root galling in grafted plants when ‘TX301’, ‘Multifort’, and ‘Aloha’ were used as root stocks than non-grafted Florida ‘47’.

Owusu *et al*. (2016) conducted experiments in tomato grafting to manage the root-knot nematode incidence. They reported reduced nematode population levels through grafting. They also observed that fruit yield, including the number and fruit weight was higher with the resistant cultivars as rootstocks in a field. The use of rootstocks with nematode resistance can be an effective for management of root-knot nematodes on susceptible tomato cultivars.

2.3 Effect of rootstocks on growth, yield and quality parameters

Marsiac and Osvald (2004) observed the influence of grafting on yield of two tomato cultivars (*Lycopersicon esculentum* Mill.) grown in a plastic house. They found higher yield of fruit of cv. 'Monroe' grafted on rootstock of 'Beaufort'.

Pogonyi *et al*. (2005) examined the effect of grafting on yield, quality and other fruit components of greenhouse tomato and reported that fruit yield was significantly higher on grafted plants than on non-grafted ones by 62% due to increased fruit number (14%) and higher average fruit weight (45%).

Passam *et al*. (2005) reported tomato as a preferable rootstock for grafting in eggplant whereas, Leonardi and Giuffrida (2006) in an investigation also reported that rootstocks may influence plant vigour and nutrient uptake.

Khah *et al*. (2006) studied the effect of grafting under both greenhouse and open field conditions where 'Heman' and 'Primavera' were used as rootstocks, while 'Big Red' was used as a scion. They observed that grafted plants were more vigorous than the non-grafted ones and had higher total yield and more number of fruits/plant without having significant effects on fruit quality. Thus, they concluded that use of improved rootstocks is required so as to get higher yield under a variety of climatic and soil conditions.

Qaryoti *et al*. (2007) grafted tomato variety Cecilia on two rootstocks He-man and Spirit and studied the effect of grafting on tomato in two growing systems. They observed increased fruit yield by 12-27% under soilless cultivation and by 16-38% in soil cultivation.

Davis *et al*. (2008) reported that grafting can affect various quality aspects of vegetables. They further reported that rootstock/scion combinations should be carefully selected for specific climatic and geographical conditions.

Mohammed *et al*. (2009) conducted experiment on grafted tomatoes to study the effect on growth and yield and observed that tube grafting method resulted in higher grafting success rate of 21%. They further concluded that grafting of tomato on suitable rootstocks had positive effect on the crop efficiency through proper selection of rootstock/scion combinations which resulted in increased growth and yield.

Di Gioia *et al*. (2010) concluded from their study an increased marketable yield by 20- 25% in grafted plants in both years as compared to non-grafted plants. However, total soluble solids (TSS) contents, titrable acidity (TA), and TSS/TA ratios were not significantly affected by grafting although vitamin C content decreased by 14 - 20% in both years in the fruit of plants grafted onto either rootstock.

Turkmen *et al*. (2010) carried out studies to determine the effect of different rootstocks and cultivars on yield of grafted tomato for two years. They observed significant differences among rootstocks, cultivars and rootstock and cultivar interactions in terms of yield, fruits per plant in both years and found the best rootstocks and cultivars Heman and Spirit. They further found that interactions between Heman and Beril F1 and Spirit and Beril F1 gave the highest yield while Beril F1 was found best cultivar in the present studies.

Ballesta *et al*. (2010) reported the physiological aspects of rootstock-scion interactions and concluded that the scion-rootstock connection is fundamental for optimal growth, water and nutrient uptake and transport.

Rouphael *et al*. (2010) observed that grafting plants on resistant rootstocks is an effective tool to control soil-borne diseases, environmental stresses and increased yield.

Flores *et al* (2010) conducted experiments to find out the effectiveness of grafting in improving fruit quality parameters *viz.*, total soluble solids (TSS) and titratable acidity (TA). They found higher TSS and TA in fruits from grafted plants grown through use of different rootstock and scion combinations.

Turhan *et al*. (2011) studied the effect of grafting on different horticultural and quality parameters viz., fruit index, fruits per plant, fruit weight, fruit yield, dry matter, pH, total soluble solids, titrable acidity, total sugars, lycopene and vitamin C content. The results showed non- significant differences in lycopene and pH content, improved yield, fruit index, number of fruits per plant and fruit weight which were lower in the fruits of grafted plants as compared to non-grafted ones.

Gebologlu *et al*. (2011) found in their study on grafted tomato under soilless culture that grafted plants increased the yield depending on the rootstock.

Gisbert *et al*. (2011) studied the performance of eggplant grafted on cultivated, wild and hybrid materials of eggplant and tomato and concluded that highly vigorous rootstocks having a good compatibility with scion and provided the best results in terms of plant survival, earliness and yield, without detrimental effects on quality.

Vinkovic *et al*. (2011) reported that grafting resulted in increased marketable fruits per plant, decreased vitamin C content and total phenolics on respective rootstocks. They further concluded that tomato grafting on suitable rootstocks had positive effects on the cultivation performance, but decreased nutritional quality of tomatoes.

Khah. 2011. Studied the performance of aubergine cv. 'Rima' grafted on tomato rootstock 'Heman' under both the greenhouse and the open-field conditions. They concluded that higher total yield without having significant effects on the quality of the fruits was produced. Further, aubergine grafted on suitable rootstocks had positive effects on the cultivar performance, especially under greenhouse conditions.

Farias *et al*. (2013) observed maximum number of fruits along with marketable yield per plant in plants grafted on *Solanum gilo, Solanum lycocarpum and Solanum stramonifolium* rootstocks.

Schwarz *et al*. (2013) in their studies found decreased content of total soluble solids and sugars concentration through grafting. Whereas, Krumbein and Schwarz (2013) also reported decreased sugars in grafted tomato while found increase in titrable acidity.

Ibrahim *et al*. (2014) from their studies on greenhouse grafted tomato plants found that grafted plants were more vigorous and had 11.90-12.41% higher yield than non-grafted plants. They also found improvement in fruit quality traits such as vitamin-C, titratable acidity and total sugars in grafted plants.

Wahab-Wallah (2014) in their studies reported significantly higher values of grafted plants in terms of growth, yield of tomato in comparison to non-grafted ones. They also observed reduced ascorbic acid and total soluble solids in grafted plants while, titrable acidity was not significantly affected by grafting.

Riga (2015) reported significant increase in fruit weight, fruit diameter and fruit size as compared to non- or self-grafted plants.

Mourao *et al*. (2017) concluded that use of double-stemmed grafted tomato plants contributed to the increased yield besides reducing demand for labour and seedlings costs.

Neu and Nair (2017) from their study compared the effects of grafted and non-grafted plants for both tomato varieties i.e. Cherokee Purple Heirloom Tomatoes (indeterminate) and Mountain Fresh Hybrid Tomatoes (determinate). They observed non significant differences in yield between the grafted and non-grafted plants.

Alvarado *et al*. (2017) evaluated native accessions of tomato rootstocks and identified outstanding genotypes for their potential for their use as rootstocks in tomato production. They observed that non-grafted plants yielded significantly or equal to self-grafted plants and also found a yield increase of 22% in grafted plants as compared to non-grafted.

Djidonou *et al*. (2017) conducted studies in grafted tomato to assess the effects of different interspecific hybrid tomato rootstocks viz., *Solanum lycopersicum* and *Solanum habrochaites* on yield, growth, nutrient accumulation and fruit composition of tomato. They observed increased total and marketable fruits with 53% and 66% higher than non-grafted and selfgrafted. In general, grafting with the interspecific rootstocks increased fruit soluble solids content (SSC), titratable acidity, vitamin C, carotenoids, and total phenolics at levels comparable with non-grafted plants.

Kumar *et al*. (2017) observed that different rootstocks affected the qualitative as well as quantitative characters. They included Avtar as a scion which was grafted on different rootstocks and affected the plant growth, yield as well as quality of the fruit significantly. Results showed that grafted plants recorded 51.40% higher number of fruits as compared to the non-grafted ones. The rootstock VI-34845 was found to be superior to all other treatments for recording higher yield (2.14kg) per plant.

Casals *et al*. (2018) studied the impact of grafting on sensory profile of tomato landraces in conventional and organic management systems. They concluded that ‘Beaufort’ rootstock reduced sweetness, acidity, and intensity of flavor in the organic system. Whereas, sweetness and intensity of flavor in the conventional systems besides improving fruit appearance along with increased yield by 52%.

Kumar *et al*. (2018) conducted experiments to study the influence of rootstocks and scions on horticultural traits and quality of tomato under protected conditions. They revealed that Treatment T-2 in which 2123 A-1 was used as a rootstock and Rakshita used as a scion has been found more suitable in which highest fruit yield per plant, longest harvest duration, highest TSS, maximum plant height and maximum number of fruits per plant were recorded.

Latifah *et al*. (2018) evaluated different varieties of tomatoes with *Solanum torvum* as a rootstock to study the effect of grafting. They concluded that Timoty grafted onto *S. torvum* produced the highest revenue, profit and revenue-cost ratio, although the production cost was higher than the control treatment. Thus, grafting not only increased profit but also reduced the incidence of diseases and *Solanum torvum* was considered most compatible rootstock for tomato grafting.

Soare *et al*. (2018) studied the effect of grafted tomato plants on growth and quality. The results revealed that grafted plants are more vigorous than non-grafted ones. They also reported higher stem diameter, plant height, maximum number of fruits per plant, average fruit weight, productivity and the production of tomatoes per plant than non-grafted ones.

Wahab, A.A. (2018) investigated the effect of tongue approach and cleft grafting methods on growth parameters, fruit quality and yield of tomato for two seasons by using cultivar Elbash1077 F_1 as a scion or rootstock. They concluded that total yield was significantly higher in the control than grafted ones.

3. MATERIALS AND METHODS

The present investigation entitled "Evaluation of rootstocks for biotic stress management in tomato under protected conditions" was undertaken in a naturally ventilated polyhouse at Research Farm of Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur during Rabi and Kharif seasons (2016-17 and 2017-18) under protected conditions. The details of materials used and methods employed in the present study are presented below:

3.1 Experimental site

3.1.1 Location

The present study was carried out in a modified naturally ventilated polyhouse at Vegetable Research Farm, Department of Vegetable Science and Floriculture, which is situated at an elevation of 1,290.8 m above mean sea level with 320. 6' N latitude and 760. 3' E longitudes. The polyhouse used for research trial had all the essential features of an ideal polyhouse such as double door, side & top ventilation, drip irrigation and shading with 50 per cent green agro UV stabilized shade net.

3.1.2 Climate

Heavy winters and mild summers with high rainfall are the main characteristic features of the area. The location is characterized by humid, sub-temperate climate with an annual rainfall of 2,500 mm, of which 80 per cent is received during June to September. The relative humidity in the region varied from 46 to 84 per cent and agro-climatically, the location represents the mid-hill zone of Himachal Pradesh. Mean monthly meteorological data have been given in (figure 3.1) and Appendix-I.

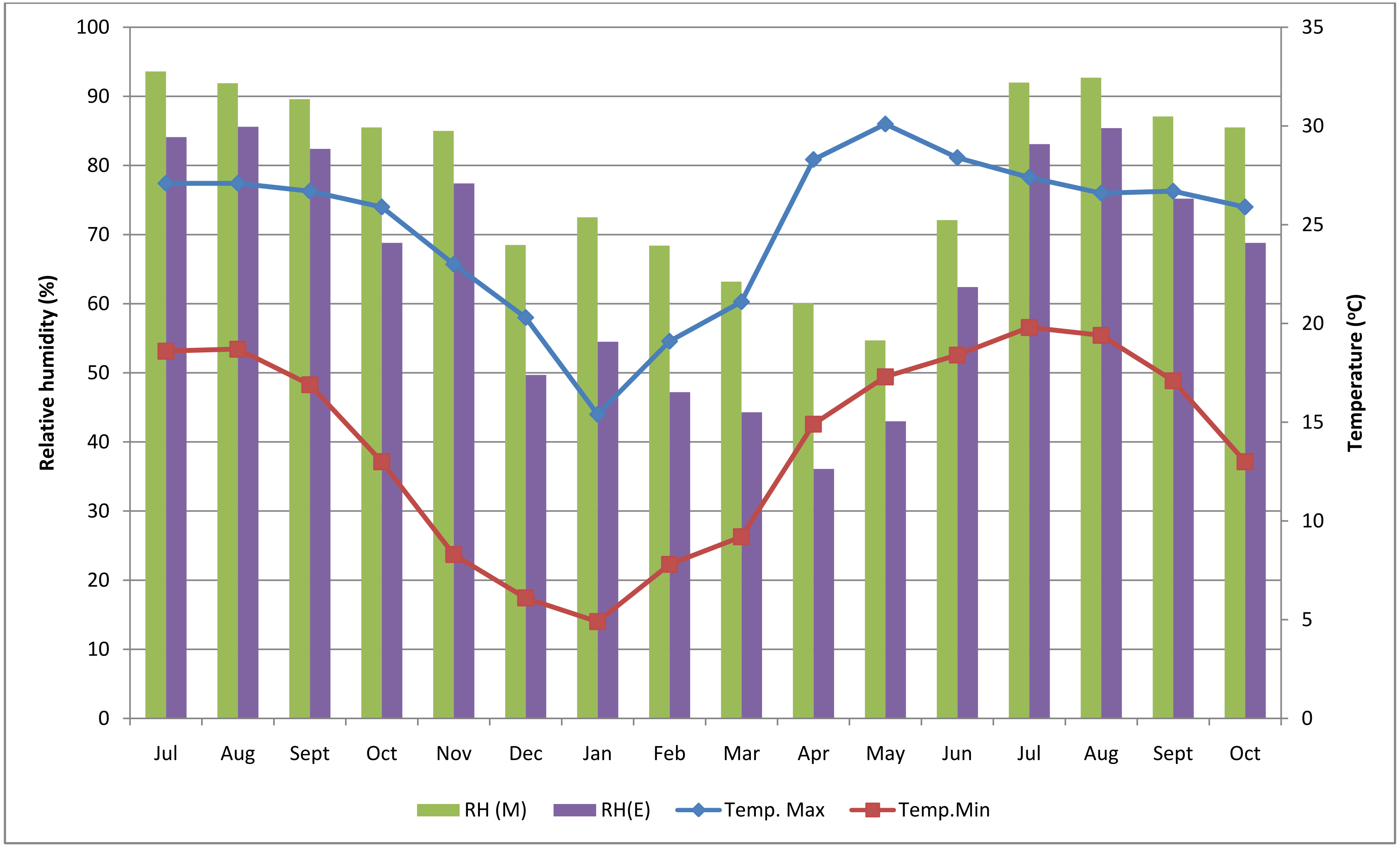


Fig 3.1: Mean monthly meteorological data recorded at Palampur during July 2017 -October 2018

3.2 Bacterial wilt incidence (%)

Screening of rootstocks against bacterial wilt (*Ralstonia solanacearum*)

1) Preparation of inoculums/ bacterial suspension

TZC broth specific for *Ralstonia solanacearum* was prepared and bacterial culture was taken from Department of Plant Pathology, CSKHPKV, Palampur. The culture was inoculated in broth and it was kept in incubator for 1hr. The scion was already tested for its reaction against bacterial wilt and was found to be highly susceptible. (Plate 3.1)

2) Planting of rootstocks in sick plots

Soil was inoculated with *Ralstonia* culture and then different rootstocks were transplanted in plots containing sick soil. After one month bacterial wilt incidence was recorded. The observations were recorded on bacterial wilt incidence at weekly intervals under natural conditions. (Plate 3.2 a & b)

$$\textbf{Bacterial wilt incidence (\%)} = \frac{\text{Number of infested plants}}{\text{Total number of plants established}} \times 100$$

3) Hoagland Solution (For quick results)

Reagents

a) 1 M KH_2PO_4 1 ml (1.36 g in 10 ml)

b) 1 M KNO_3 5 ml (1.01 g in 10 ml)

c) Ca $(NO_3)_2.4\ H_2O$ 5 ml (2.36 g in 10 ml).

d) Mg $SO_4.7H_2O$ 2 ml (2.46 g in 10 ml).

e) 65% Fe tarterate 1 ml.

f) Microelement stock solution 1 ml.

g) Distilled water 1000 ml.

