

**IMPARTING ROOT KNOT NEMATODE RESISTANCE
THROUGH GRAFTING IN TOMATO**
(Solanum lycopersicum L.)

Dissertation

**Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of**

**DOCTOR OF PHILOSOPHY
in
HORTICULTURE (VEGETABLE SCIENCE)**
(Minor Subject: Botany)

By

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CERTIFICATE I

This is to certify that the dissertation entitled, “**Imparting root knot nematode resistance through grafting in tomato (*Solanum lycopersicum* L.)**” submitted for the degree of Ph.D. in the subject of **Vegetable Science** (Minor subject: **Botany**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Mr. Sumeet Singh (L-2014-A-46-D)** under my supervision and that no part of this thesis has been submitted for any other degree.

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

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CERTIFICATE II

This is to certify that the dissertation entitled, “**Imparting root knot nematode resistance through grafting in tomato (*Solanum lycopersicum* L.)**” submitted by **Mr. Sumeet Singh (L-2014-A-46-D)** to Punjab Agricultural University, Ludhiana, in the partial fulfillment of the requirements for the degree of the Ph.D. in the subject of **Vegetable Science** (Minor subject: **Botany**) has been approved by the Student’s Advisory Committee along with the Head of the Department after an oral examination on the same, in collaboration with an External Examiner.

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ABSTRACT

The present investigation was conducted at Vegetable Research Farm, Department of Vegetable Science, Punjab Agricultural University, Ludhiana for “Imparting root knot nematode resistance through grafting in tomato (*Solanum lycopersicum* L.)” during Autumn season of 2015-2016 and 2016-17. The work plan was divided into three experiments based on different grafting methods which further divided into two different sites i.e. infested with root knot nematode and non-infested soil. Ten rootstocks with combination of two different scions (Punjab Sartaj and Punjab Ratta) were used as experiment material. For infested plots pure culture of nematodes were raised by taking galled roots of tomato plants from infested plots than galls were teased and freshly hatched second stage juveniles were raised and used for inoculum. It was observed that plant and fruit characters like plant height, fruit weight, harvest duration, marketable yield as well as total yield increased in grafted plants over non-grafted plants both in nematode free as well as Nematode infested plots. Further it was also revealed that plants grafted with Tube graft method observed highest success rate and was even responsible for earliness as well as high marketable yield in tomato plants. On evaluation of rootstocks plants grafted on EC-119197 recorded highest plant height, higher total and marketable yield, higher fruit weight and prolonged harvest duration both in Nematode infested and nematode free plots. Whereas plants grafted on rootstock PNR-7 recorded early flowering as well as early picking in infested plots. Rootstock L-097 recorded maximum fruit TSS while plants grafted on rootstock EC-119197 recorded maximum pericarp thickness. No significant effect was observed when grafted and non-grafted plants were examined for lycopene content. Overall rootstock EC-119197 can be used as a resistant rootstock against root knot nematode in addition it can fetch higher yield and better fruit quality.

Keywords: Tomato, nematode, grafting, fruit quality and fruit yield

Signature of Major Advisor

Signature of the Student

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ਸਾਰ-ਅੰਸ਼

ਮੌਜੂਦਾ ਅਧਿਐਨ ਸਾਲ 2015-2016 ਅਤੇ 2016-17 ਦੌਰਾਨ ਪੱਤਝੜ ਦੇ ਮੌਸਮ ਵਿੱਚ ਪੰਜਾਬ ਐਗਰੀਕਲਚਰਲ ਯੂਨੀਵਰਸਿਟੀ ਲੁਧਿਆਣਾ ਦੇ ਸਬਜ਼ੀ ਖੋਜ ਵਿਗਿਆਨ ਫਾਰਮ ਤੇ ਕੀਤਾ ਗਿਆ। ਇਹ ਅਧਿਐਨ ਟਮਾਟਰ ਦੀ ਕਲਮ ਅਤੇ ਜੜ੍ਹ ਮੁੱਢ ਸੰਬੰਧੀ ਤਿੰਨ ਵੱਖੋ-ਵੱਖਰੇ ਪ੍ਰਯੋਗਾਂ ਵਿੱਚ ਵੰਡਿਆ ਗਿਆ। ਇਹਨਾਂ ਤਿੰਨਾਂ ਪ੍ਰਯੋਗਾਂ ਨੂੰ ਦੋ ਵੱਖੋ-ਵੱਖਰੀਆਂ ਮਿੱਟੀਆਂ (ਨੀਮਾਟੋਡ ਪ੍ਰਭਾਵਿਤ ਮਿੱਟੀ ਅਤੇ ਨੀਮਾਟੋਡ ਰਹਿਤ ਸਧਾਰਣ ਮਿੱਟੀ) ਵਿੱਚ ਲਗਾਇਆ ਗਿਆ। ਟਮਾਟਰ ਦੀਆਂ ਦਸ ਵੱਖੋ-ਵੱਖ ਕਿਸਮਾਂ ਦੇ ਜੜ੍ਹ ਮੁੱਢ ਵਰਤੇ ਗਏ ਅਤੇ ਇਹਨਾਂ ਉੱਪਰ ਪੰਜਾਬ ਸਰਤਾਜ ਅਤੇ ਪੰਜਾਬ ਰੱਤਾ ਕਿਸਮ ਦੀਆਂ ਕਲਮਾਂ ਲਗਾਈਆਂ ਗਈਆਂ। ਨੀਮਾਟੋਡ ਪ੍ਰਭਾਵਿਤ ਖੇਤ ਲਈ ਪਹਿਲਾਂ ਤੋਂ ਪ੍ਰਭਾਵਿਤ ਬੂਟੇ ਦੀਆਂ ਜੜ੍ਹ ਗੰਢਾਂ ਲੈ ਕੇ ਉਹਨਾਂ ਨੂੰ ਪੀਸ ਕੇ ਅਤੇ ਦੂਜੀ ਸਟੇਜ ਦੇ ਜੁਵੀਨਾਇਲ ਉਪਜ ਦੇ ਨੀਮਾਟੋਡ ਖੇਤ ਲਈ ਤਿਆਰ ਕੀਤਾ ਗਿਆ। ਅਧਿਐਨ ਤੋਂ ਇਹ ਪਤਾ ਲੱਗਿਆ ਕਿ ਪੌਦੇ ਦੇ ਵਾਧੇ ਅਤੇ ਫਲ ਦੇ ਕਈ ਗੁਣ ਜਿਵੇਂ ਕਿ ਬੂਟੇ ਦੀ ਲੰਬਾਈ, ਫਲਾਂ ਦਾ ਭਾਰ, ਤੋੜਾਈ ਦਾ ਸਮਾਂ, ਬਜ਼ਾਰ ਵੇਚਣ ਯੋਗ ਉਤਪਾਦਨ, ਕਲਮ ਕੀਤੇ ਹੋਏ ਬੂਟਿਆਂ ਵਿੱਚ ਬਿਨ੍ਹਾਂ ਕਲਮ ਕੀਤੇ ਹੋਏ ਬੂਟਿਆਂ ਦੇ ਮੁਕਾਬਲੇ ਜ਼ਿਆਦਾ ਸੀ, ਭਾਵੇਂ ਕਿ ਉਹ ਨੀਮਾਟੋਡ ਪ੍ਰਭਾਵਿਤ ਖੇਤ ਜਾਂ ਨੀਮਾਟੋਡ ਰਹਿਤ ਖੇਤ ਵਿੱਚ ਸਨ। ਇਸ ਤੋਂ ਬਾਅਦ ਟਿਊਬ ਕਲਮ ਵਾਲੇ ਬੂਟਿਆਂ ਦੀ ਸਭ ਤੋਂ ਵੱਧ ਸਫਲਤਾ ਪਾਈ ਗਈ ਅਤੇ ਜਲਦੀ ਪੱਕਣ ਅਤੇ ਵੱਧ ਵੇਚਣ ਯੋਗ ਉਤਪਾਦਨ ਵੀ ਦੇਖਿਆ ਗਿਆ। EC-119197 ਦੇ ਜੜ੍ਹ ਮੁੱਢ ਕਲਮ ਵਿੱਚ ਦੂਜਿਆਂ ਕਲਮਾਂ ਦੇ ਮੁਕਾਬਲੇ ਸਭ ਤੋਂ ਵੱਧ ਪੌਦੇ ਦੀ ਲੰਬਾਈ, ਕੁੱਲ ਅਤੇ ਵੇਚਣ ਯੋਗ ਉਤਪਾਦਨ, ਵੱਧ ਫਲਾਂ ਦਾ ਭਾਰ ਅਤੇ ਜ਼ਿਆਦਾ ਤੁੜਾਈਆਂ ਦਾ ਸਮਾਂ ਦੋਵੇਂ ਨੀਮਾਟੋਡ ਰਹਿਤ ਅਤੇ ਨੀਮਾਟੋਡ ਪ੍ਰਭਾਵਿਤ ਖੇਤਾਂ ਵਿੱਚ ਦੇਖਿਆ ਗਿਆ। ਜਦਕਿ ਜਿਨ੍ਹਾਂ ਪੌਦਿਆਂ ਵਿੱਚ ਜੜ੍ਹ ਮੁੱਢ PNR-7 ਵਰਤਿਆ ਗਿਆ ਉਹਨਾਂ ਵਿੱਚ ਫੁੱਲਾਂ ਦਾ ਛੇਤੀ ਬਣਨਾ ਅਤੇ ਛੇਤੀ ਤੁੜਾਈ ਦੇਖੀ ਗਈ। ਜੜ੍ਹ ਮੁੱਢ L-097 ਵਿੱਚ ਸਭ ਤੋਂ ਵੱਧ TSS ਪਾਈ ਗਈ ਜੋ ਕਿ ਨੀਮਾਟੋਡ ਪ੍ਰਭਾਵਿਤ ਖੇਤ ਵਿੱਚ ਦੋਵੇਂ ਕਲਮ ਕੀਤੇ ਅਤੇ ਬਿਨਾਂ ਕਲਮ ਵਾਲੇ ਪੌਦਿਆਂ ਤੋਂ ਵੱਧ ਪਾਇਆ ਗਿਆ। ਜਦੋਂ ਕਿ ਟਮਾਟਰ ਦੀ ਛਿੱਲੜ ਦੀ ਮੋਟਾਈ EC-119197 ਵਿੱਚ ਸਭ ਤੋਂ ਜ਼ਿਆਦਾ ਪਾਈ ਗਈ। ਜਦੋਂ ਕਲਮਾਂ ਅਤੇ ਬਿਨ੍ਹਾਂ ਕਲਮਾਂ ਵਾਲੇ ਪੌਦਿਆਂ ਦਾ ਲਾਈਕੋਪੀਨ ਦੀ ਮਾਤਰਾ ਲਈ ਅਧਿਐਨ ਕੀਤਾ ਗਿਆ ਉਸ ਵਿੱਚ ਮਾਤਰਾ ਨੂੰ ਲੈ ਕੇ ਕੋਈ ਮਹੱਤਵਪੂਰਨ ਅੰਤਰ ਨਹੀਂ ਦੇਖਿਆ ਗਿਆ। ਜੜ੍ਹ ਮੁੱਢ EC-119197 ਨੂੰ ਨੀਮਾਟੋਡ ਦੀ ਰੋਧਕਤਾ ਲਈ ਵਰਤਿਆ ਜਾ ਸਕਦਾ ਹੈ ਤੇ ਨਾਲ ਹੀ ਇਸ ਨਾਲ ਜ਼ਿਆਦਾ ਉਤਪਾਦਨ ਅਤੇ ਫਲਾਂ ਦੀ ਵਧੀਆ ਗੁਣਵੱਤਾ ਦੇਖੀ ਗਈ।

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CHAPTER – I

INTRODUCTION

Tomato (*Solanum lycopersicum* L., syn. *Lycopersicon esculentum*, $2n=24$) is one of the most important *Solanaceous* vegetable crops. Due to its versatility it's grown widely all over the world. Tomato is also considered as protective food because of its special nutritive value. It shares major part of the daily dishes prepared in Indian kitchen being rich in vitamins, minerals and other phyto-nutraceuticals like lycopene which acts as antioxidants. Hence, it is associated with anti-carcinogenesis properties which play a beneficial role in improving human health. Therefore, it is considered as ‘‘poor man’s orange’’ (Singh *et al* 2004). Tomatoes are used for soup, salad, pickles, ketchup, puree, sauces and in many other ways. Tomato has very few competitors in the value addition chain of processing so, it has wide industrial use. It is second largest vegetable crop grown in India after potato with total area of 786.0 thousand hectare and production of 195.41 thousand MT with a productivity of 28.1 MT/ha (Anonymous 2018). In Punjab it is grown on an area of 10.17 thousand hectare with an average yield of 24.88 MT/ha with a total production of 25.26 MT (Anonymous 2019).

Tomato productivity is dependent on number of agronomic practices used for culturing disease and pest free crop. Although among these diseases soil borne pathogens plays an adverse effect on tomato crop. In order to achieve high yield of tomato, most of the production system uses synthetic chemicals and pesticides which are ultimately induced in the food chain and affecting human health. In India, tomato growers are mostly small and marginal farmers who are generally associated with intensive cultivation which gives high returns in early years, but later leads to the development of severe soil health problems. Although crop rotation can be practiced to control the soil borne pathogens but area under vegetable production system is restricted and the host can persist in the soil for many years. So it becomes very difficult to prepare a pathogen free land. This situation is further aggravated in protected cultivation of vegetables under net and poly-houses where same piece of land is used for same set of vegetables every year. This practice of monoculture and intensive cultivation has increased the intensity of soil born pathogen and affecting vegetable production system. A survey report of India revealed that samples of number of vegetables including tomato are having high in chemical residues (Anonymous 2015). So the use of these hazardous chemicals has become commonly adopted practice by farmers to overcome the losses occurred due to disease and pests. Diseases resistance varieties are good alternative for cultivation in disease prone areas. Resistant varieties produced with the help of conventional breeding techniques or by using biotechnological tools can be explored but they are time consuming and require a huge investment. In this situation there is need to find such

techniques which can be easily adopted by farmers and moreover acceptable to consumers. Grafting can be one of them as it is quick, practical in its application and eco-friendly and focusing for bumper produce. Vegetable grafting has been proved and useful in sustaining production and reducing the soil borne host pathogen. Grafting is mostly related to biotic and abiotic stress tolerance. Recently, due to ill effects of chemicals on human and environment, the market of organic products is increasing day by day. It can be observed from various research works on grafting that it is one of the best methods to be included in tomato production system as well as for the organic farming practices. Grafting gives quick results in combining traits from two plants, one in shape of root system (rootstock) and the other as a shoot (scion). Grafting is now common in many parts of the world not only to manage a broad range of pathogens including fungi, bacteria, nematodes and viruses (Fernandez-Garcia *et al* 2004) but for improving quality parameters also. South East Asia is becoming a largest market for grafted plants where 99 % of grafted watermelons are grown in Korea, 94 % in Japan and 40 % in china (Bhatt *et al* 2015). Similarly, grafting plays a significant role in *Solanaceous* crops to protect tomato from abiotic and biotic stress (Boncato and Ellamar 2015) nearly 60-70 % of tomatoes grown under protected cultivation for this purpose (Suchoff *et al* 2018).

Area under grafted plants increased due to ban on soil fumigant methyl bromide under Montreal Protocol 2005 (Besri M 2005). Canada and Mexico is exporting millions of tomato plants to North America, (Suchoff *et al* 2018). In India vegetable grafting is still in infancy due to lack of knowledge, awareness and non-availability of facilities required for vegetable grafting.

Besides soil borne pathogens, vegetable grafting has been used to induce resistance against low and high temperatures; to enhance nutrient uptake (Ruiz *et al* 1997); to improve the yield when plants are cultivated in infected soils (Kacjan-Marsic and Osvald 2004); to increase the synthesis of endogenous hormones (Proebsting *et al* 1992); to improve water use (Cohen and Naor 2002); to increase flower set and seed production (Lardizabal and Thompson 1990); to enhance vegetable tolerance to drought, salinity and flooding (Estan *et al* 2005). Interaction between rootstocks and scions results in higher vigour because of well established root system which enhances water and mineral uptake leading to increased fruit yield. Many other factors have been considered for successful grafting like successful cultivation and satisfactory income by judicious use of chemical fertilizers and synthetic pesticides (Sakata *et al* 2007). Off season cultivation of tomato enhances the profit to many farmers by early marketing and disease free produce.

Grafting has been practising on commercial level with many different methods. It generally depends upon the kind of crop, facilities available, mechanisation, purpose of grafting (for self use and commercial nursery) and most importantly farmer's experience. In

tomato tube graft or splice graft method has been used for commercial production of seedlings. In short tongue and cleft graft method can be used by farmers with small scale and less experience where as for commercial and high scale splice and robotic machines are used for grafting.