Procedure for stock solution

Microelement stock solution (100 ml of water prepared)

H_3BO_3- 0.286 g

$MnCl_2.4\ H_2O$- 0.181 g

$ZnSO_4.7H_2O$- 0.022 g

$CuSO_4.5H_2O$- 0.008 g

$H_2MO_4.H_2O$- 0.002 g

Procedure

The seedlings were raised in cocopeat; perlite and vermiculite (3:1:1). Twenty day old seedlings of each variety were uprooted gently and roots of the plants were washed under the tap water to remove the adhered particles of soils and were rinsed with distilled water and plants were planted singly in test tubes having 30 ml sterilized Hoagland's solution. Three replications were made each for tomato, brinjal, chilli and local pumpkin plants. 10 ml of 2 day old bacterial culture was put in each flask. Test tubes were filled with stock solution and later 3 plants of each rootstock were inserted per tube and then plugged with cotton so that plants are held tightly in position and 1/3rd stem dipped in the nutrient solution. Each seedling was kept for stabilization in the Hoagland solution for a day at room temperature. Next day, each seedling was inoculated by pouring a drop of bacterial cell suspension (10^8 cfu/ml) on the 3rd leaf axil from top and stem of the plant was also pricked with the sterilized dissecting needle to allow drop of inoculum to enter the stem of seedling. Test tubes were incubated at room temperature (25 ± 1^0 C) and were monitored and inspected daily and filled with stock solution and appearance of wilt incidence was recorded on frequent basis for 25 days. (Plate 3.2 c).

Disease symptom and number of wilted plants were recorded on the basis of visible appearance of plant. The grading of disease was done by following the disease scale 0-5 as suggested by Winstead and Kelman (1952). The rating scale is as:

Rating

Plants did not show any wilt symptoms	Highly resistant (HR)
1 = 1-20 % plants wilted	Resistant (R)
2 = 21-40 % plants wilted	Moderately resistant (MR)
3 = 41-60 % plants wilted	Moderately Susceptible (S)
4 = 61-80 % plants wilted	Susceptibe (S)
5= More than 80% plants wilted	Highly Susceptible (S)

Plate 3.1: Preparation of inoculum/ bacterial suspension

Plate 3.2 a & b: Preparation of sick or infested soil for bacterial wilt reaction

Plate 3.2 c Rootstock screening under pot conditions for bacterial wilt reaction

Plate 3.2 d Rootstock screening under field conditions for bacterial wilt reaction

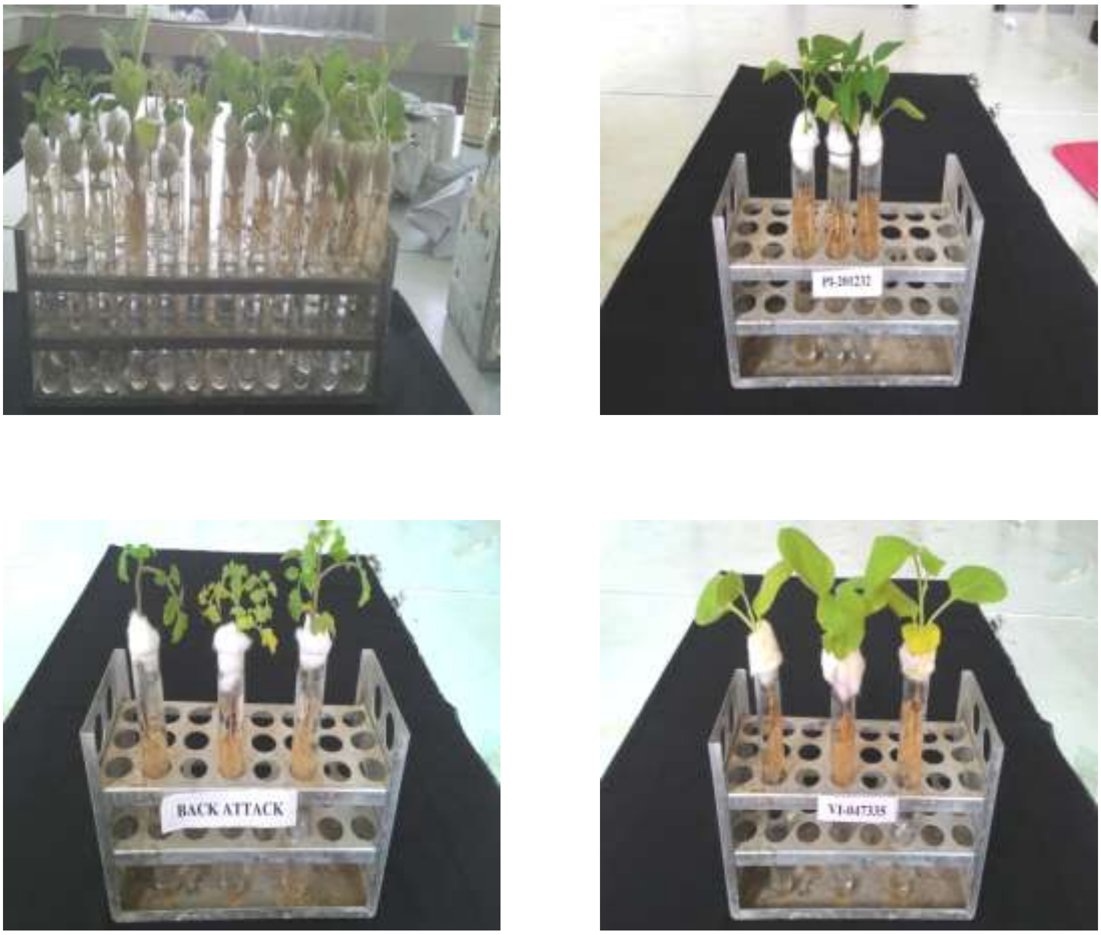


Plate 3.2 e Rootstock screening through Hoagland solution for bacterial wilt reaction

3.3. Nematode incidence.

Screening of rootstocks against nematode (*Meloidogyne icognita*)

The preliminary screening was done in pots filled with sterilised soil. Three to four seeds of each rootstock were sown in a pot, having 1 Kg of sterilized soil. After one week of germination, plants were thinned to one and J_2 of *Meloidogyne incognita* @ 1000 pots/ plant was inoculated in the rhizosphere of each plant. After 45 days of inoculation, plants were uprooted, washed gently under tap water, cut into small bits and examined under sterozoom microscope for the number of galls. Each rootstock was rated for their resistance/ susceptibility as per the following rating scheme given by (Gaur *et al*. 2001).

Rating

1 = No galls, no egg masses	Highly resistant (HR)
2 = 1-10 galls/ egg masses per plant	Resistant (R)
3 = 11-30 galls/ egg masses per plant	Moderately resistant (MR)
4 = 31-100 galls/ egg masses per plant	Susceptible (S)
5 = 101 and above egg masses per plant	Highly Susceptible (HS)

3.4 Materials and layout of the experiment

The experimental materials and plan used for the present study are presented here under the following heads:

3.4.1 Experimental material

The experimental materials used for the present study comprised of 16 different rootstocks and horticulturally superior scion GS-600 which was used as a scion at seedling stage. The different rootstocks used in the present studies were procured from world vegetable centre- Taiwan, CSKHPKV, Japan, Palampur and IIHR-Bengaluru (Table 3.4). Whereas, scion of tomato was a commercial private sector hybrid from Golden Seeds, UPL Ltd.

Plate 3.3a Soil sterilization for nematode reaction

Plate 3.3b Pot filling for nematode reaction

Plate 3.3c Seed sowing for nematode reaction

Plate 3.3d Rootstocks kept for screening

Plate 3.3e Rootstocks kept after washing

Rootstock- Green Gourd (Resistant) **Rootstock – LS-89 (Susceptible)**

Plate 3.3 f Roots showing gall formation

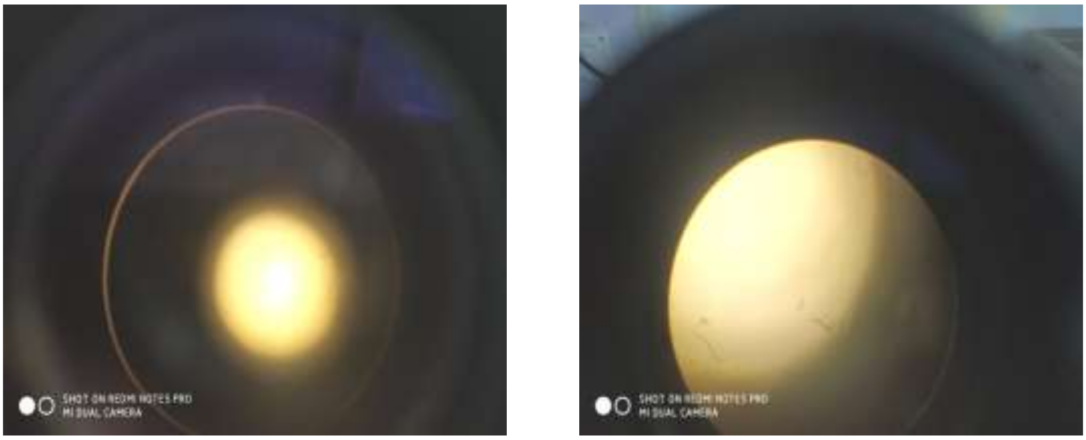


Plate 3.3g : Presence of nematodes under sterozoom microscope

Table 3.4: List of different rootstocks and scion cultivar

Rootstocks	Salient features	Source
Hawaii-7996 (Tomato)	Resistant to BW but susceptible to nematodes	World Vegetable Centre- Taiwan
Hawaii-7998 (Tomato)	Resistant to BW but susceptible to nematodes	World Vegetable Centre- Taiwan
V1-045376 (EG-203) (Brinjal)	Resistant to bacterial wilt but susceptible to nematodes	World Vegetable Centre, Taiwan
V1-047335 (EG-195) (Brinjal)	Resistant to bacterial wilt but moderately resistant to nematodes	World Vegetable Centre, Taiwan
AVPP0205 (Chilli)	Resistant to bacterial wilt & nematodes	World Vegetable Centre, Taiwan
PI-201232 (Chilli)	Resistant to bacterial wilt & nematodes	World Vegetable Centre, Taiwan
V1-034845 (Brinjal)	Resistant to both bacterial wilt & nematodes	World Vegetable Centre, Taiwan
Palam Pink (Tomato)	Resistant to bacterial wilt but highly susceptible to nematodes	CSKHPKV- Palampur
Palam Pride (Tomato)	Resistant to bacterial wilt but highly susceptible to nematodes	CSKHPKV- Palampur
LS-89 (Tomato)	Commercial rootstock and resistant to bacterial wilt but highly susceptible to nematodes	Japan
Green Gourd (Tomato)	Commercial rootstock and resistant to bacterial wilt & nematodes	Japan
Back attack (Tomato)	Commercial rootstock and resistant to bacterial wilt & susceptible to nematodes	Japan
Solanum torvum (Wild Brinjal)	Resistant to bacterial wilt but susceptible to nematodes	Japan
Arka Nidhi (Brinjal)	Resistant to bacterial wilt but susceptible to nematodes	IIHR- Bengaluru
Arka Keshav (Brinjal)	Resistant to bacterial wilt but susceptible to nematodes	IIHR- Bengaluru
Local Pumpkin	Resistant to bacterial wilt but susceptible to nematodes	Local collection
Scion (GS-600)	Fruits round with thick pericarp and have high TSS. The average yield under polyhouse conditions is 2-3kg/plant, But highly susceptible to bacterial wilt.	Golden Seeds Company, UPL Ltd

3.4.2 Grafting technique: Cleft grafting.

3.4.3 Experiment layout and design

Total forty nine treatments comprising of sixteen rootstocks and Control (non-grafted) were used. The grafted seedlings were transplanted in a Randomized Block Design (RBD) having three replications in a modified naturally ventilated quonset polyhouse of the size 25 m × 10 m at a spacing of 70 cm x 30 cm.

3.4.4 Nursery sowing of rootstocks and scion

The nursery of rootstocks and scion were raised in plastic plug trays having uniform size and cells of equal size using soil-less media (cocopeat: perlite: vermiculite) in the ratio of 3:1:1, respectively in the growth chamber of Department of Vegetable Science and Floriculture, CSKHPKV, Palampur. One seed was sown per cell by making small depression (0.5 cm) with finger so as to ensure that seed is kept in the centre of cell. Seeds of tomato, brinjal, chilli rootstocks were sown in plug trays having 98 small cells. While, seeds of pumpkin were sown in plug trays having 50 cells. Water was sprayed initially through rose can and trays were covered with net so that seeds do not come outside. Trays were regularly monitored and checked and on emergence of germination the net was removed. All the necessary precautions were observed for raising healthy seedlings.

Rootstocks were sown one week earlier than scion so that the diameter of both the stems matches with each other for ensuring successful grafting. For the first season trial sowing of rootstocks was done on 19th July 2017 and sowing of scion on 26th July 2017. For the second season trial rootstocks were sown on 7th February 2018 and sowing of scion was done on 15th February 2018. After 4-7 days of germination seedlings were sprayed with Polyfeed (19:19:19) @ 2g/lt for developing stronger stems and to ensure sturdiness. Fertigation was done twice a week to get healthy nursery. The seedlings were sprayed with water twice or thrice depending on climatic conditions. The seedlings were grown in plug trays so as to ensure that seedlings do not suffer transplanting shock. Optimum temperature was provided for germination. Tomato seedlings emerged in 15-20 days at 21-24^0 C, Brinjal in 25-30 days at 26-28^0 C while Chilli and Local Pumpkin at 24-30^0 C took 35-40 days and pumpkin completed germination in 7-8 days.

Plate 3.4 : Rootstocks ready for grafting

Plate 3.4 contd….

Plate 3.5 : Scion ready for grafting

3.4.5 Grafting

The scion variety GS-600 was grafted on various rootstocks using cleft grafting on attaining graftable height of 15-20 cm with stem thickness of 5-10 mm to ensure higher grafting success rate and compatibility. Scion seedlings were grafted on various rootstocks on 24th, 26th and 27th August 2017, while transplanting was done on 12th September 2017. Whereas, during 2018 seedlings were grafted on 12th, 14th and 15th April 2018 and transplanting was done on 24th May, 2018. Graft union was secured with a grafting clip or plastic tape to ensure good vascular connection and to ensure complete healing of grafted portions.

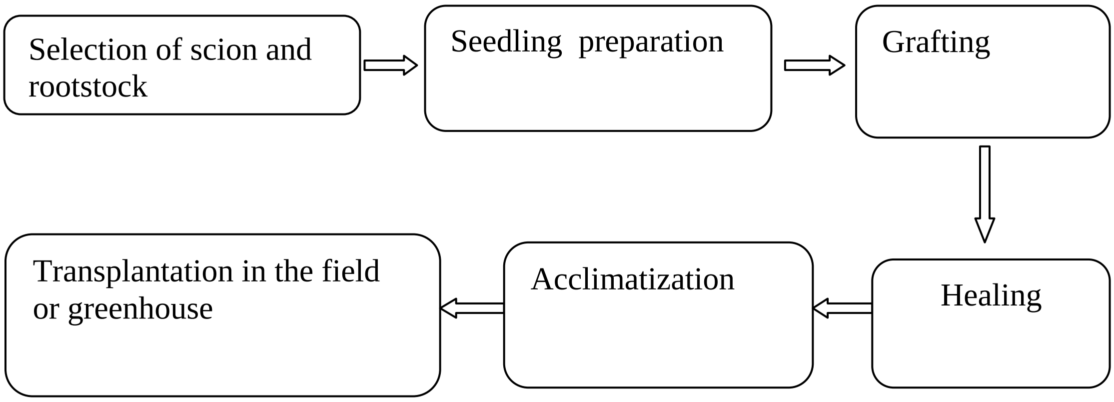


Fig 3.4.5 : Production process of grafted vegetable plantlets

3.4.6 Aftercare and handling

Immediately after grafting the plants were sprayed with water and were kept inside grafting chamber (healing chamber) for 3-4 days. Water was sprayed on grafted plants during day once or twice depending on weather conditions so as to avoid wilting and ensure complete healing. For successful healing of grafted seedlings reduced light intensity, moderate temperature (25-30^0 C) and high relative humidity (85-90%) are essential to establish good vascular connection and continue to grow as single plant. On an average tomato took 2-3 days, brinjal 3-5 days, chilli 5-7 days and local pumpkin 8-9 days for complete and strong vascular union when such conditions were maintained and care taken fully for a specific period of time. After completion of healing processes the plastic clips were removed from graft union so as to avoid cessation and stunted growth of plants.

Plate 3.6 : Grafted seedlings ready for transplanting in polyhouse

contd….

Plate 3.6 Contd….

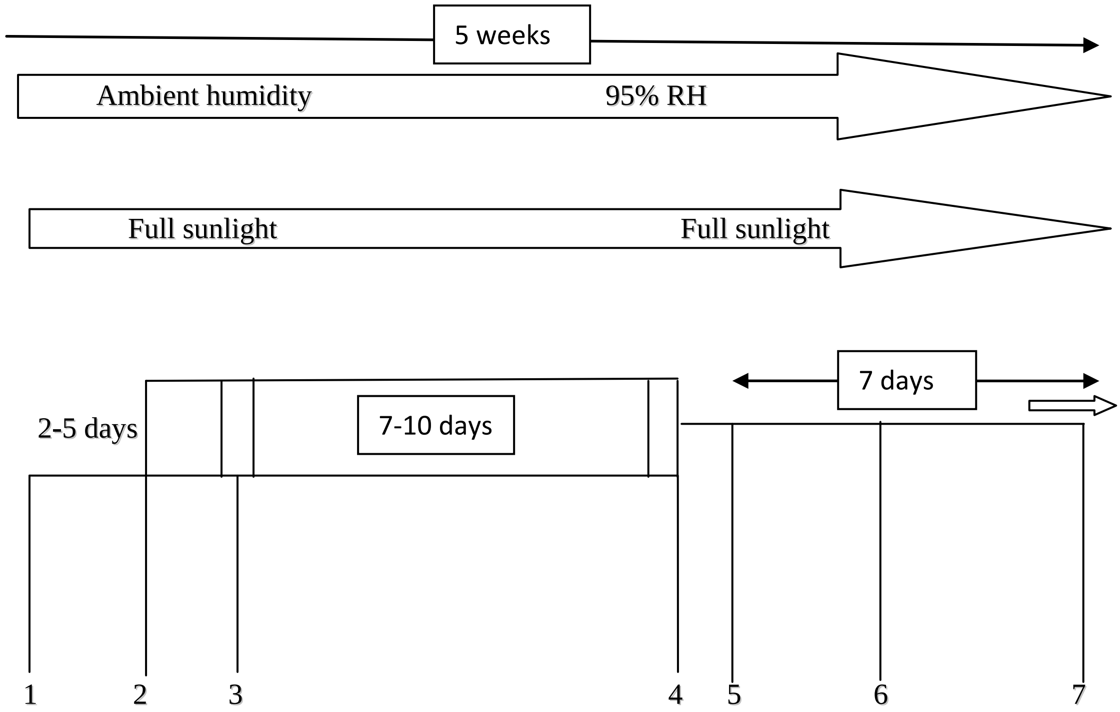
Contd….

Plate 3.6 Contd….

Plate 3.7 : Grafted plants kept inside healing chamber

3.4.7 Acclimatization

For acclimatization grafted seedlings were taken outside the healing chamber and kept under sunlight so as to provide hardening prior to transplanting and to reduce transplanting shock. On an average grafted seedlings took three to four days for complete acclimatization and later they were transplanted in well prepared beds inside naturally ventilated polyhouse.



1 Rootstock seed is planted

2 Scion seed is planted

3 Both scion and rootstock emerge within two days window

4 Grafts are made and moved into healing chamber

5 Shortly after normal turgor levels have returned, grafts can be exposed to indirect light

6 Grafted plants are moved into full light

7 Transplants are moved to field

Fig 3.4.7: A typical timeline for graft production.

Plate 3.8: Grafted plants kept for acclimatization

3.4.8 Bed preparation and transplanting

Total 6 terraces or beds were prepared having 54 plots. Well decomposed farmyard manure (FYM) @ 2 kg, urea @ 6 g, 12:32:16 @ 9 g and MOP @ 4 g were applied per plot before transplanting during both the seasons i.e. 2016-17 & 2017-18 through proper mixing by hand. In each pit one plant was planted and slightly pressed or moved without damaging the earth ball. Per plot twelve plants were raised. The beds were 2.40 m and 0.8 m wide. The gap of 60 cm was kept per plot and channels were made at a spacing of 0.8 × 0.6 cm.

3.4.9 Fertilizer application

Initially foliar application of water soluble fertilizer was done with care so as to avoid burning of leaves. Later fertigation was started after three weeks of transplanting with water soluble fertilizer N: P: K (19:19:19) @ 2.5 g/m^2. In initial stages fertilizer was applied twice a week and later at time of fruiting thrice a week. Fertigation was stopped 15 days prior to final harvest of fruits. Calcium was applied in the form of calcium chloride, twice or thrice @ 120 g to inhibit drying and wilting of flowers.

Cultural practices

The intercultural operations *viz.* hoeing, irrigation, weeding, cutting, pruning and staking were carried as per recommended package of practices to ensure a healthy crop growth and development. The crop was trained on two stems through nylon twine retaining two primary stems per plant. Proper staking and pruning were carried out at regular intervals to remove unwanted stems. Irrigation was applied through drips twice depending on crop requirement. Desuckering was also done simultaneously sometimes with pruning or when many suckers got established on plants growing from crown portion of plants especially from rootstock of plants so as to ensure good and proper growth of plants.

3.4.10 Plant protection

During first year the crop was sprayed with Dicofol (1%) and Pyromite (15ml/15l) thrice during plant growth and cropping period to protect the crop from mites. One yellow sticky trap was installed per 10 metre square. The primary purpose of installing yellow sticky traps was for control of mites, aphids and white flies. For the control of spodoptera or tobacco caterpillar Plethora was sprayed @ 15ml/10 lt of


Plate 3.9 a: Bed Preparation


Plate 3.9 b: Laying out mulch sheet

Plate 3.10 : Transplanted seedlings inside polyhouse

Plate 3.11: Transplanted seedlings one month after transplanting

Plate 3.12: Bacterial wilt symptoms in control plots after one month of transplanting

water. For powdery mildew control hexaconazol was sprayed @15ml/10 lt of water. During second season pyromite (15ml/15 l) was sprayed twice for control of mites and for whiteflies acetamiprid @ 15ml were sprayed.

3.5 Observations recorded

Five plants were randomly selected from each treatment in each replication for recording the data on following traits:

A. Horticultural traits:

(i) Days to first flowering

Days to first flowering were counted from the date of transplanting to the date of first flower opening in randomly 5 selected plants.

(ii) Days to first harvest

Days were counted from date of transplanting to the date when at least one ripe fruit was harvested in 5 randomly selected plants and average value was worked out.

(iii) Number of marketable fruits per plant

Total numbers of marketable fruits were calculated by adding the number of marketable fruits harvested in each picking.

(iv) Average fruit weight (g)

The average fruit weight was calculated by dividing the total marketable yield of five selected plants by total number of fruits.

(v) Marketable fruit Yield per plant (kg)

The fruits were harvested at different intervals of 5-7 days till last harvesting. Fruit yield per plant was calculated by adding yield of all pickings.

(vi) Fruit yield per meter square area (kg/m^2)

Yield per square metre area was calculated by counting the number of plants per square metre area and multiplied by yield per plant.

(vii) Fruit length (cm)

The length of five randomly selected fruits from each plot was measured with the help of vernier calliper and average was worked out.

(viii) Fruit width (cm)

The fruits which were selected for fruit length were also used to measure fruit width with the help of vernier calliper and average was worked out.

(ix) Harvest duration (days)

Numbers of days were counted from the first harvest upto final harvest of fruits and were averaged to calculate the total duration taken from all selected plants.

(x) Plant height (cm)

The plant height was measured from ground level to the tip of the main shoot after the last picking and later average was worked out.

B. Quality traits:

(i) Pericarp thickness (mm)

Pericarp thickness (mm) was measured from an equatorial section of the fruits with the help of vernier calliper and mean values were worked out for same fruits used to measure fruit length and fruit width.

(ii) Total soluble solids (^{O}Brix)

The total soluble solids content was determined with the help of 'Erma Hand Refractometer' using red ripe fruits by putting a drop of juice on the prism and taking the reading. The values recorded were expressed as per cent of juice (A.O.A.C. 1970).

(iii) Lycopene content (mg/100g)

Lycopene content of ripe tomato fruits was determined by 'Acetone-Ether Extraction Method' as suggested by Ranganna (2000).

Procedure

a) About 10 g of fresh tomato pulp was placed in a mortar

b) The lycopene pigment was extracted with acetone by thorough mixing with a pestle and the extract was transferred into a 500ml separation funnel containing 20ml of petroleum ether (bp 40-60°C) followed by 20ml of 5% sodium sulphate solution, where two layers appeared.

c) Extraction was repeated with different portions of petroleum ether until the product became colourless.

d) The lower part was separated and the petroleum ether with the lycopene was passed into a brown bottle containing 10g anhydrous sodium sulphate to absorb water and then kept aside for 30 minutes.

e) Petroleum ether extract was then decanted into 100ml volumetric flask.

f) Sodium sulphate slurry was washed with petroleum ether until it became colourless.

g) The extract was then transferred to a 100ml volumetric flask and made to volume with petroleum ether.

h) The absorbance of the petroleum ether extract was measured in a spectrophotometer (model Spectronic-Genesys 5) at 503nm using petroleum ether as blank.

Lycopene (mg/100g fruit pulp):

$$= \frac{3.1206 \text{ x absorbance x volume made up x dilution factor}}{1 \text{ x weight of sample x } 1000} \text{ x } 100$$

(iv) Titrable acidity (%)

Titrable acidity was determined according to A.O.A.C. 2000. Five grams of tomato juice diluted in 25ml of distilled water and titrated by 0.1N sodium hydroxide (NaOH) to pH 8.1. The titrable acidity was expressed as gram citric acid per kilogram of tomato, according to the following equation:

$$\text{Titrable acidity} = \frac{\text{Volume of NaOH required (ml) x 0.1 x1000x0.064}}{\text{Mass of tomato juice sample used (g)}}$$

Here, 0.1 is the normality of NaOH (N),

0.064 is the conversion factor for citric acid

Titrable acidity (%) = Titrable acidity (g citric acid per kg of tomato)/10.

(v) Ascorbic acid (mg/100g)

Ascorbic acid was determined according to the method suggested by ‘2, 6-dichlorophenol-indophenol Visual Titration Method’ as described by Rangana (1979). Freshly harvested red ripe fruits are taken for the estimation of ascorbic acid by volumetric method.

Reagents

a) **3% Metaphosphoric acid:** Prepared by dissolving the sticks of pellets of HPO_3 in glass distilled water.

b) **Ascorbic acid standard:** 100 mg of L-ascorbic acid was weighed and volume was made upto 100 ml with 3% HPO_3. 10 ml of this solution was further diluted to 100 ml with 3% HPO_3 (1 ml = 0.1 mg ascorbic acid).

c) **Dye solution:** 50mg of sodium salt of 2, 6-dichlorophenol-indophenol was dissolved in approximately 150 ml of hot glass distilled water containing 42 mg of sodium bicarbonate. The solution was cooled and diluted with glass distilled water to 200 ml and stored in refrigerator and standardized every day.

Procedure

Standardization of dye

5 ml of standard ascorbic acid solution was taken in a beaker and 5 ml of 3% HPO3 was added to it. This solution was titrated with the dye solution to a pink colour which persisted for 15 seconds. Dye factor (mg of ascorbic acid per ml of dye) was determined using the following formula:

Dye factor = 0.5/Titre

Here,

0.5 means 0.5 mg of ascorbic acid in 5 ml of 100 ppm standardized ascorbic acid solution.

Titre = Volume of dye used to neutralize 5 ml of 100 ppm standard ascorbic acid solution with 5 ml of metaphosphoric acid.

10 gram of macerated sample was blended with 3% HPO_3 volume was finally made upto 100 ml. Out of this, 10 ml solution was taken and titrated against 2, 6-dichlorophenol-indophenol dye till the appearance of rose pink colour which persisted for 15 seconds. The results thus, obtained were expressed in terms of ascorbic acid per 100 g of sample.

The ascorbic acid (mg/100g) was calculated by using the following formula:

$$\text{Ascorbic acid (mg/100g)} = \frac{\text{Titre x Dye factor x Volume made up}}{\text{Aliquot of extract taken for estimation x Weight of sample taken for estimation}} \times 100$$

Here,

Titre = Volume of dye used to titre the aliquot of extract of a given sample.

(vi) Fruit Firmness (kg/cm^2)

Five red ripe fruits from randomly selected plants were taken and firmness was measured with the help of Penetrometer FT-327. It consists of flat head cylindrical probe made up of stainless steel. Penetration began at the contact of probe to the tomato surface and finishes when the probe penetrated the tissues to the depth of 8 mm. The point where needle stopped was recorded as the value for the fruit firmness. Each tomato fruit was punctured three times around the equatorial area and mean values were worked out.

(vii) Organoleptic test

Fruits at the time of harvesting were provided to five persons for tasting. The respondents did not show any variation in the taste and fruits were categorized as sweet to slightly acidic.

3.6 Grafting success rate (%) Grafting success rate was calculated as:

Number of survived plants/ Total number of grafted plants x 100

3.7 Statistical analysis

Average values for each genotype in each replication for the traits studied were used for further statistical analysis. A brief outline of the procedure adopted for estimation of statistical parameters is given below.

The table for analysis of variance (ANOVA) was set as explained by Panse and Sukhatme (1984).

Table 3.5 Analysis of variance for simple RBD

Source of variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	**F ratio**	**Expected Mean Squares**
Replications (r)	(r-1)	S_r	Mr = S_r/(r-1)	Mr/Me	σ^2e + gσ^2r
Rootstocks (g)	(g-1)	S_g	Mg = S_g/(g-1)	Mg/Me	σ^2e + rσ^2g
Error (e)	(r-1) (g-1)	S_e	Me = S_e/(r-1) (g-1)		σ^2e
Total	(rg-1)	-			

where,

r = Number of replications

g = Number of rootstocks

σ^2r = Variance due to replication = Mr

σ^2g = Variance due to rootstocks = Mg

σ^2e = Error variance = Me

The replications and entries mean sum of squares were tested against error mean squares by 'F' test for (r-1), (r-1)(g-1) and (g-1), (r-1)(g-1) degree of freedom at P=0.05. From this analysis, the following standard errors were calculated, where the 'F' test was significant.

Table 3.6 The pooled over environment was done as per following analysis of variance.

Source of variation	Df	Mean sum of square	Expected mean sum of square
Replications(within environments)	E(r-1)	Mr	-
Environments	(E-1)	ME	
Rootstocks	(g-1)	Mg	σ^2e + r σ^2g × E + rEσ^2g
Rootstocks × Environment	(g-1)(E-1)	Mg × E	σ^2e + r σ^2g × E
Pooled error	E(g-1)(r-1)	Me(C)	σ^2e

Where,

r	=	number of replications,
E	=	number of environments,
g	=	number of rootstocks,
$\sigma^2 e$	=	Error variance,
$\sigma^2 g \times E$	=	Variance due to rootstocks × environment interactions, and
$\sigma^2 g$	=	Variance due to rootstocks.

$$Me(C) = \frac{(\text{Error ss at Env. I} + \text{Error ss at Env. II})}{(\text{df at Env. I} + \text{df at Env. II})}$$

The replications (within environments), environments, rootstocks, rootstocks × environment mean sum of square were tested against pooled error mean squares by 'F' test for E (r-1), E (g-1) (r-1); (E-1), E(g-1) (r-1); (g-1), E(g-1) (r-1) and (g-1) (E-1), E (g-1) (r-1) degree of freedom at P = 0.05, respectively.

From these analysis, the following standard errors were calculated where the 'F' test was significant.

Standard error for the entry mean:

SE (m) = Individual environment = $\pm$ $(Me/r)^{1/2}$

Pooled environment = $\pm$ $(Me(C)/rE)^{1/2}$

Standard error for the difference of entry mean:

SE(d) for individual environment = $\pm$ $(2Me/r)^{1/2}$

SE(d) for pooled environment = $\pm$ $(2Me(C)/rE)^{1/2}$

The critical difference (CD) at 5 per cent level of significance was obtained by multiplying SE(d) by the table value of 't' at error degree of freedom and P = 0.05.

CD = SE (d) × t' value at error degree of freedom and P = 0.05

Coefficient of variation (CV) % = ($Me^{1/2}$ or $Me(C)^{1/2}$/general mean) × 100.