Root knot nematode is very harmful to the crop which leads to severe loss to the farmers financially and does not have a proper remedy for controlling this disease. Grafting can be the best alternative method to solve these problems both in the field and net/poly house cultivation. It is being practiced in Solanaceous and Cucurbitaceous crops. Although many rootstocks have been standardised for tomato production worldwide but the presence of the pathogens and occurrence of diseases are impacted by geographical, ecological, environmental and anthropogenic factors that affect rootstock selection. India has potential germplasm of these vegetables which can be exploited for grafting as well as for selection of ideal rootstock. But, a little information is available regarding grafting for disease free produce along with its economic feasibility under Indian conditions. Therefore, the present study entitled “Imparting root knot nematode resistance through grafting in tomato (*Solanum lycopersicum* L.)” has been conducted with the following objectives:

- To study the compatibility of root stocks and scion in tomato
- To standardize method of grafting against root knot nematode in tomato
- To evaluate identified root stock-scion combination for growth, yield and quality

CHAPTER – II

REVIEW OF LITERATURE

In many parts of Asia and Europe grafting vegetable crops has become a common practice. Although, it was introduced to control *Fusarium wilt* in watermelon (Murata and Ohara 1936), but its ability to confer resistance against wide range of disease have expanded its use in many *Cucurbits* and *Solanaceous* crops. Tomato grafting was practiced at commercial level in 1960's (Lee and Oda 2003) and has now become an important cultivation practice for the tomato crop in many parts of the world. So, now used broadly for managing nematodes (RKN) all over the world, but little work has been carried out in naturally infested soils. Nematodes are obligate endoparasites that infect more than 1,700 plant species. Although more than 50 species of *Meloidogyne* have been described which harm plants but four species that is *M. incognita*, *M. arenaria*, *M. javanica*, and *M. hapla*, are considered the most important species which cause high damage to crops economically (Lee and Oda 2003). In countries like USA nematode species *M. incognita* is most prevalent on tomato and generally occurs in southern part of the country and *M. hapla* occurs in northern climates. When population of nematode is less they may cause little damage to crop, but severe infestations result in extensive root-galling which causes wilting and nutritional deficiencies which ultimately causes stunting of the plant. Although, chemicals can be used for managing disease and are also cost effective but due to high residual effect of soil fumigants nematicides like methyl bromide, methyl iodide and 1, 3-dichloropropene is currently in the process of worldwide phase out. Cultural practices like crop rotation with non hosts may help in reducing root galling among susceptible vegetable crops but wide range of host and non-profitable rotations may become economically less viable. Many commercial tomato cultivars carry a major gene *Mi* for resistance in tomato. It was identified in accession *Lycopersicon peruvianum* and successfully introgressed into commercial varieties which confer effective resistance against *M. incognita*, *M. arenaria*, and *M. javanica*. Programmed cell death (PCD) (P=0.05) was mediated by *Mi*-gene which caused resistance, a hypersensitive response (HR) occurs resulting in cell death and ultimately disruption of the nematode life cycle. This resistance mechanism is effective, but can be lost at soil temperatures above 28°C (Ioannou 2002).

Overall, grafting can allow two genetically different plants to fuse together and work as one plant so for a quicker genetic resistance and a reduction in the use of chemicals grafting may be useful. Valuable susceptible cultivars that are not resistant to specific soil-borne pest and diseases can be grown. The only requirements of rootstocks are that they should be compatible with the scion and provide the desired traits without contributing negative traits. This allows a breeder to use more divergent germplasm as a source of

resistance in the form of rootstock. Most rootstocks currently available resulted from screening pre-existing germplasm and very few were developed by making crosses to generate variation and selecting superior genotypes (King *et al* 2010). It is probable that tomato and eggplant rootstocks developed with the *Mi-3* gene for nematode resistance would be useful for conditions where soil temperatures exceed 30°C (Ioannou 2001).

2.1 Tolerance against disease

Tomato production is limited worldwide due to diseases and is severely constrained due to infestation by root-knot nematodes (RKN, *Meloidogyne* species) on other hand crop has a very limited genetic variation which makes it more vulnerable. Root knot nematode invades root system of plants resulting in formation of galls on roots hindering nutrient and water uptake of plants hence damaging roots of plants. The damaged roots also become susceptible to other plant pathogens (Abad *et al* 2003). There is a high economic loss caused in tomato by RKN which is generally ranging between 30-75 percent (Palacios and Moss 1972). Different methods such as chemical, conventional agricultural practices and resistance breeding etc. have been devised to manage RKN but are not up to the mark and hence, grafting is becoming an alternative technique for controlling RKN. In tomato production system, plants grown under protected structures are highly affected by root-knot nematode (*Meloidogyne* spp.).

Grafting is becoming a promising alternative to soil fumigants and an emerged as a valuable tool in integrated pest management practice in various crop production systems (Kubota *et al* 2008). Beaufort when used as rootstock can significantly reduced root galling (Kaskavalci *et al* 2009). Similar results were obtained by Burelle *et al* (2016). Where they observed that non-grafted plants of Florida 47 showed more root galling than plants grafted on rootstock TX301, Multifort and Aloha further reported that plants grafted on TX301 also reported higher yield among other grafted plants as well as non-grafted plants of Florida 47. While investigating quality parameters of plants, fruit of plants grafted on Maxifort had higher TSS as well as higher pericarp thickness than non-grafted plants of Florida 47. Cary *et al* (2008) showed that grafting on “Maxifort” rootstock in heirloom tomato showed similar yield result as done under fumigation of methyl bromide under root knot Nematode infested soil. Lopez-Perez *et al* (2006) also observed that when different nematode resistant rootstocks were used under high nematode densities reported less galling index than non-grafted plants but at final population uneven resistance was reported although lesser gall count was recorded in grafted plants. Similarly a research conducted in Spain showed an uneven infection patterns as well as uneven production rate juveniles (*M. javanica*) in tomato. Among 10 rootstocks all were conferred with the *Mi* genes, on examining these rootstocks cultivars Maxifort and Beaufort were susceptible to infection. Similar results were seen when plants were grown in greenhouse where *M. incognita* on Beaufort rootstock was found to be susceptible, but fruit

yield was not affected by nematode damage, suggesting host tolerance. In conclusion of this study it was indicated that *Mi* gene is not functioning in a manner that is typical of HR-mediated resistance in some inter-specific hybrid tomato rootstock cultivars, including Maxifort and Beaufort. These rootstocks are commercial most viable and are grown at very large area in USA (United states of America) further Maxifort has been recommended for production of organic heirloom tomato. The ability of these rootstocks for providing resistance in naturally infested soils is vulnerable but relevance of grafting has become a viable tactic for disease control and yield benefits in organic and conventional tomato production systems in North Carolina. So, it was further suggested that hybrid rootstock which carry *Mi 3* genes may serve the purpose and new rootstocks may be introduced for controlling root-knot nematodes. An experiment was conducted by Charles *et al* (2012) in which they suggested that there was a significant reduction in galling when hybrid rootstocks (Survivor rootstock) were used as compared to non-grafted and self-grafted plants. A reduction in population around 80.8% was reported in organic field and by 97.1 percent in transitional field. Heterografting has been used in early stages of grafting where weed Jimson (*Datura stramonium* L.) was used as a rootstock for grafting sweet pepper, tomato and eggplants which recorded high resistance to nematode (Lowman and Kelly 1946). Similarly Dao-feng *et al* (2007) conducted an experiment to study the effect of nematodes on grafted plants and concluded that plants grafted on rootstock Maxifort, Beaufiort and Arnold produced higher yield as compared to the non-grafted ones. Deng *et al* (2007) took nine rootstocks which were resistant cultivars of tomato against *M. incognita* and conferred *Mi*-gene mediated resistance. These were used for grafting with ‘Zhongza No.9’ as scion in solar-greenhouse production. Superior horticulture characters were observed in grafted plants and galling on roots of resistance rootstocks suggested that rootstock cultivars ‘041-373’, ‘031D158’, ‘Genaros’, ‘Baofa009’ and ‘Trs-401’ were all resistant (‘R’) to nematode both in filed and in artificially inoculated pot area in tomato production.

Northern area of USA is highly infested with *S. rolfsii* and *M. incognita* causing high damage to organic tomatoes. An experiment was conducted by Rivard *et al* (2010) at a location where soils were naturally infested with RKN, and three rootstocks were used. Plants grafted on rootstock ‘Big Power’ were highly effective at reducing RKN galling and even effected soil populations of root knot nematode which recorded significant reduction in population at final fruit harvest when compared with non-grafted ones and some of other grafted plants. On observing yield characters maximum fruit yield was observed in tomatoes that were grafted on Big Power as compared to plants grafted on Beaufort and Maxifort. Beaufort and Maxifort had a similar level of root galling as in non-grafted or self-grafted plants. In MAKIS-project, Marian *et al* (2011) revealed a demonstrative plot which indicated that a significant reduction in incidence of attack produced by *M incognita* and *Fusarium*

oxysporum f.sp.lycopersici was significantly reduced when plants were grafted on resistant rootstocks. Kunwar *et al* (2015) used grafting as a tool for managing root-knot nematodes and bacterial wilt. They used a susceptible scion to nematode ‘BHN 602’ was used. BHN 602 was grafted on rootstocks RST-04-106-T, BHN 998, and BHN 1054 which reported high resistance against root-knot nematodes and against bacterial wilt. In conclusion grafted plants demonstrated high resistance against both diseases and were able to generate significantly higher yield than non-grafted plants which also represents the potential of grafting for managing multiple pathogens using the similar rootstocks so can be concluded that grafting can be one of the best alternatives for sustainable crop productivity in nematode-infested soils. A two year experimental trial was conducted by Burelle *et al* (2016) in field for evaluation of grafted plants and with chemical treatments in *Meloidogyne incognita* infested field and Paladin Pic-21 (dimethyl disulfide: chloropicrin) was found as best treatment among chemicals for controlling disease (root-knot nematode) in tomato and melon but found that grafting commercial scions onto *M. incognita* resistant rootstocks has a good potential for nematode management combined with soil treatments or as a stand-alone component in crop production systems.