4. RESULTS AND DISCUSSION

The experiment entitled "Evaluation of rootstocks for biotic stress management in tomato under protected conditions" was carried out at Vegetable Research, Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur during Rabi and Kharif seasons (2016-17 and 2017-18) under protected environment. Out of sixteen rootstocks only thirteen rootstocks were found compatible with scion GS-600, whereas three rootstocks viz., PI-201232, AVPP0205 and Local pumpkin did not show compatibility. However, initially they showed some growth but later on their growth was ceased. Therefore, only one parameter i.e. plant height was observed on plants grafted on these rootstocks, whereas other parameters could not be recorded due to poor stock-scion compatibility. The results have been discussed under the following heads:

4.1 Bacterial wilt incidence (%)

4.2 Nematode incidence

4.3 Horticultural traits

4.3.1 Days to first flowering

4.3.2 Days to first harvest

4.3.3 Number of marketable fruits per plant

4.3.4 Average fruit weight (g)

4.3.5 Marketable fruit yield per plant (kg)

4.3.6 Marketable fruit yield per square meter (kg)

4.3.7 Fruit length (cm)

4.3.8 Fruit width (cm)

4.3.9 Harvest duration (days)

4.3.10 Plant height (cm)

4.4 Quality traits

4.4.1 Pericarp thickness (mm)

4.4.2 Fruit Firmness (kg/cm^2)

4.4.3 Total soluble solids (^{0} Brix)

4.4.4 Ascorbic acid (mg/100g)

4.4.5 Titrable acidity (%)

4.4.6 Lycopene (mg/100g)

4.4.7 Organoleptic test

4.5 Grafting success rate (%)

4.6 Cost of cultivation

4.1 Bacterial wilt incidence (%)

Bacterial wilt is a soil borne disease of tomato caused by *Ralstonia solanacearum.* (Sikirou *et al*. 2004). It appears initially on younger leaves and slowly the plant dies. When environmental conditions are favorable, rapid and complete wilting soon follows after 2-3 days after the appearance of initial symptoms. The economic losses up to 90% have been reported on tomatoes and potatoes (Mallikarjun and Byadagi, 2008). Severity of the disease increases mostly if root nematodes are found in close association with *Ralstonia solanacearum* (Deberdt *et al*. 1999).

All the sixteen rootstocks were found resistant for bacterial wilt incidence under both pot and field conditions after screening and did not exhibit wilting symptoms and showed good plant growth, vigour and increased yield. Whereas, scion GS-600 was found as highly susceptible variety for bacterial wilt.

Table 4.1 Screening of rootstocks of tomato, brinjal, chilli and local pumpkin for bacterial wilt incidence

Sr. No.	Rootstocks	Reaction	
		Pots condition	Field condition
Tomato			
1	Hawaii-7998	Resistant	Resistant
2	Hawaii-7996	Resistant	Resistant
3	Back Attack	Resistant	Resistant
4	Green Gourd	Resistant	Resistant
5	LS-89	Resistant	Resistant
6	Palam Pink	Resistant	Resistant
7	Palam Pride	Resistant	Resistant
Brinjal			
8	VI-34845	Resistant	Resistant
9	Arka Nidhi	Resistant	Resistant
10	Arka Keshav	Resistant	Resistant
11	VI-47335 (EG-195)	Resistant	Resistant
12	VI-45376 (EG-203)	Resistant	Resistant
13	*Solanum torvum*	Resistant	Resistant
Chilli			
14	AVPP0205	Resistant	Resistant
15	PI-201232	Resistant	Resistant
Pumpkin			
16	Local Pumpkin	Resistant	Resistant
Scion	GS-600	Highly susceptible	Highly susceptible

4.2 Screening of rootstocks for nematode resistance

Sixteen rootstocks were screened for nematode resistance out of which four rootstocks were found to be resistant and one showed moderately resistance.

Root-knot nematodes, *Meloidogyne* spp. causes high level of economic losses in wide range of agricultural crops worldwide (Siguenza *et al*. 2005). Root-knot is predominantly caused by four *Meloidogyne* species i.e, *Meloidogyne incognita, Meloidogyne arenaria, Meloidogyne javanica and Meloidogyne hapla*. They are regarded as one of the most important polyphagous pests and have great impact on health, yield and quality of the crop.

Total sixteen rootstocks were screened for nematode resistance, out of seven rootstocks of tomato one rootstock Green Gourd showed resistance, whereas out of six brinjal rootstocks one rootstock VI-34845 exhibited resistance, four were susceptible and one rootstock VI-47335 showed mild resistance. Two chilli rootstocks viz., AVPP0205 and PI-201232 were found resistant. One rootstock of local pumpkin was recorded as susceptible to *Meliodogyne incognita*.

Table 4.2 Screening of rootstocks of tomato, brinjal, chilli and local pumpkin against *Meliodogyne incognita*.

Sr. No.	Rootstocks	RKI after 45 days of inoculation	Reaction
Tomato			
1	Hawaii-7998	37	Susceptible
2	Hawaii-7996	78	Susceptible
3	Back Attack	35	Highly Susceptible
4	Green Gourd	1	Resistant
5	LS-89	157	Susceptible
6	Palam Pink	93	Susceptible
7	Palam Pride	39	Susceptible
Brinjal			
8	VI-34845	5	Resistant
9	Arka Nidhi	35	Susceptible
10	Arka Keshav	31	Susceptible
11	VI-47335 (EG-195)	16	Moderately Resistant
12	VI-45376 (EG-203)	62	Susceptible
13	*Solanum torvum*	75	Susceptible
Chilli			
14	AVPP0205	3	Resistant
15	PI-201232	2	Resistant
Pumpkin			
16	Local Pumpkin	56	Susceptible

Results/conclusion (Table 4.2):

Crop	Total rootstocks	Highly Resistant	Resistant	Moderately Resistant	Susceptible	Highly Susceptible
Tomato	**7**	**0**	**1**	**0**	**5**	**1**
Brinjal	**6**	**0**	**1**	**1**	**4**	**0**
Chilli	**2**	**0**	**2**	**0**	**0**	**0**
Local Pumpkin	**1**	**0**	**0**	**0**	**1**	**0**

Plate 4.1 General view of experimental crop

Plate 4.2 : Scion-rootstock incompatibility between chilli rootstocks and tomato scion

Plate 4.3: Rootstock and scion incompatibility between local pumpkin and tomato scion

4.3 Horticultural traits

4.3.1 Days to first flowering

Earliness in flowering is desirable to get early crop in the market to ensure maximum returns and is considered as a major attribute in deciding the formation of fruit and its appropriate harvesting time so as to get better yield both in terms of quantity and quality. Moreover, this can also have a direct impact on fruit quality, as quality of fruits play an indispensable role in seeking attention of the consumers.

Days to first flowering were significantly affected by the different rootstocks used in the study. Data shown in Table 4.3 clearly depicts that in the year 2016-17 plants grafted on the rootstock LS-89 took minimum number of days (32.00) to produce first flower as compared to control (34.00) which were two days earlier in flowering than non-grafted. Rootstock Back Attack took maximum number of days (40.00) to produce the first flower. In the year 2017-18 plants grafted on rootstock Arka Keshav were earlier to produce the first flower and the duration taken to produce the first flower was 22.67days. Rootstocks viz., Arka Keshav i.e. LS-89 (24.00 days), VI-45376 (24.33 days), Back attack (24.67 days), Palam Pink (25.00 days), Hawaii-7996 (25.34 days),VI-34845 (25.67 days), Palam Pride (26.00 days), *Solanum torvum* (26.33 days), VI-47335 (26.50 days) and Hawaii-7998 (26.80 days) were statistically at par for days to first flowering. Non-grafted plants produced first flower in 27 days, thus, they took 4.33 days more than the grafted plants. Rootstock Arka Nidhi was late in flowering as compared to other rootstocks with 32 days.

The pooled analysis of data showed that plants grafted on rootstock LS-89 were earlier in flowering with 28.00 days which were statistically at par with Arka Keshav (29.00 days), VI-45376 (29.52 days), Palam Pink (29.90 days), Hawaii-7996 (29.96 days) and VI-47335 (30.42days). Non-grafted plants took 30.50 days to produce the first flower which were 2.5 days later than the grafted plants (28.00). Rootstock Green Gourd took maximum number of days (33.45) and was late in flowering.

Table 4.3 Effect of rootstocks on days to first flowering of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	40.00	24.67	32.33
Palam Pride (Tomato)	35.60	26.00	30.80
Palam Pink (Tomato)	34.80	25.00	29.90
Hawaii-7998 (Tomato)	34.75	26.80	30.78
Green Gourd (Tomato)	36.89	30.00	33.45
Hawaii-7996 (Tomato)	34.58	25.34	29.96
LS-89 (Tomato)	32.00	24.00	28.00
VI-34845 (Brinjal)	37.00	25.67	31.33
Arka Nidhi (Brinjal)	34.67	32.00	33.33
Arka Keshav (Brinjal)	35.33	22.67	29.00
Solanum torvum (Brinjal)	35.68	26.33	31.00
VI-47335 (Brinjal) (EG-195)	34.33	26.50	30.42
VI-45376 (Brinjal) (EG-203)	34.70	24.33	29.52
Control (GS-600)	34.00	27.00	30.50
CD (0.05)	1.81	4.21	2.45
CV (%)	3.74	11.90	5.85

The grafted plants were earlier in flowering due to the use of efficient, improved and vigorous rootstocks, which might have resulted in increase of both water and nutrient uptake more efficiently than the non-grafted plants. Early flowering leads to more number of fruits/flowers thereby, ensuring early crop which may fetch more prices in the market .These results are in conformity with the findings of Ibrahim et al. (2014) and Khah (2011).

4.3.2 Days to first harvest

Earliness in terms of yield plays a vital role in securing higher returns which is directly correlated by the days taken from transplanting to the first harvest (Tamilselvi and Pugalendhi, 2017).

As per Table 4.4 during 2016-17 plants grafted on rootstock LS-89 took minimum days 56.76 starting from transplanting stage to first harvest and were 13.68 days earlier in producing first harvest than control plots which took 70.44 days followed by VI-45376 (63.11 days),Hawaii-7998 (63.55 days), Hawaii-7996 (65.18

days) and VI-47335 (69.77 days). Maximum days for first harvest were taken by the rootstock Back attack (84.59 days).

Plants grafted on rootstock Arka Keshav produced first harvest in 53.11 days and were earlier by 16.55 days to non-grafted plants which recorded first picking in 69.66 days during 2017-18 followed by rootstocks VI-45376 (55.40 days), VI-47335 (56.14 days) and Hawaii-7998 (57.07 days).

Pooled analysis of data showed that plants grafted on rootstock LS-89 produced first harvest in 57.88 and was at par with rootstock VI- 45376 with 59.26 days. Maximum days to first harvest were taken by rootstock Green Gourd (75.50 days).

Table 4.4 Effect of rootstocks on days to first harvest of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	84.59	60.33	72.46
Palam Pride (Tomato)	73.48	66.88	70.18
Palam Pink (Tomato)	76.44	66.55	71.50
Hawaii-7998 (Tomato)	63.55	57.07	60.31
Green Gourd (Tomato)	77.00	74.00	75.50
Hawaii-7996 (Tomato)	65.18	73.99	69.59
LS-89 (Tomato)	56.76	59.00	57.88
VI-34845 (Brinjal)	81.63	66.03	73.83
Arka Nidhi (Brinjal)	72.00	74.12	73.06
Arka Keshav (Brinjal)	82.00	53.11	67.56
Solanum torvum (Brinjal)	76.55	73.33	74.94
VI-47335 (Brinjal) (EG-195)	69.77	56.14	62.96
VI-45376 (Brinjal) (EG-203)	63.11	55.40	59.26
Control (GS-600)	70.44	69.66	70.12
CD (0.05)	2.58	1.88	1.47
CV (%)	2.57	2.17	1.57

During 2016-17 plants were grafted during July-August and experiment was laid out in September which took maximum number of days to first harvest due to lower temperature in the month of December-January as compared to 2017-18.

Grafted plants were earlier in harvest because of successful interactions between rootstocks and scion which ensures full compatibility, capacity of great assimilations of photosynthates, better nutrient use efficiency as rootstocks have strong and vigorous root system, thus, there is proper translocation of water and nutrients throughout the plant system, and proper functioning or utilization of hormones which may have resulted in healthy plant growth. The use of efficient, vigorous rootstocks also helped in deciding the extent of earliness. These results found similarity with the findings of Bogoescu and Doltu, 2015, Gisbert et al. (2011), Ibrahim et al. (2014), Khah et al. (2006) and Velkov and Pevicharova, 2016.

4.3.3 Number of marketable fruits per plant

Number of fruits is an important factor which contributes remarkably for total yield on a plant or per hectare basis. To obtain higher yield number of fruits per plant should be more with marketable quality and fruit weight.

Rootstocks significantly affected the number of fruits per plant as evident from the (Table 4.5). Plants grafted on rootstock Green Gourd produced maximum number of marketable fruits per plant (24.33) during 2016-17 which was statistically at par with Palam Pride (22.67). Whereas, in 2017-18 highest number of marketable fruits per plant were also observed in plants grafted on rootstock Green Gourd (23.00) which were at par with Arka Keshav (22.67), Back Attack (22.33), VI-45376 (22.33), *Solanum torvum* (22.67), LS-89 (22.67), Palam Pride (21.33) and VI-47335 (21.00). Pooled analysis of data also showed maximum number of fruits per plant in plants grafted on rootstock Green Gourd (23.67) followed by VI-45376 (22.17), *Solanum torvum* (21.67), Arka Keshav (21.17), and VI-47335 (21.17). Non-grafted plants recorded 32.40% less number of marketable fruits than grafted. The increased number of marketable fruits in grafted plants as compared to non- grafted was due to use of vigorous rootstocks which led to improvement of cytokinin content in scion which ultimately improved fruit load on the plants. Similar findings were also reported by Fernandez et al (2013), Kumar et al (2017),Rahmatian et al (2014), Tamilselvi and Pugalendhi, (2017) and Velkov and Pevicharova, 2016.

Table 4.5 Effect of rootstocks on number of marketable fruits per plant of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	21.33	22.33	21.83
Palam Pride (Tomato)	22.67	21.33	22.00
Palam Pink (Tomato)	21.67	19.33	20.50
Hawaii-7998 (Tomato)	19.67	20.33	20.00
Green Gourd (Tomato)	24.33	23.00	23.67
Hawaii-7996 (Tomato)	20.00	18.33	19.17
LS-89 (Tomato)	19.00	22.67	20.83
VI-34845 (Brinjal)	19.33	18.00	18.65
Arka Nidhi (Brinjal)	20.67	17.33	19.00
Arka Keshav (Brinjal)	19.67	22.67	21.17
Solanum torvum (Brinjal)	20.67	22.67	21.67
VI-47335 (Brinjal) (EG-195)	21.33	21.00	21.17
VI-45376 (Brinjal) (EG-203)	22.00	22.33	22.17
Control (GS-600)	15.33	16.67	16.00
CD (0.05)	1.78	2.23	1.49
CV (%)	6.33	7.87	5.28

4.3.4 Average fruit weight (g)

Rootstocks had significant effects on average fruit weight of tomato during both the years (Table 4.6). Plants grafted on rootstock Green Gourd recorded highest average fruit weight (90.83 g) followed by rootstock Palam Pride (88.66 g) during 2016-17. Whereas, plants grafted on rootstock Green Gourd also recorded highest average fruit weight (92.17 g) during 2017-18 followed by Palam Pride (85.85 g), Arka Keshav (84.25 g), LS-89 (81.15 g), Palam Pink (80.70 g) and Hawaii-7998 (80.67 g). Similarly, pooled analysis of data also showed maximum average fruit weight in plants grafted on rootstock Green Gourd (91.50 g) which was followed by Palam Pride (87.25 g), Arka Keshav (85.34 g), Palam Pink (81.88 g) and VI-45376 (80.33 g). Non-grafted plants recorded 24.06 % less fruit weight in comparison to grafted ones.

Higher average fruit weight in grafted plants might be due to interactions between rootstocks and scion which influenced more efficient uptake of minerals, water and nutrients throughout the plant system. Results are supported by the conclusions drawn from the findings of Fernandez et al. (2013), Moncada et al. (2013), Rahmatian et al. (2014) and Riga, 2015.

Table 4.6 Effect of rootstocks on average fruit weight (g) of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	77.85	79.00	78.43
Palam Pride (Tomato)	88.66	85.85	87.25
Palam Pink (Tomato)	83.06	80.70	81.88
Hawaii-7998 (Tomato)	76.76	80.67	78.72
Green Gourd (Tomato)	90.83	92.17	91.50
Hawaii-7996 (Tomato)	82.00	78.01	80.00
LS-89 (Tomato)	78.42	81.15	79.79
VI-34845 (Brinjal)	79.67	76.67	78.17
Arka Nidhi (Brinjal)	70.15	75.00	72.58
Arka Keshav (Brinjal)	86.43	84.25	85.34
Solanum torvum (Brinjal)	73.00	75.98	74.49
VI-47335 (Brinjal) (EG-195)	72.67	74.76	73.72
VI-45376 (Brinjal) (EG-203)	82.72	77.93	80.33
Control (GS-600)	69.79	68.98	69.48
CD (0.05)	2.22	1.95	1.60
CV (%)	1.96	1.75	1.42

4.3.5 Marketable fruit yield per plant (kg)

It is apparent from the data presented in the Table 4.7 that different rootstocks affected the fruit yield per plant significantly. Plants grafted on rootstock Green Gourd produced maximum fruit yield per plant (2.21 kg) followed by Palam Pride (2.01 kg), VI-45376 (1.82 g) and Palam Pink (1.80 g).

In the year, 2017-18 maximum fruit yield was also recorded in plants grafted on rootstock Green Gourd (2.12 kg) which was followed by Arka Keshav (1.91 kg), LS-89 (1.84 kg) and Palam Pride (1.83 kg). Pooled analysis of data showed that plants grafted on rootstock Green Gourd resulted in maximum yield per plant (2.16 kg) followed by Palam Pride (1.92kg), Arka Keshav (1.80kg) and VI-45376 (1.78 kg). Thus, grafted plants produced 48.61% more yield than non-grafted.

Table 4.7 Effect of rootstocks on marketable fruit yield per plant (kg) of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	1.66	1.76	1.71
Palam Pride Tomato)	2.01	1.83	1.92
Palam Pink Tomato)	1.80	1.56	1.68
Hawaii-7998 Tomato)	1.51	1.64	1.58
Green Gourd Tomato)	2.21	2.12	2.16
Hawaii-7996 Tomato)	1.64	1.43	1.54
LS-89 Tomato)	1.49	1.84	1.67
VI-34845 (Brinjal)	1.54	1.38	1.46
Arka Nidhi (Brinjal)	1.45	1.30	1.38
Arka Keshav (Brinjal)	1.70	1.91	1.80
Solanum torvum Brinjal)	1.51	1.72	1.61
VI-47335 (Brinjal) (EG-195)	1.55	1.57	1.56
VI-45376 (Brinjal) (EG-203)	1.82	1.74	1.78
Control (GS-600)	1.07	1.15	1.11
CD (0.05)	0.03	0.02	0.02
CV (%)	1.43	1.18	1.02

The differences in yield response observed may be due to method of grafting, different growth characteristics of cultivars and different response to grafting, growth period and compatibility of rootstock and scions. Higher yield in grafted plants is attributed to resistance provided by the rootstocks against soil borne diseases (Bacterial wilt & Nematodes), better absorption and translocation of phosphorus, nitrogen, magnesium and calcium which leads to improved nutrient uptake as rootstocks have well developed and strong root systems which release more cytokinins into the xylem sap resulting in increased yield and also due to increased the rate of photosynthesis Similar findings were reported by Aloni et al. (2010), Bogoescu and Doltu , (2015), Blestos et al. (2003), Lee. (1994), Marsiac and Osvald, (2004) and Pulgar et al. (2000).

Plate 4.4 : Plants at Green Fruiting stage Plants at Red ripe stage

4.3.6 Marketable fruit yield per square metre (kg)

From the Data presented in the Table 4.8 it is inferred that rootstocks exerted significant influence on yield per square metre. During 2016-17, Maximum yield per square metre was obtained in plants grafted on rootstock Green Gourd (26.52 kg) followed by Palam Pride (24.12), VI-45376 (21.84 kg), Palam Pink (21.60 kg) and Arka Keshav (20.40 kg).

In the year, 2017-18 maximum yield per square metre was also reported in plants grafted on rootstock Green Gourd (25.44 kg) followed by Arka Keshav (22.92 kg), LS-89 (22.08 kg), VI-45376 (20.88 kg) and *Solanum torvum* (20.64 kg). Pooled analysis of data also showed maximum yield per square metre in the rootstock Green Gourd (25.92 kg) followed by Palam Pride (23.04 kg), Arka Keshav (21.66 kg), VI-45376 (21.36 kg), Back Attack (20.52 kg) and LS-89 (20.04 kg). Grafted plants produced 48.61% more yield per square metre than non-grafted.

Table 4.8 Effect of rootstocks on marketable yield per square metre (kg) of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack	19.92	21.12	20.52
Palam Pride	24.12	21.96	23.04
Palam Pink	21.60	18.72	20.16
Hawaii-7998	18.12	19.68	18.90
Green Gourd	26.52	25.44	25.92
Hawaii-7996	19.68	17.16	18.42
LS-89	17.88	22.08	20.04
VI-34845	18.48	16.56	17.52
Arka NIdhi	17.40	15.60	16.50
Arka Keshav	20.40	22.92	21.66
Solanum torvum	18.12	20.64	19.38
VI-47335 (EG-195)	18.60	18.84	18.72
VI-45376 (EG-203)	21.84	20.88	21.36
Control (GS-600)	12.84	13.80	13.32
CD (0.05)	0.96	1.18	0.74
CV (%)	5.04	6.25	3.90

The higher marketable yield obtained by grafting was due to an improvement in water and nutrient uptake by the vigorous rootstocks more efficiently, prolonged harvest duration, earliness in flowering and fruiting, increased fruit weight, number of fruits per plant, rootstock scion combinations, or due to low sunlight and low carbon-dioxide content in greenhouses during winter months.. These results are in conformity with the findings of Alvarado et al (2017), Al-Harbi et al (2016), Kumar et al (2017), Kyriacou et al (2017),Rahmatian et al (2014) and Turkmen et al (2010).

Plate 4.5 : Top high yielding rootstocks

4.3.7 Fruit length (cm)

Plants grafted on rootstock Palam Pink produced 5.69 cm long fruits and were 0.82 cm longer as compared to non-grafted plants which recorded fruit length of 4.22 cm during 2016-17 (Table 4.9) followed by Hawaii-7998 (5.63 cm), Green Gourd (5.30 cm), Palam Pride (5.20 cm) and Back Attack (5.14 cm).

Similarly, in the year 2017-18 plants grafted on rootstock Palam Pink also recorded maximum fruit length of 5.29 cm and produced 10.20% cm longer fruits than non-grafted plants. Rootstocks viz., LS-89 (5.05 cm) and Palam Pride (4.91 cm) were statistically at par with Palam Pink. The pooled analysis of data also observed longest fruits in Palam Pink rootstock (5.29 cm) which was statistically at par with Hawaii-7998 (4.71 cm).

Table 4.9 Effect of rootstocks on fruit length (cm) of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	5.14	5.00	5.07
Palam Pride (Tomato)	5.20	4.91	5.05
Palam Pink (Tomato)	5.69	5.29	5.49
Hawaii-7998 (Tomato)	5.63	4.71	5.20
Green Gourd(Tomato)	5.30	4.77	5.04
Hawaii-7996 (Tomato)	4.53	4.89	4.71
LS-89 (Tomato)	4.94	5.05	5.00
VI-34845 (Brinjal)	4.65	4.60	4.58
Arka Nidhi (Brinjal)	4.81	4.43	4.62
Arka Keshav (Brinjal)	4.89	4.38	4.63
Solanum torvum (Brinjal)	4.84	4.78	4.81
VI-47335(Brinjal) (EG-195)	4.73	4.46	4.60
VI-45376 (Brinjal) (EG-203)	4.60	4.84	4.53
Control (GS-600)	4.22	4.50	4.55
CD (0.05)	0.48	0.39	0.35
CV (%)	7.15	5.91	5.23

Fruit length was significantly affected by different rootstocks in both the years 2016-17 & 2017-18 as well as in the pooled data. The fruit length in grafted plants increased due to vigorous root systems of rootstocks which might have resulted in increased efficiency of water and nutrient composition or due to better utilization of endogenous hormones.These results are in conformity with Gisbert et al, (2011), Khah et al (2006), Leonardi and Giuffrida, (2006), Schwarz et al (2013), Tamilselvi and Pugalendhi, (2017) and Turhan et al (2011).

4.3.8 Fruit width (cm)

Maximum fruit width was recorded in the plants grafted on rootstock Palam Pink (6.59 cm) during 2016-17 which were observed statistically at par with Hawaii-7998(6.46 cm), Green Gourd (6.31 cm), LS-89 (6.01 cm) and Back Attack (5.92 cm). Non- grafted plants resulted in fruit width of 5.00 cm and thus, they had 0.92 cm less fruit width than the plants grafted on Palam Pink rootstock (Table 4.10). Whereas, in 2017-18 maximum fruit width of 5.39 cm was also observed in rootstock Palam Pink. Rootstocks viz., Back Attack (5.41 cm), Palam Pride (5.37 cm), *Solanum torvum* (5.35 cm), VI-45376 (5.27 cm), LS-89 (5.17 cm), Hawaii-7996 (5.40 cm), VI-34845 (5.24 cm), Arka Nidhi (5.20 cm) and Hawaii-7998 (5.07 cm) were statistically at par for fruit width.

Table 4.10. Effect of rootstocks on fruit width (cm) of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	5.92	5.41	5.67
Palam Pride (Tomato)	5.55	5.37	5.46
Palam Pink (Tomato)	6.59	5.39	5.99
Hawaii-7998 (Tomato)	6.46	5.07	5.76
Green Gourd (Tomato)	6.31	4.85	5.58
Hawaii-7996 (Tomato)	5.42	5.40	5.41
LS-89 (Tomato)	6.01	5.17	5.59
VI-34845 (Brinjal)	5.15	5.24	5.20
Arka Nidhi (Brinjal)	5.24	5.20	5.22
Arka Keshav (Brinjal)	5.45	5.02	5.23
Solanum torvum (Brinjal)	5.19	5.35	5.27
VI-47335(Brinjal) (EG-195)	5.45	4.86	5.15
VI-45376 (Brinjal) (EG-203)	5.22	5.27	5.24
Control (GS-600)	5.00	4.80	4.90
CD (0.05)	0.87	0.37	0.48
CV (%)	11.34	5.22	6.59

Similarly, in pooled analysis of data maximum fruit width of 5.99 cm was observed in plants grafted on rootstock Palam Pink. Other rootstocks found statistically at par with Palam Pink were Hawaii-7998 (5.76 cm), Back Attack (5.67 cm), LS-89 (5.59 cm) and Green Gourd (5.58 cm).The possible reasons for increased fruit width in grafted plants may be attributed to differences in vigour of the rootstocks as some rootstocks were more vigorous and efficient than others, or there are chances of more enhanced water and nutrient uptake, or due to changes induced by rootstocks in the concentration of hormones. These findings are in line with Aloni et al. (2010), Khah (2011) and Mohammad et al (2009).

4.3.9 Harvest duration (days)

Critical investigation of data in the Table 4.11 revealed that rootstocks significantly affected the harvest duration. Prolonged harvest duration is desired for obtaining higher returns and also to avoid glut in the market. Thus, cultivars/varieties should be selected as such which have longer harvest duration.

During 2016-17, plants grafted on rootstock Green Gourd had maximum harvest duration (74.68 days) and were found statistically at par with Palam Pride (70.40 days), Hawaii-7998(71.56 days) and Arka Nidhi (72.50 days).Thus, plants grafted on rootstock VI-34845 recorded an extended harvest duration of 22.5 days than the non-grafted plants (50.00 days).

Plants grafted on rootstock Green Gourd also took maximum days (70.57) for harvest duration in the year 2017-18, whereas, non-grafted plants resulted in lesser harvest duration of 16.11 days. Rootstocks viz., Palam Pink (69.67 days), Hawaii-7998 (67.39 days), Arka Nidhi (66.89 days) and Arka Keshav (70.00 days) were statistically at par. Pooled analysis of data also depicted maximum harvest duration in plants grafted on rootstock Green Gourd (72.62 days) which was significantly superior over other rootstocks and were followed by Arka Nidhi (69.70 days), Hawaii-7998 (69.48 days), Palam Pink (69.22 days) and Palam Pride (67.97 days). Grafted plants (72.62) had prolonged harvest duration than non-grafted (66.76) by 20.34 days.

Prolonged harvest duration in grafted plants may be the result of enhanced nutrient and water uptake by the rootstocks as they are more vigorous, efficient in utilizing nutrients to the maximum extent which may have resulted in healthy foliar as well as root growth which might increased the efficiency of metabolic processes and this has led to extended period of harvest duration even under adverse stress conditions. These results are in conformity with Dan and Aribawa, 2017 and King et al, 2010.

Table 4.11 Effect of rootstocks on harvest duration (days) of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	58.50	62.00	60.25
Palam Pride (Tomato)	70.40	65.54	67.97
Palam Pink(Tomato)	68.78	69.67	69.22
Hawaii-7998 (Tomato)	71.56	67.39	69.48
Green Gourd(Tomato)	74.68	70.57	72.62
Hawaii-7996 (Tomato)	63.00	59.44	61.22
LS-89 (Tomato)	66.78	58.75	62.77
VI-34845 (Brinjal)	60.67	58.76	59.72
Arka Nidhi Brinjal)	72.50	66.89	69.70
Arka Keshav Brinjal)	56.00	70.00	63.00
Solanum torvum Brinjal)	52.55	62.34	57.45
VI-47335 Brinjal) (EG-195)	58.69	60.00	59.35
VI-45376 Brinjal) (EG-203)	60.00	57.77	58.89
Control (GS-600)	50.00	54.46	52.28
CD (0.05)	5.30	4.37	2.90
CV (%)	6.76	10.26	4.79

4.3.10 Plant height (cm)

Plants grafted on rootstock Back Attack recorded maximum plant height of 304.27 cm plants during 2016-17 which was significantly superior to other rootstocks (Table 4.12) followed by Hawaii-7998 (230.87cm), Palam Pride (228.33cm), LS-89 (228.23cm) and Green Gourd (203.33cm). VI-34845(243.67cm), Arka Keshav (239.00cm), VI-47335 (231.33cm), Palam Pink (219.67cm) and LS-89 (215.67cm).

Whereas, in 2017-18 maximum plant height of 253.33 cm was also observed in plants grafted on rootstock Back Attack , which was significantly superior to other rootstocks plants grafted on rootstocks and was found statistically at par with VI-34845 (243.67 cm), Arka Keshav (239.00 cm), Palam Pink (219.67 cm), VI-47335 (231.33 cm) and LS-89 (215.67 cm). Similarly, in pooled analysis of data plants grafted n rootstock Back Attack also produced maximum plant height of 278.80 cm which were followed by Arka Nidhi (227.33 cm), LS-89 (221.95 cm), Hawaii-7998 (214.27 cm) and Palam Pride (212.83 cm). Thus, grafted plants had greater plant height of 46.20% as compared to non-grafted ones. Similar results were also observed in the studies of Khiareddine et al. (2019), Al-Harbi et al. (2018), Alvarez-Hernandez (2012) and Kumar et al (2017).

Grafted tomato plants had faster growth as compared to non-grafted plants which is very well depicted from the data of 2016-17 as well as in the pooled data presented in the Table 4.1. Maximum plant height of grafted plants as compared to the grafted may be due to good compatibility between rootstocks and scions during early stages of growth, which resulted in proper translocations of minerals and hormones throughout the plant system. Moreover, the grafted plants were more vigorous as compared to non-grafted ones. The other reasons for the less plant height in control plants was due to incidence of bacterial wilt. The Chilli Rootstocks viz., PI-201232, AVPP0205 and Local Pumpkin in the present studies showed formation of vascular union in the initial stages grafted on tomato scions, but at later stages the growth of plants remained stunted, without flowering and fruiting at all in both years i.e. 2016-17 & 2017-18. The possible reasons for slow growth in plant height in chilli and local pumpkin rootstocks may be due to tissue and structure difference, physiological and biochemical characteristics, growing stage of rootstock and scion, hormones, environmental factors, failure of rootstock and scion to form a strong union, cessation of growth or sometimes due to overgrowth of the scion, or due to premature death of either rootstock or scion after grafting which may be the result of decreased water and nutrient flow These results are in conformity with Davis et al. 2008 who also recorded similar findings.