In an experiment conducted by Lu *et al* (1992) a wild tomato plants was used as a rootstock with resistance to bacterial wilt for a local Chinese tomato cultivars. The rootstocks ‘CH-2-26’ was able to control 100 percent attack of bacterial wilt where as ‘CH-2-25’ and ‘CH-2-21’ controlled nearly 86.7 percent and 80.0 percent respectively, further delaying symptoms of disease until the 25th and 40th day after planting, compared to the susceptible plants. Many other rootstocks like H7996 has been recommended for tomato rootstocks for its high level of resistance to bacterial wilt (Wang *et al* 1998). Many areas of Brazil are highly infected by *R. solanacearum* where tomato cultivars are highly susceptible to this infection because of suitable environmental conditions. *Solanum* genera harbors resistance against *R. solanacearum*. Rootstock like ‘Anchor T’ and ‘BGH 3472’ (*S. lycopersicum*) Jurubeba (*S. jurubeba*), and Juna (*S. toxicarium*) has been used as resistant rootstock (Peil 2003 and Goto *et al* 2010) and successfully grafted plants are produced. Intergenic or heterografting by utilizing *Solanum nigrum* may also prove useful against nematode attack in tomato (Satpathy and Pradhan 1996). In northern conditions of India tomato rootstocks like, Nematex, SL-120, Banarj Joint, PV-1 and Hisar Lalit gives complete resistance against nematode infection (ICAR 2015). A tomato hybrid KNVF was used against nematode in France (Rezoni and Lamberi 1974).

An experiment was conducted by Attia *et al* (2003) to study the effect of grafted and non-grafted plants of pepper (cv. Gedon) when grown under infested conditions. Soil was infested with *Rhizoctonia root rot* and *Fusarium wilt*. They reported that grafted plants were significantly less prone to attack of wilt but non-grafted plants grown in the infested soil were

severely infected with wilt disease. When plants of sweet pepper (cv. Gedeon) were grafted on 'California Wonder' which recorded highest yield as well as best fruit characters, it obtained highest fruit length, fruit diameter and fruit weight. Whereas when cv. Gedeon was grafted on 'Chili Putih Kelanten' maximum vigor was obtained and highest flower count was also recorded. Moreover, to introgress resistance to bacterial wilt in tomato cultivars is a difficult job as it is influenced by quantitative gene effect and strongly influenced by the environment (Scott *et al* 2005). So use of a specific rootstock has been exploited well to manage bacterial wilt in tomato (Lin *et al* 2008 and Rivard *et al* 2012). In year 2005 and 2006 Rivard and Louws (2006) conducted a field trial to check the efficiency of grafted plants against soil-borne disease in which heirloom tomato were grafted on resistant rootstocks. In conclusion high resistance was reported against wilt which recorded a control percentage of 75% in year 2005 and 79% in 2006, respectively. On further analyzing there was complete check on disease when Heirloom scion was grafted rootstock 'Maxifort' which showed no symptoms of *Fusarium wilt* (caused by *Fusarium oxysporum* f.sp. *lycopersici*) whereas non- and self-grafted plants recorded a disease incidence of 45-50%.

In the northern part of USA again an experiment was conducted by Rivard and Louws (2008) in which high resistance was reported when heirloom tomato scion was grafted on 'German Johnson' and 'Maxifort'. They also concluded that host specific rootstock may also be vulnerable to disease after a particular time period so there is need of new rootstocks (Garibaldi *et al* 2008 and Rivard *et al* 2010). They found that rootstock 'CRA 66' and 'Hawaii 7996' (breeding lines) reported high resistance against bacterial wilt. In a study conducted by Minuto *et al* (2008) compared different rootstock and suggested that rootstock 'He-man' and 'Energy' conferred more resistance against *C. coccodes* infestation than 'Beaufort'. Similarly in another experiment three different rootstocks were compared against *Sclerotium rolfsii* in which tomato rootstock Big Power, Beaufort and Maxifort were tested in naturally infested fields. It reported only 0% to 5% of disease incidence among grafted plants than non-grafted or self-grafted plants (Rivard *et al* 2010). Hence, grafting is becoming a potentially new alternative besides methyl bromide in tomato for controlling soil-borne disease (Louws *et al* 2010, Louws 2012 and McAvoy *et al* 2012).

A study was conducted by Cardoso *et al* in the year 2012 to examine different rootstocks. They reported that Hawaii 7996 was highly resistant against bacterial wilt. In another experiment BHN 602 was grafted onto rootstock BHN 1054, Cheong Gang, BHN 998 and RST-04106-T which showed signs of tolerance to bacterial wilt (McAvoy *et al* 2012). In an experiment conducted by Gilardi *et al* (2014), around 19 genotypes were evaluated in naturally infested soils of *C. coccodes*. They found that rootstock such as 'Rugantino' demonstrated high resistance against *C. coccodes* and recorded least infected roots with a 32 % infected roots. Further plants of 'Tomahawk' was grafted on rootstocks Arnold, Armstrong

and Superpro V295 also recorded less incidence of disease than other grafted plants. In another experiment of King *et al* (2008) Methyl bromide was proven non effective for control of bacterial wilt because of high re-colonization rates, and alternative soil fumigants such as Telone C35 (1,3-dichloropropene and chloropicrin; Dow AgroSciences LLC, Indianapolis, IN) and chloropicrin (Arvesta Corp., San Francisco, CA) have little efficacy in controlling the disease (Driver and Louws, 2002).

Europe began to adopt grafting as part of an integrated approach to replace methyl bromide, and grafting is now in wide spread use in countries of the Mediterranean Basin. Besides used as an alternative for soil-borne pathogens many researchers have used different rootstocks for controlling different pathogens. Even foliar diseases have also been controlled with the help of grafting. Certain diseases like TMV virus has been successfully controlled with the help of grafting. Nishi (2001) stated that if scion carries a certain amount of resistance against virus that can be escalated with the use of resistant rootstock. Some researchers have even found grafting to be an advantage over methyl bromide as a result of comparable disease resistance, reduced environmental impact, improved performance in addition to disease resistance and also reduced the cost (Miguel *et al* 2004).

2.2 Yield increase and fruit quality

Many studies have revealed that grafting carries a significant effect on yield attributes of crop and has an overall increment in marketable yield of tomatoes when compared to the non-grafted cultivars (Barrett *et al* 2012, Djidonou *et al* 2013, Rivard *et al* 2010 and Rysin and Louws 2015).

For getting higher yields from infested soils use of soil fumigant is now phasing out which may create a problem of getting luxuriant yields in infested soils but grafting now is covering a major area for getting high yields in infested soils and were used at high levels in world's major production areas like USA, Europe, and Asia (Qiao *et al* 2010, Deacon *et al* 2016, Desaegeer *et al* 2017 and Grieneisen *et al* 2017). Although grafting was considered majorly for imparting resistance in tomatoes besides that available rootstocks somehow also demonstrated more economic returns as it favored a bumper crop over non-grafted plants (Rivard and Louws 2008, Louws *et al* 2010; Gilardi *et al* 2013, Burelle *et al* 2016 and Reddy 2016). Even many reports have been published that grafted plants are capable of producing high yields in comparison of fumigation treatments in pathogen infested experimental systems (Rivard *et al* 2010 and Burelle *et al* 2016). Other studies which did not include a fumigation treatment have reported achieving high yields in pathogen-infested fields through the use of grafted tomatoes with rootstocks resistant to the pathogens involved (López-Pérez *et al* 2006, McAvoy *et al* 2012; Rivard *et al* 2012). Remarkable results from farmers have created a perception among many farmers that grafted plants are able to produce higher yield in tomatoes but in addition, the effects of grafting on fruit quality has also been successfully

obtained by farmers (Flores *et al* 2010 and Kyriacou *et al* 2017). Khah in year 2005 conducted an experiment that grafted plants have higher plant height, leaf area index, as well as the fresh and dry weights of stems and leaves, yield and early yield was also reported which was comparatively higher than the non grafted plants. Enhanced water and nutrient uptake improved stomatal conductance in tomato when grafted onto vigorous rootstock (Fernandez-Garcia *et al* 2004) subsidiary improving photosynthesis rates of grafted plants which further helped in increasing crop productivity (Matsuzoe *et al* 1993). According to Besri (2003) 15-20% of yield increase was reported for the grafted tomatoes even when only half of the plants were planted. Grafting resulted in bigger fruit size in tomatoes, and thus increased the yield (Pogonyi *et al* 2005). Similar observation was also recorded by Gisbert *et al* (2011) and Rahman *et al* (2002) when they grafted eggplant cultivars onto perennial and wild Solanaceous species. Khah (2005) reported that fruits harvested from the grafted eggplants plants had lesser number of seeds than the fruits harvested from non-grafted plants. Grafting also affects shape, skin color, skin or smoothness of rind, texture of fruit flesh, soluble solids concentration, firmness and improves postharvest life of the fruits in pepper, tomato and eggplants as affirmed by Nkansah *et al* (2013) and Cheng *et al* (2012). In an experiment conducted by Tsouvaltzis *et al* (2004) found that tomato cultivar, ‘Sacos’ was grafted onto ‘Primavera’ which helped in absorption of calcium more than non-grafted plants. Similar results were also confirmed by Khah *et al* (2006) when they grafted tomato onto ‘HeMan’ rootstock.

Many scientists have reported the benefits of grafting on yield increase, under both stress and non-stress conditions, which mainly depends upon the rootstock genotype (Kacjan-Marsic and Osvald 2004; Khah *et al* 2006; Leonardi and Giuffrida 2006 and Pogonyi *et al* 2005). In another experiment of Khah *et al* (2006) he demonstrated that when tomato scion ‘Big Red’ was grafted onto ‘He-man’ rootstock it produced higher total yield in open-field as well as in greenhouse without any adhering fruit quality characteristics of tomato. Kacjan-Marsic and Osvald (2004) obtained significantly higher (27%) fruit yield per plant when tomato scion ‘Monroe’ was grafted onto ‘Beaufort’ rootstock, whereas the fruit yield decreased by 33% with the use of scion ‘Belle’ as compared with their respective non-grafted plants. Marsic and Osvald (2004) observed the influence of grafting on yield of two tomato cultivars (*Solanum lycopersicum* L.) grown in a plastic house. They found higher yield of fruit of cv. ‘Monroe’ when grafted onto rootstock of Beaufort.

Similarly, Pogonyi *et al* (2005) reported an increased yield using ‘Lemance’ tomato scion grafted onto ‘Beaufort’ rootstock. This yield increase in grafted tomato was mainly due to higher fruit biomass and greater number of fruits per plant than non-grafted plants.

A significantly higher yield was obtained when a susceptible tomato scion ‘Blitz’ was used on resistant rootstock ‘Beaufort’ which recorded higher yield than non-grafted plants

(Lopez-Perez *et al* 2006). Davis *et al* (2008) studied the effect of grafting on vegetable quality parameters and concluded from their study that grafting can affect various quality aspects of vegetables. Cantu *et al* (2009) evaluated the yield and growth of tomato cv. 'Paron' grafted on rootstocks with different agronomic specificities and concluded that grafting did not interfere with the production or quality of the fruits, but caused shortening of the internodes in the tomato cultivar. Mohammed *et al* (2009) found that grafting increased productivity of tomato up to 21% as compared to non-grafted plants when grown under infested conditions. An experiment conducted by Poudel and Lee (2009) to check the response of tomato when grafted on eggplant and concluded that total soluble solid (Brix), total yield and average fruit weight were significantly influenced by eggplant rootstocks and recorded higher yield than non-grafted plants. Di Gioia *et al* (2010) examined different the influence of rootstock on vegetative growth, fruit yield and fruit quality in tomato and concluded that when grafting is done with an appropriate rootstock-scion combination improved the plant growth and marketable yield without reducing the sensory quality of the fruit or its biochemical parameters as well. Turkmen *et al* (2010) observed in an experiment on effect of different rootstocks and cultivars on yield and some yield components of grafted tomato and recorded that grafting has a great potential to increase the growth and yield of tomato.

Turhan *et al* (2011) observed that the tomato fruit quality attributes such as lycopene content and pH were not changed with grafting, whereas vitamin C, TA, and SSC were decreased in grafted plants. Vrcek *et al* (2011) reported that vitamin C, total phenolics, and total antioxidant activity in tomato declined because of grafting. Gebologlu *et al* (2011) found in their study on grafted tomato under soilless culture that grafted plants increased the yield depending on the rootstock. In experiment conducted by Turhan *et al* (2011) explained that tomato fruit yield and fruit index, number of fruits/truss and fruit weights were improved by grafting. Fruit quality, measured in terms of dry matter, concentration of soluble solids, total sugar, and vitamin C content, was lower in the fruits of grafted plants than in non-grafted ones. No significant difference in lycopene and pH content was found. Titratable acid content was improved by grafting. A positive effect of grafting was recorded when Beaufort was used as rootstock. Barette *et al* (2012) observed no significant differences in fruit parameters like vitamin C, soluble solids content (SSC), pH, or total titratable acidity (TTA) when fruits from nongrafted, self-grafted, and grafted 'Brandywine' (with the two different rootstocks) were compared accordingly in both the years of experiment. Moncada *et al* (2013) reported the effect of grafting on yield and quality of eggplant (*Solanum melongena* L.) and concluded that the grafting of eggplant onto *Solanum torvum* increased the size of the fruit and had no negative effect on yield and quality and showed very good compatibility. Kumar *et al* (2015) demonstrated that fruit quality traits such as skin color, fruit shape index, titratable acidity (TA), soluble solids content (SSC), and dry matter content are positively affected by the

rootstock. Fullana-Pericas *et al* (2018) assessed the performance of the ‘Ramellet’ tomato, when grafted onto different rootstocks and they found significant correlation between water-use efficiency, plant growth and yield. Overall, the results highlight the potential of grafting to alter several physiological traits of local landraces and to provide new clues towards advancing our understanding in the underlying determinants of water-use efficiency and plant yield.

Ibrahim *et al* (2014) and Al-Harbi *et al* (2016) reported an increase of yield and WUE in tomato cv. Faridah grafted onto the inter-specific tomato hybrid “Unifort” (*S. lycopersicum* L. × *S. pimpinellifolium* L.), grown under both full and deficit irrigation regimes. Grafting onto vigorous rootstock contributes to enhanced nutrient uptake and translocation of grafted plants (Savvas *et al* 2010).

Krumbein and Schwarz (2013) demonstrated that the enhancement of carotenoids (lycopene and b-carotene) and flavor compounds (sugars, acids, and aroma volatiles) in tomato fruits grown under shaded condition depends on rootstock–scion combinations. In summary, the quality characteristics of grafted tomato fruits are greatly influenced by rootstock–scion combinations, growing system, and environmental conditions.

2.3 Plant vigour promotion

For instance, both net CO₂ assimilation rate (AN) and stomatal conductance (gs) have been reported to increase after grafting scion onto a vigorous rootstock in tomato (He *et al* 2009, Lee *et al* 2010, Liu *et al* 2011, Penella *et al* 2016 and Yang *et al* 2015) as well as in other crops like watermelon (Yang *et al* 2012), apple tree (Liu *et al* 2012) and orange tree (Machado *et al* 2013). These results indicate that grafting alters the intrinsic water-use efficiency at leaf level (Water Use Efficiency, estimated as the ratio of AN/gs) (Kumar *et al* 2017)

While considering one aspect of weed management is of plant vigour which is directly related to competitiveness of weeds with grafted plants on field. In a study of weed management vigorous grafted tomatoes over powered growth of certain broad leaf weeds. In short grafted tomato was considered more vigorous than weed as well as non-grafted tomato (Kacjan-Marsic and Osvald 2004 and Khah *et al* 2006). In further investigation it was concluded that grafting has no apparent advantage or disadvantage in weed competitiveness or suppressing weed growth. The development of an adequate root system structure has been related to improved growth of melon plants grafted onto *Cucurbita* species (Bletsos 2005). Khah *et al* (2006) concluded from their study that grafted plants were more vigorous and produced higher yield than non grafted plants. Grafting onto interspecific rootstocks (*S.lycopersicum* × *S. hirsutum*) improved plant vigour and led to crop two-branch plants. The same yields were obtained with half the plant density, and moreover, without reducing the

quality of the fruit.

A study was carried by Leonardi and Giuffrida (2006) on tomato ('Rita' F1) and eggplant ('Mission Bell' F1) grafted with three rootstocks (Energy, PG3 and Beaufort) and self-grafted (control). Self-grafted tomato plants and those grafted on intra-specific rootstocks (PG3 and Energy) were less vigorous and produced less dry epigeous biomass than plants grafted on inter-specific rootstock (Beaufort).