Table 4 12. Effect of rootstocks on plant height (cm) of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	304.27	253.33	278.80
Palam Pride (Tomato)	228.33	197.33	212.83
Palam Pink (Tomato)	201.67	219.67	210.67
Hawaii-7998 (Tomato)	230.87	197.67	214.27
Green Gourd (Tomato)	203.33	206.00	204.67
Hawaii-7996 (Tomato)	176.47	230.00	203.23
LS-89 (Tomato)	228.23	215.67	221.95
VI-34845 (Brinjal)	175.87	243.67	209.77
Arka Nidhi Brinjal	201.33	210.00	227.33
Arka Keshav Brinjal	198.20	239.00	218.60
Solanum torvum (Brinjal)	137.80	213.33	175.57
VI-47335 (Brinjal) (EG-195)	157.33	231.33	194.33
VI-45376 (Brinjal) (EG-203)	151.33	205.33	178.33
PI-201232 (Chilli)	16.87	18.27	17.57
AVPP0205 (Chilli)	17.27	18.30	17.78
Local Pumpkin	13.33	12.80	13.07
Control (GS-600)	140.00	160.00	150.00
CD (0.05)	13.53	37.95	19.83
CV (%)	4.74	12.26	6.66

4.4 Quality traits

4.4.1 Pericarp thickness (mm)

Pericarp thickness is an important quality parameter for increasing shelf life of tomato. Fruits which have thick pericarp are suitable for long distance transportation and suffer less from post harvest losses than those which have thinner pericarp. Thus, fruits with thick pericarp are more firm in texture.

Maximum pericarp thickness (6.90 mm) during 2016-17 was found in plants grafted on rootstock Palam Pride followed by Hawaii-7998 (6.70 mm), Back Attack (6.60 mm) and Arka Nidhi (6.50 mm) (Table 4.13). Whereas, maximum pericarp thickness of 6.30 mm was also observed in plants grafted on rootstock Palam Pride during 2017-18 followed by Hawaii-7996 (6.00 mm), Back Attack (5.92 mm) and Arka Keshav (5.90 mm). Similarly, pooled analysis of data also recorded maximum pericarp thickness in plants grafted on rootstock Palam Pride (6.60 mm) followed by Back Attack (6.26 mm), Hawaii-7998 (6.24 mm) and Hawaii-7996 (6.22 mm). Thus, grafted plants excelled superiority and had 15.45% more pericarp thickness than non-grafted ones.

Increased pericarp thickness in grafted plants might be due to multiple interactions between rootstocks and scion combinations. Similar findings were reported in the studies of Kyriacou et al. (2017) and Kumar et al. (2017).

Table 4.13. Effect of rootstocks on Pericarp thickness (mm) of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	6.60	5.92	6.26
Palam Pride (Tomato)	6.90	6.30	6.60
Palam Pink (Tomato)	5.88	5.74	5.81
Hawaii-7998 (Tomato)	6.70	5.79	6.24
Green Gourd (Tomato)	6.00	5.89	5.94
Hawaii-7996 (Tomato)	6.44	6.00	6.22
LS-89 (Tomato)	5.86	5.56	5.71
VI-34845 (Brinjal)	6.20	5.70	5.95
Arka Nidhi (Brinjal)	6.50	5.50	6.00
Arka Keshav (Brinjal)	6.30	5.90	6.10
Solanum torvum (Brinjal)	6.10	5.74	5.92
VI-47335 (Brinjal) (EG-195)	5.82	5.60	5.71
VI-45376 (Brinjal) (EG-203)	5.90	5.55	5.72
Control (GS-600)	5.70	5.47	5.58
CD (0.05)	0.11	0.02	0.05
CV (%)	12.53	3.86	7.52

4.4.2 Fruit firmness

Fruit firmness is one of the typical attribute used for describing the texture of fruits. Firm fruits are more important from consumer point of view in seeking their attention as well as for transportation to distant markets.

From the data presented in the table 4.14 it is inferred that rootstocks showed significant differences in both the years i.e. 2016-17 & 2017-18 as well as in pooled analysis of data. Maximum fruit firmness was recorded in plants grafted on rootstock Palam Pink (4.59kg/cm^2) which was found statistically at par with Palam Pride (4.50kg/cm^2), Hawaii-7998 (4.49kg/cm^2) and Arka Keshav (4.26kg/cm^2) during the year 2016-17.

Similarly in the year, 2017-18 plants grafted on rootstock Palam Pink recorded maximum fruit firmness (4.10 kg/cm^2) and was statistically at par with Back Attack (3.79kg/cm^2), Hawaii-7998 (3.97 kg/cm^2), *Solanum torvum* (3.90kg/cm^2) and VI-45376 (3.89 kg/cm^2). Pooled analysis of data also recorded maximum fruit firmness in plants grafted on the rootstock Palam Pink (4.34 kg/cm^2) which was statistically at par with Palam Pride (4.17 kg/cm^2) and Hawaii-7998 (4.28kg/cm^2) . Thus, grafted plants had 17.05% more firm fruits than non-grafted,

Table 4.14. Effect of rootstocks on fruit firmness (kg/cm^2) of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	3.99	3.79	3.89
Palam Pride (Tomato)	4.50	3.84	4.17
Palam Pink (Tomato)	4.59	4.10	4.34
Hawaii-7998 (Tomato)	4.49	3.97	4.28
Green Gourd (Tomato)	4.08	3.66	3.87
Hawaii-7996 (Tomato)	4.07	3.74	3.90
LS-89 (Tomato)	3.74	3.69	3.71
VI-34845 (Brinjal)	3.85	3.53	3.69
Arka Nidhi (Brinjal)	3.91	3.82	3.86
Arka Keshav (Brinjal)	4.26	3.78	4.02
Solanum torvum (Brinjal)	4.01	3.90	3.96
VI-47335 (Brinjal) (EG-195)	3.77	3.83	3.80
VI-45376 (Brinjal) (EG-203)	3.73	3.89	3.81
Control (GS-600)	3.60	3.59	3.60
CD (0.05)	0.36	0.24	0.23
CV (%)	6.45	4.55	4.26

The effect of rootstocks on affecting fruit firmness may be related to changes in morphology of cells, cell turgor, chemical and mechanical properties of cell walls of fruit or due to increase in the production of endogenous hormones from the interactions of rootstock and scions and changed water and nutritional status of scion. Similar results were reported by Rouphael et al. (2010) and El-Wanis et al. (2014).

4.4.3 Total soluble solids (°Brix)

Tomatoes showing high percentage of soluble solids are more preferred in processing industries for making desired processed products. High TSS affects flavor and quality of tomato fruits. Flavor is determined by the ratio of sugars and acids in the fruits. Higher percentage of sugars and acids contribute to overall flavor and quality of fruits. Critical investigation of data presented in the Table 4.15 depicts that rootstocks played crucial role in increasing TSS of grafted tomatoes.

Table 4.15. Effect of rootstocks on total soluble solids (°Brix) of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	4.89	4.70	4.80
Palam Pride (Tomato)	5.20	4.47	4.83
Palam Pink (Tomato)	5.55	4.83	5.19
Hawaii-7998 (Tomato)	5.60	4.58	5.09
Green Gourd (Tomato)	4.95	4.90	4.92
Hawaii-7996 (Tomato)	5.66	4.52	5.09
LS-89 (Tomato)	5.17	4.60	4.88
VI-34845 (Brinjal)	5.13	4.85	4.99
Arka Nidhi (Brinjal)	5.67	5.33	5.48
Arka Keshav (Brinjal)	5.00	4.80	4.90
Solanum torvum (Brinjal)	5.03	4.80	4.91
VI-47335 (Brinjal) (EG-195)	5.52	4.63	5.07
VI-45376 (Brinjal) (EG-203)	5.60	5.23	5.41
Control (GS-600)	4.85	4.44	4.64
CD (0.05)	0.39	0.55	0.42
CV (%)	5.74	8.46	6.34

Maximum TSS of 5.67°Brix and 5.33°Brix was recorded in plants grafted on rootstock Arka Nidhi and was found statistically at par with VI-45376 (5.60°Brix), Palam Pink (5.55 °Brix), Hawaii-7998 (5.60 °Brix), Hawaii-7996 (5.66 °Brix) and VI-47335 (5.52 °Brix) during both years of study i.e. 2016-17 and 2017-18. (Table 4.15). Other rootstocks which recorded statistically at par values w.r.t TSS were Green Gourd (4.90°Brix), VI-34845 (4.85°Brix), Palam Pink (4.83°Brix), *Solanum torvum* (4.80°Brix) and Arka Keshav (4.80°Brix).Similarly, pooled analysis of data also showed maximum TSS by plants grafted on rootstock Arka Nidhi (5.48 °Brix) and was found significantly superior to other rootstocks. Thus, grafted plants had 15.33% higher total soluble solids than non-grafted.

Total soluble solid contents in grafted plants was high in grafted plants as compared to non-grafted may be due to better light penetration in the crop canopy which lead to greater activity of photosynthesis. These findings are in conformity with Blestos and Olympios, (2008), Kammis et al. (2004), Poudel and Lee, (2009), Mohammed et al. (2009), Kumar et al. (2017) and El-Wanis et al. (2014).

4.4.4 Ascorbic Acid (mg/100 g)

Tomato is a rich source of Vitamin C and plays a vital role in human health by combating various degenerative diseases like diabetes, atherosclerosis, glaucoma, macular degeneration, stroke, heart diseases and cancer. Besides, it also increases the absorption of iron, boosts immune system (Chambial et al, 2013).

Critical investigation of data presented in the Table 4.16 shows that plants grafted on the rootstock Palam Pink had maximum Vitamin C content (23.33 mg/100 g) which was found statistically at par with the rootstock VI-34845 (23.13 mg/100 g) during 2016-17. Whereas in 2017-18 higher ascorbic acid was also observed in plants grafted on rootstock Palam Pink (20.55 mg/100 g) and was found statistically at par with the rootstock *Solanum torvum* (18.13 mg/100g), Hawaii-7998 (18.00 mg/100 g), Arka Nidhi (17.97 mg/100 g) and VI-34845 (17.93 mg/100g).

Similarly, pooled analysis of data also showed maximum ascorbic acid content in plants grafted on the rootstock Palam Pink (21.94 mg/100 g) which was found statistically at par with VI-34845 (20.53 mg/100g). Thus, grafted plants on rootstock Palam Pink produced 29.35% higher ascorbic acid as compared to non-grafted. The possible reasons for increased Vitamin C in grafted plants may be attributed to influence of grafting and rootstock combinations used. Similar findings were reported by Poudel and Lee (2009), Kumar et al (2017), Rahmatian et al. (2014), Schwarz et al. (2013), Huang et al. (2015) and Balliu et al. (2008).

Table 4.16 Effect of rootstocks on ascorbic acid content (mg/100g) of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	16.33	16.97	16.65
Palam Pride (Tomato)	16.00	17.55	16.77
Palam Pink (Tomato)	23.33	20.55	21.94
Hawaii-7998 (Tomato)	20.17	18.00	19.08
Green Gourd (Tomato)	15.33	17.66	16.50
Hawaii-7996 (Tomato)	15.73	17.00	16.36
LS-89 (Tomato)	18.30	17.40	17.85
VI-34845 (Brinjal)	23.13	17.93	20.53
Arka Nidhi (Brinjal)	18.43	17.97	18.20
Arka Keshav (Brinjal)	20.60	16.50	18.55
Solanum torvum (Brinjal)	16.67	18.13	17.40
VI-47335 (Brinjal) (EG-195)	18.40	16.40	17.40
VI-45376 (Brinjal) (EG-203)	16.00	17.63	16.82
Control (GS-600)	15.00	16.00	15.50
CD (0.05)	1.86	2.62	1.78
CV (%)	7.48	11.31	7.42

4.4.5 Titrable Acidity (%)

Titrable acidity provides the measure of citric acid present in tomato which has direct impact on the flavor of fruit and also influences organoleptic properties. Increased titrable acidity is known to enhance fruit flavor. Data shown in Table 4.17 clearly depicts that in the year 2016-17 plants grafted on rootstock VI-47335 reported maximum titrable acidity (0.68%) which was statistically at par with VI-34845 (0.66%). During 2nd year of experiment rootstock VI-47335 also found to record highest value of titrable acidity (0.66%), which was statistically at par with rootstock Green Gourd (0.64%), Arka Nidhi (0.62%) and Palam Pink (0.61%).

Pooled analysis of data also exhibited maximum titrable acidity in plants grafted on rootstock VI-47335 (0.67%) and was found significantly superior to other rootstocks.

Titrable acidity is enhanced through grafting due to direct effect of rootstocks which lead to greater accumulation of organic acids in developing fruits or ability of enhanced uptake of nutrients like potassium through vigorous root system. Similar findings were reported by Leonardi and Giuffrida, 2006, Albacete et al. (2009) , Ibrahim et al. (2001), Flores et al. (2010), Turhan et al. (2011), Schwarz et al. (2013), Huang et al. (2015) and Riga (2015).

Table 4.17. Effect of rootstocks on titrable acidity (%) of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	0.34	0.40	0.37
Palam Pride (Tomato)	0.55	0.54	0.54
Palam Pink (Tomato)	0.45	0.61	0.53
Hawaii-7998 (Tomato)	0.44	0.45	0.45
Green Gourd (Tomato)	0.51	0.64	0.58
Hawaii-7996 (Tomato)	0.47	0.57	0.52
LS-89 (Tomato)	0.61	0.51	0.56
VI-34845 (Brinjal)	0.66	0.53	0.59
Arka Nidhi (Brinjal)	0.52	0.62	0.57
Arka Keshav (Brinjal)	0.41	0.47	0.44
Solanum torvum (Brinjal)	0.63	0.52	0.57
VI-47335 (Brinjal) (EG-195)	0.68	0.66	0.67
VI-45376 (Brinjal) (EG-203)	0.60	0.44	0.56
Control (GS-600)	0.38	0.36	0.37
CD (0.05)	0.04	0.06	0.02
CV (%)	5.28	5.59	3.27

4.4.6 Lycopene (mg/100g)

Lycopene is a carotenoid which is considered as better antioxidant and anticancerous is formed during fruit ripening stage and provide red colour to the fruit. This pigment is present in sufficient amounts in tomato. Red colour is considered as an important parameter from consumer's point of view.

Critical investigation of data presented in Table 4.18 that during 2016-17 maximum lycopene was reported in plants grafted on rootstock Back Attack (6.73 mg/100g) which was found statistically at par with Arka Nidhi (6.61 mg/100g), Hawaii-7998 (6.53 mg/100g) and Hawaii-7996 (6.42 mg/100g). During 2017-18 maximum lycopene was again observed in plants grafted on rootstock Back Attack (6.78 mg/100g) and was statistically at par with rootstock VI-47335 (6.44 mg/100g), VI-45376 (6.64 mg/100g), Hawaii-7998 (6.52 mg/100g) and LS-89 (6.43 mg/100g).

Table 4.18. Effect of rootstocks on Lycopene content (mg/100g) of tomato under protected conditions

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	6.73	6.78	6.75
Palam Pride (Tomato)	6.33	6.35	6.34
Palam Pink (Tomato)	6.00	5.92	5.96
Hawaii-7998 (Tomato)	6.53	6.52	6.53
Green Gourd (Tomato)	6.17	5.89	6.03
Hawaii-7996 (Tomato)	6.42	5.85	6.13
LS-89 (Tomato)	6.35	6.43	6.39
VI-34845 (Brinjal)	6.07	5.86	5.96
Arka Nidhi (Brinjal)	6.61	5.96	6.28
Arka Keshav (Brinjal)	5.72	6.45	6.09
Solanum torvum (Brinjal)	6.17	5.84	6.00
VI-47335 (Brinjal) (EG-195)	5.76	6.44	6.10
VI-45376 (Brinjal) (EG-203)	6.27	6.64	6.46
Control (GS-600)	5.48	5.22	5.35
CD (0.05)	0.32	0.33	0.21
CV (%)	3.81	3.86	2.47

Pooled analysis of data also showed maximum lycopene in rootstock Back Attack (6.75mg/100g) which was found significantly superior than other rootstocks. Grafted plants on rootstock Back Attack produced 20.74% higher lycopene content than non-grafted. Increased lycopene in grafted plants may be on account of significant rootstock–scion interaction. Similar results were reported by Fernandez – Garcia et al, (2004) and Miskovic et al. (2016).

4.5 Organoleptic Test

Fruits at the time of third harvesting were given to five people for predicting the taste, so as to judge the flavor, ratio of sugars and acids present .The present investigation revealed that fruit taste varied from sweet to slightly acidic and there was no critical difference in the taste as well as flavor of grafted and non-grafted fruits during both the years.