Previous studies showed no difference in the biomass of weeds between grafted and non-grafted tomato (Ghosheh *et al* 2010 and Chaudhari *et al* 2016b), indicating that grafting in tomato does not eliminate the need for timely application of herbicides, intensive hand-weeding, or both. However, grafting has been found to have a positive impact on management of parasitic weeds such as broomrape species (*Phelipanche aegyptiaca* and *P. ramosa*). Dor *et al* (2010) demonstrated that resistant rootstock significantly reduced broomrape infections when grafted to either a susceptible or resistant (self-graft) scion. The other challenging aspect of weed management is to know the tolerance of grafted plants to herbicides which are registered to use for weed control in nongrafted crops. 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 provide the best results in terms of plant survival, plant vigour, earliness and yield, without detrimental effects on quality.

2.4 Abiotic stress

Abiotic stress is the most important limiting factor in the current climatic situation for plant growth and horticultural productivity worldwide. Extreme temperature, draught and salinity are the major ones which have influenced crop productivity the most (Schwarz *et al* 2010). Increasing global warming, expansion of the saline affected area and lack of availability of quality water storage in arid lands are becoming a limiting factor for crop production and climatologists believe that the combined environmental stress in the tropics will only get worse over time. Though several stress tolerant cultivars have been produced through breeding but the complex nature of the genetic tolerance of environmental factors makes it difficult and time consuming (Ashraf and Foolad, 2007) and grafting can be a rapid alternative to develop abiotic stress tolerant planting material. Various research studies have shown that, grafting can remarkably enhance extreme temperature tolerance in plants. low temperature stress were remarkably enhanced in tomatoes when it was grafted unto high altitude rootstock 'LA 1777' of *S. habrochaites*, 'KNVF' (the interspecific hybrid between *S. lycopersicum* × *S. habrochaites*) and a back cross hybrid rootstocks between *S. habrochaites* 'LA 1778, x *S. lycopersicum* cv. T5 (Okimura *et al* 1986, Bloom *et al* 2004 and Venema *et al* 2008). As these rootstocks are related to the eggplants it is possible that they can be used to improve vegetative growth and yield of eggplants at very low temperature (Gao *et al* 2006).

Torvum vigour' and accession of *S. torvum* can also be used as rootstock for both tomato and eggplant to impart low temperature tolerance (Okimura *et al* 1986). The use of cold tolerant rootstock for grafting has been demonstrated as one of the best alternatives to overcome the low temperature stress in tomato (Ntatsi *et al* 2014 and Riga 2015). Venema *et al* (2008) reported that tomato breeding line 'LA 1777' (*S. habrochaites*) when used as a rootstock improved cold tolerance in grafted plants by mainly increasing the root mass ratio compared with non-grafted plants. The adaptation of grafted plants onto 'LA 1777' was attributed to the higher level of antioxidant compounds in tomato shoots as a consequence of significantly higher levels of soluble carbohydrates, total amino acids, guaiacol peroxidase (GPX) activity in leaves and fruits, and superoxide dismutase activity in fruits (Ntatsi *et al* 2014). Furthermore, Ntatsi *et al* (2011) demonstrated that rootstock which induces abscisic acid production could significantly reduce photo inhibition and improve tomato growth rate under cold stress. Suchoff *et al* (2018) found that 'Multifort' rootstock significantly reduced the amount of cold-induced stress as observed by larger leaf area and higher levels of CO₂ assimilation and photosystem II quantum efficiency. 'Multifort' had significantly longer roots, having 42 % to 56 % more fine root (diameter less than 0.5 mm) length compared with the other nongrafted and grafted treatments. The ability for 'Multifort' to maintain root growth at suboptimal temperatures may improve root system sink strength, thereby promoting movement of photosynthate from leaf to root even under cold conditions. This work demonstrates that a commercially available rootstock can be used to improve suboptimal temperature tolerance in cold-sensitive 'Moneymaker' scions.

Several researches have demonstrated that different tomato rootstocks have high temperature tolerance and have the ability to transfer tolerance to scions when appropriately grafted (Bloom *et al* 2004, Venema *et al* 2008 and Zijlstra and Nijs 1987). Wild species of tomato have wider temperature thresholds than the domesticated lines and can be used as root stocks (Venema *et al* 2005). The grafted plants exhibited greater quantity of flowers, trusses and fruit production in when compared to non-grafted controls at temperatures considered non-optimal for the scion. However, using eggplant rootstock may be more promising for higher temperature. Apart from this various other heat-tolerant rootstocks offers a certain degree of resistance against thermal stress in tomato (Rivero *et al* 2003b). Chilli pepper rootstocks (*C. chacoense*, *C. baccatum*, *C. frutescence*, and *C. annum*) also improved performance of the scions and confirmed high yields under high-temperature environments (Palada and Wu 2008). Similarly when eggplants scion (*S. melongena* cv. *Yuanqie*) grafted onto heat-tolerant rootstock (*S. melongena* cv. *Nianmaoquie*) performed very well, giving a significant increase in growth and yield by 10 % (Wang *et al* 2007). Tomato scion 'Tmknvf2' grafted onto 'RX-335' rootstock had performed better in terms of vegetative growth at a higher temperature (35⁰C) than nongrafted plants (Rivero *et al* 2003a, 2003b). Similarly, in

Germany, Abdelmageed and Gruda (2009) documented the positive effects of grafting when tomato scion 'UC 82-B' grafted onto heat-tolerant tomato 'Summerset' or eggplant 'Black Beauty' rootstock under high temperature stress. They reported improved vegetative growth (higher biomass), higher chlorophyll fluorescence, greater leaf area and dry biomass, higher pollen grains per flower, and lower electrolyte leakage in grafted plants than non-grafted plants. Although above graft combination had a positive effect on plant growth attributes, the increase in fruit yield was not remarkable. Thus, it necessitates the testing of suitable combination of rootstock and scion for heat tolerance not only for vegetative growth but also for reproductive performance.

Day by day moisture stress is becoming an increasingly important issue in agriculture throughout the world especially in arid and semiarid regions (Schwarz 2010). One of the most common problems with the arid climate is unprotected water resource and grafting can be a rapid and proactive way to cope up with such kind of situation and increase water use efficiency (Garcia-Sanchez *et al* 2007 and Satisha *et al* 2007). In an experiment it was observed that grafting cherry tomatoes onto drought resistant rootstocks significantly enhanced fruit quality and yield (Sanchez Rodriguez *et al* 2012). Using reciprocal grafting between the drought tolerant "Zarina" and sensitive "Josefina" tomato (*Solanum lycopersicum* L.) genotypes, Sánchez-Rodríguez *et al* (2012) reported that increased tolerance in grafted plants to moderate water deficit was a drought-adaptive response mainly related to tolerant rootstock, which provided better plant growth and yield. Moreover, Altunlu and Gul (2012) demonstrated that when the interspecific hybrid "Beaufort" (*S. lycopersicum* L. × *S. habrochaites* S. Knapp and D. M. Spooner) was used as rootstock, it mitigated the growth depression of tomato plants induced by water stress, compared with tomato grafted onto weak root structure rootstock ("Resistar") or self-grafted plants. Such findings indicate a drought-adaptive response of tomato grafted onto "Beaufort" rootstock. Comparing 144 tomato lines as rootstocks for grafting tomato "Boludo F1," Albacete *et al* (2015) found that 38 % of lines exhibited higher shoot fresh weight compared to self-grafted plants under water deficit conditions. This finding confirmed that drought induced growth inhibition in tomato can be alleviated by grafting. Petran (2013) reported that use of turkey berry rootstock (*S. torvum* Swartz) under water-stressed conditions induced dwarfness in tomato scions ("Celebrity" and "3212") and delayed wilting, especially with "3212." Similarly, grafting tomato cv. "BHN602" onto the tomato rootstock "Jjak Kkung" reduced the plant growth and leaf area under well-watered conditions in comparison with non-grafted or grafted plants BHN602/Cheong Gang (Nilsen *et al* 2014). However, under drought conditions, the decrease in plant biomass and leaf area in BHN602/Jjak Kkung combination was less pronounced in comparison with non-grafted or grafted plants BHN602/Cheong Gang. The above findings

indicate that the increase in drought resistance in tomato scions grafted onto turkey berry rootstock or tomato rootstock “JakKkung” represents a drought-avoidance response. This characteristic has limited agronomic value because growth reduction (especially leaf area reduction), constitutively induced by rootstock, is often associated with lower yield potential. In tomato, the use of drought-tolerant cv. Zarina as rootstocks for cv. Josefina increased root dry biomass and root metabolic efficiency, in comparison to self-grafted plants when water stress was imposed by reducing the irrigation to 50 % of field capacity (Sánchez-Rodríguez *et al* 2014). Recently, an introgression line (IL, “LA3957”) used as rootstock for grafting tomato resulted in a higher root dry matter and root to shoot ratio, besides showing better resistance to drought stress than self-grafted plants (Poudyala *et al* 2015). Accumulation of macro and micronutrients (N, P, K, Fe, and Cu) in susceptible tomato scion “Josefina” increased when grafted onto drought-tolerant “Zarina” rootstocks (Sánchez Rodríguez *et al* 2014). Working with similar plants, Sánchez Rodríguez *et al* (2013) concluded that drought-tolerant rootstock could improve absorption, upward transfer, and accumulation of NO_3^- in tomato scion, thus stimulating nitrate reductase (NR) activity and NO_3^- assimilation. Consequently, improved growth of grafted plants under moderate water stress was noted.

Sometimes, frequent heavy rainfall that occurs during cropping season such as rainy season in tropical and subtropical parts of India causes water logging, resulting in reduction of oxygen in the root zone and may cause hindrance in root respiration which lead to rotting and disease attack that leads to plant death. In this situation, tomato cultivation in open-fields is challenging. These obstacles caused by excess of water availability or flooding can be fixed by grafting onto tolerant plant. Petran, (2013) found that, grafting tomato on *S. torvum* rootstocks improved the flood tolerance and yield significantly. Symptoms associated with flood stress like depression in photosynthetic rate, stomatal conductance, transpiration and soluble proteins has been proved to be lessened when crops are grafted onto flood tolerant rootstock which improves water use efficiency in drought conditions and flood resistance of crops by grafting onto tolerant rootstocks is an appealing low-input option (Kato *et al* 2001). Bhatt *et al* (2015) found that in comparison with self or non-grafted high-yielding tomato ‘Arka Rakshak’, grafting onto eggplant rootstock ‘Arka Keshav’, ‘Arka Neelkanth’, ‘BPLH-1’, and ‘Mattu Gulla’ exhibited higher physiological adaptation to water logging and gave relatively higher fruit yield. Similarly, Bahadur *et al* (2015) observed that grafting onto eggplant rootstock ‘IC-111056’ and ‘IC354557’ improved water logging tolerance in tomato scion ‘Arka Rakshak’ and ‘Arka Samrat’.

Due to application of excess and injudicious application of chemical fertilizers about one third of the land of the globe has now become saline (Rivero *et al* 2003a) excess salinity, either of the soil or of the applied irrigation water is one of significant environment factors that enormously impacts the crop growth and productivity (Santa-Cruz *et al* 2002). Grafting

has been demonstrated as a simple and cheap technique to improve adaptation of tomato plants to salt stress (Colla *et al* 2010, Estan *et al* 2005 and Santa-Cruz *et al* 2001, 2002). According to the study of Fernandez-Garcia *et al* (2004b) when the salinity resistant rootstocks ‘Radja’, ‘Pera’ and hybrid ‘Volgogradskij’ × ‘Pera’ were used as rootstocks at high levels of sodium chloride, the yield was significantly increased by 80 % more than the non-grafted plants, again the amount of sodium and chlorine in the leaves of the grafted plants were also less as the rootstock must have barred the delivery of these harmful ions into the scion. Studies showed significant yield increase in grafted plants (up to 80 %) compared with non-grafted and self-grafted tomato plants under saline conditions (Estan *et al* 2005, 2009). In Greece, Savvas *et al* (2011) demonstrated that the effect of grafting on tomato fruit yield depends on the rootstock and the level of salinity. The yield improvement is contributed to the ability of rootstock to maintain lower concentration of chloride and sodium ions in the leaves (Cuartero *et al* 2006). Albacete *et al* (2009) observed that the enhanced fruit yield of grafted plants under salinity was associated with the supply of root-derived ionic and hormonal factors that regulate leaf area and senescence. Recently, the effectiveness of tobacco as a rootstock to confer salinity (NaCl) tolerance to tomato scion ‘Elazig’ was explored by Iseri *et al* (2015). Tobacco roots showed better adaptive responses to salt stress compared with tomato as indicated by changes in proline and antioxidant enzyme [ascorbate peroxidase (APX) and catalase (CAT)] levels.

2.5 Other uses of grafting

Grafted pomato plants have been launched in the United Kingdom in September 2013 by a horticultural mail order company ‘Thompson and Morgan’, who are selling the pre-grafted plants branded as “TomTato”. ‘Thompson and Morgan’ trialed the plant for several years before selling it and claimed that each plant can yield more than 500 sweet cherry tomatoes (10.2 °Brix) sweeter than any other tomato available in the supermarkets as well as a decent crop of potatoes of a versatile variety, which can be boiled, mashed, roasted or made into chips (Hansord 2013). Ibrahim *et al* (2014) found grafting as beneficial alternative method for tomato production and conserving water under greenhouse conditions. In Spain, Flores *et al* (2010) demonstrated that grafting had no effect on tomato yield under standard growing conditions; however, under saline conditions, grafting significantly affected the fruit quality of fresh and processed tomato by enhancing TA (Titrable acidity) and SSC (Soluble solid content). In Italy, Kumar *et al* (2015b) found that excess nickel (Ni, 50 mM) in the rooting medium depressed the growth and fruit yield of nongrafted tomato ‘Ikram’, self-grafted or grafted onto different rootstocks. In contrast, some fruit quality characteristics including fruit firmness, brightness, TSS, and dry matter content were enhanced under Ni stress regardless of the graft combination.

Many researchers reported that the effect of grafting on herbicide tolerance depends

on the herbicide and rootstock–scion combinations (Chaudhari *et al* 2015, 2016a, 2017a, 2017b and Ghosheh *et al* 2010). Chaudhari *et al* (2017b) also reported that grafted and non-grafted tomato plants under drought stress exhibit similar tolerance to metribuzin. Chaudhari *et al* (2017b) reported that grafting did not affect absorption, translocation, and metabolism of post applied halosulfuron in tomato and eggplant. To better incorporate grafted tomato into production systems, herbicide evaluation programs would need to include tolerance data to both the rootstock and scion to reduce the potential economic loss due to herbicide injury in grafted plants. However, Ghosheh *et al* (2010) reported that grafted tomato under greenhouse conditions had relatively higher sensitivity to a mixture of metribuzin and sethoxydim applied after transplant compared with nongrafted plants. The possible explanation for the different responses of grafted tomato plants to herbicides in these studies could be due to different rootstock–scion combinations and time when injury was reported after herbicide application. Weed management with herbicides can be more challenging in interspecific grafting using a rootstock and scion from different species of solanaceous crops. Rootstock tolerance to herbicides may or may not confer its benefits to the entire plant. Tomato tolerance of the herbicides metribuzin and halosulfuron was not conferred to the eggplant scion when tomato was used as a rootstock; however, these herbicides are safe to use in tomato crops (Chaudhari *et al* 2016a).

Grafting can be performed for various other reasons. For example, tomato, eggplant, and pepino can be grafted on potato so that 4 or more different kind of vegetables could be harvested from a single plant. Chinese cabbages and cabbages may be grafted on top of radish. Grafting can be made for some physiological studies such as flower induction and early flowering. Grafting is also commonly used for bioassays of virus infection (Lee and Oda 2003 and Davis *et al* 2008).

CHAPTER – III

MATERIALS AND METHODS

The present study entitled “Imparting root knot nematode resistance through grafting in tomato (*Solanum lycopersicum* L.)” was conducted during Autumn season of 2015-2016 and 2016-17 at Vegetable Research Farm, Department of Vegetable Science, Punjab Agricultural University, Ludhiana (Punjab). The details of the materials used and the techniques adopted during the investigation have been presented in this chapter.

3.1 Experimental site (Location)

The experiment was conducted at Vegetable Research Farm, Department of Vegetable science, Punjab Agricultural University, Ludhiana. Ludhiana is situated at 30 ° 54’ N latitude and 75 ° 48’ E longitude at a mean height of 247 meters above sea level.

3.2 Weather and Climate

The region is characterized by hot summer and cold winters with semi-arid and sub tropical climate, which represents a typical monsoon conditions prevailing in central districts of Punjab. The mean maximum and minimum temperature show considerable fluctuations during summer, while minimum temperature falls below freezing point accompanied by frosty spells during winter. The average rainfall is about 500-700 mm, most of which is normally received from July-September. The rainfall between December and March accounts for 16 % of the rainfall while remaining 14 % is received in other months of the year.

3.3 Soil Analysis

A composite soil sample was taken before planting at a depth of 10-15 cm and it was subjected to physico-chemical analysis. The particulars of the analysis are given below in Table 3.1

Table 3.1 Physical and chemical properties of the soil in the experimental field

Sr. No.	Particulars	Level / content
(i)	Soil texture	Loamy sand
(ii)	Soil pH	7.9
(iii)	Organic carbon (%)	0.20
(iv)	Electrical conductivity (mmhos/cm)	0.21
(v)	Available Nitrogen (kg ha ⁻¹)	205.45
(vi)	Available Phosphorus (kg ha ⁻¹)	13.9
(vii)	Available potassium (kg ha ⁻¹)	170.25

Soil texture

The soil texture was determined by the international pipette method given by Piper in 1966.

pH

The pH was determined by Beckman’s glass electrode pH meter in 1:2 soil water suspensions (Jackson 1967).