4.6 Grafting success rate (%)

The analysis of variance indicated that all the grafted plants exhibited an appreciable grafting success rate, which ranged between 92.00-97.33%. Data shown in Table 4.19 clearly depicts that in the year 2016-17 plants grafted on rootstock Hawaii-7998 showed higher success rate (97.33%). Rootstocks viz., Palam pride (96.67%), LS-89 (96.59%), VI-45376 (96.33 %), Green Gourd (96.14%), Hawaii-7996 (96.00 %), Arka Keshav (95.00%) and *Solanum torvum* (95.67%) were found statistically at par. Similarly in the year 2017-18 plants grafted on rootstock Hawaii-7998 also showed higher success rate (96.67%) and was at par with rootstocks Palam Pride (95.11%), Palam Pink (96.55%), Hawaii-7996 (95.33%), LS-89 (94.67%), VI-34845 (95.00%), Arka Nidhi (95.67%), Arka Keshav (96.59%), VI-47335 (94.33 %) and VI-45376 (95.33 %). The pooled analysis of data also showed high success rate (97.00%) in Hawaii-7998 rootstock. In rootstocks PI-201232, AVPP0205 and Local Pumpkin no grafting success rate(%) was recorded as none of them survived till the end of trial due to poor rootstock-scion vascular union which ultimately lead to poor compatibility .

Higher grafting success rate in grafted plants may be attributed to compatibility between rootstock and scion, good callus formation, vascular bundle differentiation and connectivity at the graft interface which ensured successful graft union through proper healing and also due to lack of transplanting shock. Similar results were reported in the findings of Ogata et al. 2005.

Table 4.19 Effect of rootstocks on grafting success rate (%) of tomato under protected conditions.

Rootstocks	2016-17 (Rabi)	2017-18 (Kharif)	Pooled
Back Attack (Tomato)	94.33	93.85	94.09
Palam Pride (Tomato)	96.67	95.11	95.89
Palam Pink (Tomato)	93.67	96.55	95.11
Hawaii-7998 (Tomato)	97.33	96.67	97.00
Green Gourd (Tomato)	96.14	94.15	95.15
Hawaii-7996 (Tomato)	96.00	95.33	95.67
LS-89 (Tomato)	96.59	94.67	95.63
VI-34845 (Brinjal)	92.00	95.00	93.50
Arka Nidhi (Brinjal)	92.74	95.67	94.20
Arka Keshav (Brinjal)	95.00	96.59	95.80
Solanum torvum (Brinjal)	95.67	92.67	94.17
VI-47335 (Brinjal) (EG-195)	93.33	94.33	93.83
VI-45376 (Brinjal) (EG-203)	96.33	95.33	95.83
CD (0.05)	2.80	2.51	1.97
CV (%)	2.24	2.00	1.58

4.6 Cost of cultivation

Cost of cultivation is considered as an important aspect of production of any crop. It gives an idea about the investments on inputs, agricultural operations and outputs received. In the present study, it was noticed that grafted plants grown under protected conditions resulted in higher benefit: cost ratio than non-grafted ones. Data presented in table 4.20 and appendixes clearly indicate that in the year 2016-17 grafted tomato plants resulted in higher benefit: cost ratio (10.88) as compared to non-grafted tomato (8.72). Whereas, during 2017-18 grafted tomato plants resulted in higher benefit: cost ratio (10.64) as compared to non-grafted tomato (9.67). Whereas, the average value of grafted tomato for benefit cost ratio is 10.76 as compared to non-grafted tomato (9.48).

Table 4.20. Comparison of cost and returns between grafted and non-grafted tomato

Cost		Grafted tomato			Non-grafted tomato		
A.		**2016-17**	**2017-18**	**Mean**	**2016-17**	**2017-18**	**Mean**
(i)	Input cost/m^2	28.91	28.02	28.46	12.83	11.94	12.39
(ii)	Labour cost/m^2	19.82	19.82	19.82	16.61	16.61	16.61
Total cost/m^2		48.73	47.84	48.29	29.44	28.55	28.10
	Returns						
1.	**Yield (kg/m^2)**	26.52	25.44	25.98	12.84	13.80	13.32
2.	**Sale rate (?/kg)**	20.00	20.00	20.00	20.00	20.00	20.00
3.	**Gross returns (?/m^2)**	530.40	508.80	519.60	256.80	276.00	266.40
4.	**Net returns (?/m^2)**	481.67	460.96	471.31	227.36	247.45	238.30
5.	**Benefit: cost ratio**	10.88	10.64	10.76	8.72	9.67	9.48

5. SUMMARY AND CONCLUSIONS

The present investigation entitled “Evaluation of rootstocks for biotic stress management in tomato under protected conditions’’ was conducted at Vegetable Research Farm, Department of Vegetable Science and Floriculture, CSKHPKV, Palampur, for two years i.e. during 2016-17 and 2017-18. The experiment was laid out in a Randomized Block Design with three replications and cleft grafting method was used to graft desirable scion on resistant rootstocks. The treatments comprised of sixteen different rootstocks and one commercial hybrid GS-600 which was horticulturally superior and was used as a scion. The observations were recorded on five randomly selected plants on various quantitative and qualitative parameters such as days to first flowering, days to first harvest, number of marketable fruits per plant, fruit length (cm), fruit width (cm), marketable fruit yield per plant (kg), marketable fruit yield per square metre (kg), average fruit weight (g), harvest duration (days), plant height (cm), pericarp thickness (mm), ascorbic acid content (mg/100g), total soluble solids (°Brix), fruit firmness (kg/cm^2), lycopene content (mg/100 g) and titrable acidity (%).

Bacterial wilt is a soil borne disease of tomato caused by *Ralstonia solanacearum*. All the sixteen rootstocks were found resistant for bacterial wilt incidence under both pot and field conditions after screening and did not exhibit wilting symptoms and showed good plant growth,vigour and increased yield. While scion (GS-600) was found highly susceptible to bacterial wilt incidence.

Root-knot nematodes, *Meloidogyne* spp causes high levels of economic losses in wide range of agricultural crops worldwide. Total sixteen rootstocks screened for nematode resistance, out of seven rootstocks of tomato one rootstock Green Gourd showed resistance, whereas out of six brinjal rootstocks one rootstock VI- 34845 exhibited resistance, four were susceptible and one rootstock VI-47335 showed mild resistance. Two chilli rootstocks viz., AVPP0205 and PI-201232 were found resistant. One rootstock of local pumpkin was recorded as susceptible to *Meliodogyne incognita*.

The analysis of variance indicated that the rootstocks significantly affected the plant growth, yield as well as quality of fruits during both the years i.e. 2016-17 and 2017-18. Plants grafted on rootstock LS-89 were earlier to produce first flower (32.00) than non-grafted by two days during the year 2016-17. Whereas, in the year 2017-18 plants grafted on rootstock Arka Keshav took minimum days (22.67) to produce first flower. The pooled analysis of data showed that plants grafted on rootstock LS-89 were earlier in flowering with 28.00 days. Days to first harvest were earlier in plants grafted on rootstock LS-89 (56.76) during 2016-17 and plants grafted on rootstock Arka Keshav took 53.11 days for first harvest during 2017-18. Pooled analysis of data showed that plants grafted on rootstock LS-89 produced first harvest in 57.88 days.

Rootstocks significantly affected the number of fruits per plant. Plants grafted on rootstock Green Gourd produced maximum number of marketable fruits per plant (24.33) during 2016-17. Whereas, in 2017-18 highest number of marketable fruits per plant were also observed in plants grafted on rootstock Green Gourd (23.00). Pooled analysis of data also showed maximum number of fruits in plants grafted on rootstock Green Gourd (23.67). Non-grafted plants recorded 32.40% less number of marketable fruits than grafted.

Rootstocks had significant effects on average fruit weight of tomato during both the years. Plants grafted on rootstock Green Gourd recorded highest average fruit weight (90.83g). Whereas, it also produced highest average fruit weight (92.17 g) during 2017-18. Similarly, pooled analysis of data also showed maximum average fruit weight in plants grafted on rootstock Green Gourd (91.50 g). Non-grafted plants recorded 24.06 % less fruit weight in comparison to plants grafted on rootstock Green Gourd.

Different rootstocks affected the fruit yield per plant significantly. Plants grafted on rootstock Green Gourd produced maximum fruit yield per plant (2.21 kg). In the year, 2017-18 maximum fruit yield was also recorded in plants grafted on rootstock Green Gourd (2.12 kg) and was statistically superior to other rootstocks. Pooled analysis of data showed that plants grafted on rootstock Green Gourd resulted in maximum yield per plant (2.16 kg). Thus, grafted plants produced 48.61% more yield than non-grafted.

Rootstocks also exerted significant influence on yield per square metre during 2016-17. Maximum yield per square metre was obtained in plants grafted on rootstock Green Gourd (26.52 kg). In the year, 2017-18 maximum yield per square metre was reported in plants grafted on rootstock Green Gourd (25.44 kg). Pooled analysis of data also showed maximum yield per square metre in plants grafted on rootstock Green Gourd (25.92 kg). Grafted plants produced 48.61% more yield per square metre than non-grafted.

Highest fruit length was found in rootstock Palam Pink (5.69 cm) during 2016-17 whereas in the year 2017-18 plants grafted on rootstock Palam Pink also recorded maximum fruit length of 5.29 cm. The pooled analysis of data also observed longest fruits in plants grafted on rootstock Palam Pink (5.49 cm). Thus, highest fruit length was observed in grafted plants. Maximum fruit width was recorded in the plants grafted on rootstock Palam Pink (6.59 cm) during 2016-17. Whereas, in 2017-18 maximum fruit width of 5.39 cm was also observed in plants grafted on rootstock Palam Pink. Similarly, in pooled analysis of data maximum fruit width of 5.99 cm was observed in plants grafted on rootstock Palam Pink.

Plants grafted on rootstock Green Gourd had maximum harvest duration (74.68 days) during 2016-17 and 70.57 days for harvest duration in the year 2017-18. Pooled analysis of data also depicted maximum harvest duration in the plants grafted on rootstock Green Gourd (72.62 days). Grafted plants 72.62 had prolonged harvest duration than non-grafted 66.76 by 20.34 days.

Plants grafted on rootstock Back Attack recorded maximum plant height of 304.27 cm plants during 2016-17 which was significantly superior to other rootstocks during 2016-17. Whereas, in 2017-18 maximum plant height of 253.33 cm was also observed in plants grafted on rootstock Back Attack. Similarly, in pooled analysis of data plants grafted on rootstock Back Attack produced maximum plant height of 278.80 cm which produced 46.20% more height in comparison to control plots.

Pericarp thickness is an important quality parameter for increasing shelf life of tomato. Grafted plants excelled over non-grafted plants for pericarp thickness in both years of the study. Maximum pericarp thickness (6.90 mm) during 2016-17 was found in plants grafted on rootstock Palam Pride followed by Hawaii-7998 (6.70 mm), Back

Attack (6.60 mm) and Arka Nidhi (6.50 mm) (Table 4.13). Whereas, maximum pericarp thickness of 6.30 mm was also observed in plants grafted on rootstock Palam Pride during 2017-18 followed by Hawaii-7996 (6.00 mm), Back Attack (5.92 mm) and Arka Keshav (5.90 mm). Similarly, pooled analysis of data also recorded maximum pericarp thickness in plants grafted on rootstock Palam Pride (6.60 mm) followed by Back Attack (6.26 mm), Hawaii-7998 (6.24 mm) and Hawaii-7996 (6.22 mm). Thus, grafted plants excelled superiority and had 15.45% more pericarp thickness than non-grafted ones.

Fruit firmness is one of the typical attribute used for describing the texture of fruits. Rootstocks showed significant differences in both the years i.e. 2016-17 & 2017-18 as well as in pooled analysis of data. Maximum fruit firmness was recorded in plants grafted on rootstock Palam Pink (4.59kg/cm^2) which was found statistically at par with Palam Pride (4.50kg/cm^2), Hawaii-7998 (4.49kg/cm^2) and Arka Keshav (4.26kg/cm^2) during the year (2016-17).

Similarly in the year, 2017-18 rootstock Palam Pink recorded maximum fruit firmness (4.10 kg/cm^2) and was statistically at par with Back Attack (3.79kg/cm^2), Hawaii-7998 (3.97 kg/cm^2), *Solanum torvum* (3.90kg/cm^2) and VI-45376 (3.89 kg/cm^2). Pooled analysis of data also recorded maximum fruit firmness in plants grafted on the rootstock Palam Pink (4.34 kg/cm^2) which was statistically at par with Palam Pride (4.17 kg/cm^2) and Hawaii-7998 (4.28kg/cm^2) . Thus, grafted plants had 17.05% more firm fruits than non-grafted.

Tomatoes showing high percentage of soluble solids are more preferred in processing industries for making desired processed products. Maximum TSS of 5.67°Brix and 5.33°Brix was recorded in plants grafted on rootstock Arka Nidhi during 2016-17 and 2017-18 and was found statistically at par with VI-45376 (5.60°Brix), Palam Pink (5.55 °Brix), Hawaii-7998 (5.60 °Brix), Hawaii-7996 (5.66 °Brix) and VI-47335 (5.52 °Brix) during both years of study. Other rootstocks which recorded statistically at par values w.r.t TSS were Green Gourd (4.90°Brix), VI-34845 (4.85°Brix), Palam Pink (4.83°Brix), *Solanum torvum* (4.80°Brix) and Arka Keshav

(4.80°Brix).Similarly, pooled analysis of data also showed maximum TSS by plants grafted on rootstock Arka Nidhi (5.48 °Brix) and was found significantly superior to other rootstocks. Thus, grafted plants had 15.33% higher total soluble solids than non-grafted.

Titrable acidity provides the measure of citric acid present in tomato which has direct impact on the flavor of fruit and also influences organoleptic properties. In the year, 2016-17 plants grafted on rootstock VI-47335 reported maximum titrable acidity (0.68%) which was statistically at par with VI-34845 (0.66%). During 2nd year of experiment rootstock VI-47335 also found to record highest value of titrable acidity (0.66%), which was which was statistically at par with plants grafted on rootstock Green Gourd (0.64%), Arka Nidhi (0.62%) and Palam Pink (0.61%).Pooled analysis of data also exhibited maximum titrable acidity in plants grafted on rootstock VI-47335 (0.67%) and was found significantly superior to other rootstocks.

Lycopene is a carotenoid which is considered as better antioxidant, anticancerous and is formed during fruit ripening stage and provide red colour to the fruit. During 2016-17 maximum lycopene was reported in plants grafted on rootstock Back Attack (6.73 mg/100g). During 2017-18 maximum lycopene was again observed in plants grafted on rootstock Back Attack (6.78 mg/100g). Pooled analysis of data also showed maximum lycopene in plants grafted on rootstock Back Attack (6.75 mg/100g). Thus, grafted plants produced 20.74% higher lycopene content than non-grafted.

The analysis of variance indicated that all the grafted plants exhibited an appreciable grafting success rate, which ranged between 92.00-97.33%. In the year, 2016-17 plants grafted on rootstock Hawaii-7998 showed higher success rate (97.33%). Rootstocks viz., Palam pride (96.67%), LS-89 (96.59%), VI-45376 (96.33 %), Green Gourd (96.14%), Hawaii-7996 (96.00 %), Arka Keshav (95.00%) and *Solanum torvum* (95.67%) which were found statistically at par. Similarly in the year 2017-18 plants grafted on rootstock Hawaii-7998 also showed higher success rate (96.67%) and was at par with rootstocks Palam Pride (95.11%), Palam Pink (96.55%), Hawaii-7996 (95.33%), LS-89 (94.67%), VI-34845 (95.00%), Arka Nidhi (95.67%), Arka Keshav (96.59%), VI-47335 (94.33 %) and VI-45376 (95.33 %).

Conclusions

The following conclusions were drawn from the present study:

- All rootstocks used in the study were found resistant to bacterial wilt. For nematode incidence rootstocks Green Gourd (Tomato), Brinjal (VI-34845), Chilli rootstocks (PI-201232 and AVPP0205) were found to be resistant. Whereas, Brinjal rootstock VI-47335 (EG-195) was found moderately resistant.
- Rootstocks Green Gourd and VI-34845 were found resistant for bacterial wilt as well as for nematode incidence. These rootstocks also provided higher yield. Therefore, these rootstocks can be used for countering biotic stresses such as bacterial wilt and nematodes efficiently under protected conditions.
- For early production to fetch higher returns plants grafted on rootstock LS-89 proved best as it was found superior to other rootstocks for days to first flowering and days to first harvest, whereas, plants grafted on rootstock Green Gourd recorded longer harvest duration and highest yield per plant and per square metre.
- The rootstock Hawaii-7998 showed higher grafting success rate when scion GS-600 was grafted on it.
- Grafted plants on various rootstocks excelled in quality over non-grafted plants and were high-caliber for TSS which was found high in plants grafted on rootstock Arka Nidhi. Lycopene content was recorded maximum in plants grafted on rootstock Back Attack. Whereas, titrable acidity an important quality trait was detected maximum in plants grafted on rootstock VI-47335. Fruit firmness hold great significance for enhanced shelf life as well as maintaining quality during transit was recorded highest in plants grafted on rootstock Palam Pink. Ascorbic acid content which has exceptional importance in human health was also adjudged highest in plants grafted on rootstock Palam Pink. This rootstock also recorded maximum fruit length as well as fruit width. Pericarp thickness which plays remarkable role in long

distance transportation was recorded highest in plants grafted on rootstock Palam Pride.

- Benefit cost ratio is a critical factor in crop production to determine the expenses incurred and returns received in any crop production. Higher Benefit: cost ratio during 2016-17 was found in plants grafted on rootstock Green Gourd (10.88) as compared to non-grafted tomato (8.72). Whereas, during 2017-18 grafted tomato plants resulted in higher benefit: cost ratio (10.64) as compared to non-grafted tomato (9.67). Whereas, the average value of grafted tomato for benefit cost ratio is 10.76 as compared to non-grafted tomato (9.48).

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APPENDICES

Appendix-I

Mean monthly meteorological data recorded at Palampur during July 2017 - October 2018

Month	Temperature (°C)			RH (%)		
	Max	Min	Mean	Mor	Eve	Mean
Jul	27.1	18.6	22.9	93.6	84.1	88.9
Aug	27.1	18.7	22.9	91.9	85.6	88.8
Sept	26.7	16.9	21.8	89.6	82.4	86.0
Oct	25.9	13.0	19.5	85.5	68.8	77.2
Nov	23.0	8.3	15.6	85.0	77.4	81.2
Dec	20.3	6.1	13.2	68.5	49.7	59.1
Jan	15.4	4.9	10.1	72.5	54.5	63.5
Feb	19.1	7.8	13.5	68.4	47.2	57.8
Mar	21.1	9.2	15.1	63.2	44.3	53.7
Apr	28.3	14.9	21.6	60.1	36.1	48.1
May	30.1	17.3	23.7	54.7	43.0	48.9
Jun	28.4	18.4	23.4	72.1	62.4	67.3
Jul	27.4	19.8	23.6	92.0	83.1	87.5
Aug	26.6	19.4	23.0	92.7	85.4	89.0
Sept	26.7	17.1	21.9	87.1	75.2	81.2
Oct	25.9	13.0	19.5	85.5	68.8	77.2

Appendix-II: Economics/cost of inputs of 250 m^2 polyhouse under protected conditions, 2016-17

Sr.No.	Inputs	Quantity & units	Rate/unit (Rs.)	Cost (Rs.)	Grafted tomato (Rs.)	Non-grafted tomato (Rs.)
1.	Seed (Rootstock)	4.00 g	300/kg	1.20	1.20	-
	Tomato	2.50 g	1500/kg	3.75	3.75	-
a)	Brinjal	2.00 g	1600/kg	3.20	3.20	-
b)	Chilli	3.00 g (72 seeds)	1/seed	72.00	72.00	-
c)	Local Pumpkin					
d)	Seed (Scion GS-600)	8.00 g (4 g each for grafted and non-grafted)	550/8 g	550.00	275.00	275.00
2.	Nylon ropes (for staking)	15.00 kg (7.5 kg each)	70.00/kg	1050.00	525.00	525.00
3.	Wiring	4 kg 500 g (2 kg 250 g each)	80.00/kg	360.00	180.00	180.00
4.	Growing media (for nursery)					
a)	Cocopeat	2 kg (1 kg each)	30.00/kg	60.00	30.00	30.00
b)	Perlite	2 kg (1 kg each)	30.00/kg	60.00	30.00	30.00
c)	Vermiculite	1 kg (0.5 kg each)	60.00/kg	60.00	30.00	30.00
5.	Protrays/plug trays	64 Nos (32 each)	25.00/tray	1600.00	800.00	800.00
6.	Grafting clips	1960 Nos.	2.00/No	3920.00	3920.00	-
7.	Cello tape	2 No.	10/No	20.00	20.00	-
8.	Yellow sticky traps	25 No	50/No	1250.00	625.00	625.00
9.	**Manures and Fertilisers**					
a)	Farmyard Manure (FYM)	1 q 8 kg (For Both)	200 /q	216.00	108.00	108.00
b)	Urea	3 kg 24 g	284/50 kg	17.18	8.59	8.59
c)	MOP	2 kg 16 g	48.00/kg	96.76	48.38	48.38
d)	IFFCO (12:32:16)	4 kg 86 g	1105/50 kg	90.30	45.15	45.15
e)	NPK (19:19:19)	1 kg 620 g	150.00/kg	243.00	121.50	121.50
f)	Calcium Chloride	120 g	910/500g	218.40	109.20	109.20
10.	**Insecticides and Fungicides**					
a)	Acetamiprid	45 g	180/100g	81.00	40.50	40.50
b)	Dicofol	50 ml	110/100ml	55.00	27.50	27.50
c)	Pyromite	50 ml	110/100ml	55.00	27.50	27.50
d)	Plethora	45 ml	478/100 ml	215.10	107.55	107.55
e)	Dithane M-45	120 g	191/500g	45.84	22.92	22.92
f)	Hexaconazol	45 ml	250/126 ml	89.28	44.64	44.64
	Total			**10433.01**	**7226.58**	**3206.43**
	Input cost/m^2			**41.73**	**28.91**	**12.83**

Appendix III: Labour cost of 250 m^2 polyhouse, 2016-17

Sr.No.	Particulars	Mandays (No.)	Cost (Rs.)	Grafted tomato (Rs.)	Non-grafted tomato (Rs.)
1.	Land preparation	3	802.60	401.30	401.30
2.	Manures and Fertilisers	1	267.53	133.77	133.77
3.	Sowing	1.5	401.30	200.65	200.65
4.	Layout	2	535.06	267.53	267.53
5.	Grafting	3	802.60	802.60	-
6.	Transplanting	0.5	133.77	66.88	66.88
7.	Hoeing and weeding	3	802.60	401.30	401.30
8.	Fertigation	2	535.06	267.53	267.53
9.	Foliar application	0.5	133.77	66.88	66.88
10.	Staking	4	1070.12	535.06	535.06
11.	Pruning	3	802.60	401.30	401.30
12.	Plant protection sprays	1	267.53	133.77	133.77
13.	Irrigation	1	267.53	133.77	133.77
14.	Harvesting	2	535.06	267.53	267.53
15.	Machinery (Power tiller)	2.5 (Hour) @ Rs. 700/hour	1750.00	875.00	875.00
	Total		**9107.13**	**4954.86**	**4152.27**
	Labour cost/m^2		**36.43**	**19.82**	**16.61**
	*Calculated @ INR. 267.53/manday				

Appendix IV: Economics/cost of inputs of 250 m² polyhouse under protected conditions, 2017-18

Sr.No.	Inputs	Quantity & units	Rate/unit (Rs.)	Cost (Rs.)	Grafted tomato (Rs.)	Non-grafted tomato (Rs.)
1.	Seed (Rootstock)					
	Tomato	4.00 g	300/kg	1.20	1.20	-
a)	Brinjal	2.50 g	1500/kg	3.75	3.75	-
b)	Chilli	2.00 g	1600/kg	3.20	3.20	-
c)	Local Pumpkin	3.00 g (72 seeds)	1/seed	72.00	72.00	-
d)	Seed (Scion GS-600)	8.00 g (4 g each for grafted and non-grafted)	550/8 g	550.00	275.00	275.00
2.	Nylon ropes (for staking)	15.00 kg (7.5 kg each	70.00/kg	1050.00	525.00	525.00
3.	Wiring	4 kg 500 g (2 kg 250 g each)	80.00/kg	360.00	180.00	180.00
4.	Growing media (for nursery)					
a)	Cocopeat	2 kg (1 kg each)	30.00/kg	60.00	30.00	30.00
b)	Perlite	2 kg (1 kg each)	30.00/kg	60.00	30.00	30.00
c)	Vermiculite	1 kg (0.5 kg each)	60.00/kg	60.00	30.00	30.00
5.	Protrays/plug trays	64 Nos (32 each)	25.00/tray	1600.00	800.00	800.00
6.	Grafting clips	1960 Nos.	2.00/No	3920.00	3920.00	-
7.	Cello tape	2 No.	10/No	20.00	20.00	-
8.	Yellow sticky traps	25 No	50/No	1250.00	625.00	625.00
9.	**Manures and Fertilisers**					
a)	Farmyard Manure (FYM)	1 q 8 kg (For Both)	200 /q	216.00	108.00	108.00
b)	Urea	3 kg 24 g	284/50 kg	17.18	8.59	8.59
c)	MOP	2 kg 16 g	48.00/kg	96.76	48.38	48.38
d)	IFFCO (12:32:16)	4 kg 86 g	1105/50 kg	90.30	45.15	45.15
e)	NPK (19:19:19)	1 kg 620 g	150.00/kg	243.00	121.50	121.50
10.	**Insecticides and Fungicides**					
a)	Pyromite	50 ml	110/100ml	55.00	27.50	27.50
b)	Plethora	45 ml	478/100 ml	215.10	107.55	107.55
c)	Dithane M-45	120 g	191/500g	45.84	22.92	22.92
	Total			**9989.23**	**7004.64**	**2984.59**
	Input cost/m²			**39.96**	**28.02**	**11.94**

Appendix V: Labour cost of 250 m^2 polyhouse, 2017-18

Sr.No.	Particulars	Mandays (No.)	Cost (Rs.)	Grafted tomato (Rs.)	Non-grafted tomato (Rs.)
1.	Land preparation	3	802.60	401.30	401.30
2.	Manures and Fertilisers	1	267.53	133.77	133.77
3.	Sowing	1.5	401.30	200.65	200.65
4.	Layout	2	535.06	267.53	267.53
5.	Grafting	3	802.60	802.60	-
6.	Transplanting	0.5	133.77	66.88	66.88
7.	Hoeing and weeding	3	802.60	401.30	401.30
8.	Fertigation	2	535.06	267.53	267.53
9.	Foliar application	0.5	133.77	66.88	66.88
10.	Staking	4	1070.12	535.06	535.06
11.	Pruning	3	802.60	401.30	401.30
12.	Plant protection sprays	1	267.53	133.77	133.77
13.	Irrigation	1	267.53	133.77	133.77
14.	Harvesting	2	535.06	267.53	267.53
15.	Machinery (Power tiller)	2.5 (Hour) @ Rs. 700/hour	1750.00	875.00	875.00
	Total		**9107.13**	**4954.86**	**4152.27**
	Labour cost/m^2		**36.43**	**19.82**	**16.61**
	*Calculated @ INR. 267.53/manday				

Appendix VI: Computation of gross returns, net returns and benefit cost ratio for grafted tomato during the year 2016-17

Computation of gross returns = Yield/m^2 x sale rate

Computation of gross returns for 2016-17 = 26.52 x 20 = 530.40

Computation of net returns for 2016-17 = Gross returns/m^2- Input cost/m^2

Computation of net returns for 2016-17 = 530.40-48.73 = 481.67

Benefit cost ratio for 2016-17 = $\frac{\text{Gross returns/m}^2}{\text{Inputs cost/m}^2}$

Benefit cost ratio for 2016-17 = 530.40/48.73 = 10.88

Appendix VII: Computation of gross returns, net returns and benefit cost ratio for grafted tomato during the year 2017-18

Computation of gross returns = Yield/m^2 x sale rate

Computation of gross returns for 2017-18= 25.44 x 20 = 508.80

Computation of net returns for 2017-18 = Gross returns/m^2- Input cost/m^2

Computation of net returns for 2017-18 = 508.80-48.73 = 460.96

Benefit cost ratio for 2017-18 = $\frac{\text{Gross returns/m}^2}{\text{Inputs cost/m}^2}$

Benefit cost ratio for 2017-18 = 508.80/48.73 = 10.64

Appendix VIII: Computation of gross returns, net returns and benefit cost ratio for non-grafted tomato during the year 2016-17

Computation of gross returns = Yield/m^2 x sale rate

Computation of gross returns for 2016-17= 12.84 x 20 = 256.80

Computation of net returns for 2016-17 = gross returns/m^2- input cost/m^2

Computation of net returns for 2016-17= 256.80-29.44 = 227.36

Benefit cost ratio for 2016-17 = $\frac{\text{Gross returns/m}^2}{\text{Inputs cost/m}^2}$

Benefit cost ratio for 2016-17 = 256.80/29.44 = 8.72

Appendix IX: Computation of gross returns, net returns and benefit cost ratio for non-grafted tomato during the year 2017-18

Computation of gross returns = Yield/m^2 x sale rate

Computation of gross returns for 2017-18= 13.80 x 20 = 276.00

Computation of net returns for 2017-18 = gross returns/m^2- input cost/m^2

Computation of net returns for 2017-18= 276.00-28.55 = 247.45

Benefit cost ratio for 2017-18 = $\frac{\text{Gross returns/m}^2}{\text{Inputs cost/m}^2}$

Benefit cost ratio for 2017-18 = 276.00/28.55 = 9.67

Appendix X: Mean computation of gross returns, net returns and benefit cost ratio for grafted tomato during the year 2016-17

Mean computation of gross returns = Yield/m^2 x sale rate

Mean computation of gross returns for 2016-17= 25.98 x 20 = 519.60

Mean computation of net returns for 2016-17= gross returns/m^2- input cost/m^2

Mean computation of net returns for 2016-17= 519.60-48.29 = 471.31

Benefit cost ratio for 2016-17 = $\frac{\text{Gross returns/m}^2}{\text{Inputs cost/m}^2}$

Benefit cost ratio for 2016-17= 519.60/48.29 = 10.76

Appendix XI: Mean computation of gross returns, net returns and benefit cost ratio for non- grafted tomato during the year 2017-18

Mean computation of gross returns = Yield/m^2 x sale rate

Mean computation of gross returns for 2017-18= 13.32 x 20 = 266.40

Mean computation of net returns for 2017-18= gross returns/m^2- input cost/m^2

Mean computation of net returns for 2017-18= 266.40-28.10 = 238.30

Benefit cost ratio for 2017-18= $\frac{\text{Gross returns/m}^2}{\text{Inputs cost/m}^2}$

Benefit cost ratio for 2017-18= 266.40/28.10 = 9.48

Brief Biodata of student

Father's Name : Dr. Ashok Sharma

Mother's Name : Smt. Brinda Sharma

Date of Birth : 08th December, 1992

Permanent Address with : D/O Dr. Ashok Sharma Vill: Saralu, P.O.Rajpur, Tehsil Palampur District: Kangra, (H.P.) Pin code-176 061

Contact Number : Mobile:- 9459475967

Academic Qualifications:

Qualification	**Year**	**School/Board/ University**	**Marks (%)**	**Major Subjects**
Matriculation	2008	ICSE	72.00	English, Mathematics, Hindi, Science, History, Civics & Geography, Environmental Education, Computer
10+2	2010	CBSE	71.00	Physics, Chemistry, Biology, English, Physical Education
B.Sc. (Hons.) Horticulture	2014	Dr. Y S Parmar University of Horticulture & Forestry, Solan	79.70	All Horticultural subjects
M.Sc. Agriculture	2016	CSK HPKV, Palampur	78.50	Vegetable Science with minor Plant Breeding and Genetics
Ph.D Agriculture	2019	CSK HPKV, Palampur	77.50	Vegetable Science with minor Entomology and Plant Pathology
Thesis Title in Ph.D.		Evaluation of rootstocks for biotic stress management in tomato under protected conditions		
Fellowships/Scholarships/Gold Medals/Awards:		Merit scholarship for Bachelor's Degree from Dr.Y.S.Parmar University of Hort. & Fort. Nauni, Solan (H.P.) Merit scholarship for Master's Degree from CSKHPKV, Palampur, HP, India		
		Merit scholarship for Ph.D Degree from CSKHPKV, Palampur, HP, India		

Research Publications: Full length research papers- 3
Accepted Papers: 4
Book Chapters: 1