Electrical conductivity

It was determined by solubridge conductivity meter in 1:2 soil water suspensions (Jackson 1967).

Available Nitrogen

It was estimated by alkaline potassium permanganate method by Subbiah and Asija (1965).

Available Phosphorus

It was estimated by method given by (Olsen *et al* 1954).

Available Potassium

It was estimated with ammonium acetate and estimated by Hange's flame photometer (Jackson 1967).

3.4 Land preparation

The land was ploughed once with mould board plough and harrowed twice to bring the soil to a fine tilth. Stubbles and weeds were collected and disposed off.

3.5 Experiments and Materials

The investigation was divided into three experiments which have been further divided into two sub-experiments. In first experiment, plants were grafted with tongue graft method in which both nematode free as well as Nematode infested plots were divided into Part A and Part B respectively. Similarly, for second experiment plants were grafted with tube graft method and were further divided into sub part A and B i.e. nematode free and Nematode infested plots. While in third experiment, likely it was divided into two sub plots and plants were grafted with cleft method.

3.5.1 Experimental material

Ten different rootstocks carrying resistant against Root Knot Nematode were used. Two PAU recommended varieties were used as scions which were susceptible to Nematode. The list of used rootstock and scion were presented in Table 3.2 and 3.3.

Table 3.2: List of different rootstocks and cultivar

Sr.	Rootstocks	Character	Source
1.	NR-5	Highly resistant	PAU, Ludhiana
2.	PNR-7	Highly resistant	PAU, Ludhiana
3.	NR-10	Highly resistant	PAU, Ludhiana
4.	L-0272	Highly resistant	AVRDC, Taiwan
5.	L-0275	Highly resistant	AVRDC, Taiwan
6.	L-097	Highly resistant	AVRDC, Taiwan
7.	Hisar Lal	Highly resistant	HAU, Hisar
8.	EC-531804	Highly resistant	Exotic collection
9.	EC-631955	Highly resistant	Exotic collection
10.	<i>Solanum torvum</i>	Highly adapted to equatorial conditions	Native to India

Table 3.3: List of different scion cultivar

Sr.	Scion	Character	Source
1.	Punjab Sartaj	Indeterminate variety	PAU, Ludhiana
2.	Punjab Ratta	Determinate variety	PAU, Ludhiana

3.5.2 Methodology and Experiments

The nursery of rootstocks and scion was raised in plug trays using soil-less media (Cocopeat: Perlite: Vermiculite in the ratio of 3:1:1). Difference of two days was made between sowing of rootstocks and scion. Rootstocks were sown on 10th October 2015, and scions were sown on 13th October 2015. Whereas for the second year of experiment similarly, sowing for scion variety was done on 15th October 2016 and for rootstock 12th October 2016. For attaining proper height and vigor of seedlings they were placed under protected structure. Plants were grafted at age 21 to 25 days after sowing and then were shifted to growth chamber after grafting and were further healed for 10 to 12 days. Then grafted plants after proper healing were transplanted in polyhouse and further observations were recorded for horticulture as well as for quality traits.

3.5.2.1 Experiment No. 1: Part A; Evaluation of different rootstocks and scions combination for yield and quality traits by using tongue graft method.

Location: Vegetable Research Farm, Department of Vegetable Science, PAU, Ludhiana.

Methodology: Ten rootstocks and two scions were used in combinations as well as individually for evaluation by tongue graft technique (Lee and Oda 2003). The grafting cut for rootstock was made in a downward direction and the scion cut in an upward direction at an angle, usually 30°–40° to the perpendicular axis, and deep enough to allow the fusion of many vascular bundles as possible. After the graft was completed, specially designed clips were placed to fix the graft position.

Part B; Evaluation of different rootstocks and scions combinations by tongue graft method against root knot nematode.

Location: Vegetable Research Farm, Department of Vegetable Science, PAU, Ludhiana.

Methodology: Sterilized soil was used and filled in pots to raise infection which was inoculated with 2 J2 RKN/g of soil. The infected soil was then transferred into plots at the time of transplanting of grafted seedlings.

3.5.2.2 Experiment No. 2: Part A; Evaluation of different rootstocks and scions combination for yield and quality traits by using tube graft method.

Location: Vegetable Research Farm, Department of Vegetable Science, PAU, Ludhiana.

Methodology: Ten rootstocks and two scions were used in combinations as well as individually for evaluation by tube graft technique (Rivard and Louws 2006). Tomato stem was cut at an angle of 30° slightly above the cotyledon and true leaf stage. It is critical that

scion and rootstock diameter should be same. After that a 10 mm long latex tube was slid on the rootstock and then scion was pushed into tube carefully to join scion and rootstock.

Part B; Evaluation of different rootstock and scion combination by using tube graft method against root knot nematode.

Location: Vegetable Research Farm, Department of Vegetable Science, PAU, Ludhiana.

Methodology: Sterilized soil was used and filled in pots to raise infection which was inoculated with 2 J2 RKN/g of soil. The infected soil was then transferred into plots at the time of transplanting of grafted seedlings.

3.5.2.3 Experiment No. 3 Part A; Evaluation of different rootstock and scion combination for yield and quality traits by using cleft graft method.

Location: Vegetable Research Farm, Department of Vegetable Science, PAU, Ludhiana.

Methodology: Ten rootstocks and two scions were used in combinations as well as individually for evaluation by cleft graft technique (Lee and Oda 2003). Shoots of rootstock below cotyledons were removed and a cut was created in the rootstock stump that bisects it. Above or below cotyledon were removed and scion is trimmed into a wedge shape with two diagonal cuts. The prepared scion shoot is put into the bisected rootstock stump.

Part B; Evaluation of different rootstock and scion combination by using cleft graft method against root knot nematode.

Location: Vegetable Research Farm, Department of Vegetable Science, PAU, Ludhiana.

Methodology: Sterilized soil was used and filled in pots to raise infection which was inoculated with 2 J2 RKN/g of soil. The infected soil was then transferred into plots at the time of transplanting of grafted seedlings.

Technique of grafting: Following technique and observations were used for grafting in all three experiments and for Nematode infested plots additional Root Galling Index (RGI) was calculated.

Number of rootstocks: 10

Number of scion: 2

Total number of combinations: (rootstock \times scion) $10 \times 2 = 20$ plants (grafted plants)

Total number of individual plants: 2

Total number of treatments: 20 (grafted) + 2 (non-grafted) = 22 treatments

Number of replications: 3

Number of plants per replication: 10

Design to be used: CRD (Factorial)

3.5.3 Observations recorded

Five plants were randomly selected from each treatment in each replication and the following observations were recorded.

3.5.3.1 Horticultural traits

(i) Days to first flowering

The days to first flowering in tomato plants were counted from the date of transplanting to the date of first opening of flower in randomly selected five plants.

(ii) Days to first harvest

The days to first flowering were counted from the date of transplanting to the date when at least one mature fruit was harvested in randomly selected five plants.

(iii) Number of marketable fruits per plant

Randomly selected five plants were harvested and Number of fruits was counted and at each harvest fruits were counted and an average number was worked out on per plant basis.

(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 for each treatment and was expressed in grams.

(v) Fruit length (cm)

Five randomly selected plants were used to estimate data for fruit Length from each plot. Length was measured with the help of scale and was measured in centimeters. An average fruit length was calculated.

(vi) Fruit width (cm)

Same scale used for recording the length was also used to measure the fruit width in centimeter and the mean values were worked out.

(vii) Harvest duration (days)

All plants were selected to determine duration of harvest. Days were counted from the first picking to final harvest of tomato fruits in each treatment and average values were calculated.

(viii) Plant height (cm)

Plant height was determined by using scale in centimeters from soil line to the tip of the plant at the time of last harvesting and average was worked out to express the plant height in centimeters.

3.5.3.2 Quality traits

(i) Pericarp thickness (mm)

After recording the fruit length and width, the same fruits were used for measuring the pericarp thickness with the help of Vernier Caliper and mean values were calculated.

(ii) TSS (°Brix)

Red ripe marketable fruits from tagged plants in each treatment were obtained during harvest and crushed in pestle and mortar. The liquid extract obtained was used to record total soluble solids (°Brix) with the help of ERMA hand refractrometer.

(iii) Lycopene (mg/100 g of fresh weight)

Lycopene content was calculated by weighing 2 g flesh and added with 10 ml acetone and complete dried with petroleum ether. Absorbance was recorded with UV spectrophotometer at 505 nm wavelength.

3.5.3.3 RGI (Root Galling Index): Root knot nematode infestation was rated as root galling scale as given below and method discussed below

Categorization scale for root gall index (RGI)

Rating index (GI)	Number of Galls (Taylor and Sasser 1978)
0	0
1	1-2
2	3-10
3	11-30
4	31-100
5	>100

Effect of root knot nematode on different rootstocks and scion to be used in experiment

Pure culture of nematodes was raised by taking galled roots of tomato plants from infested plots than galls were teased and freshly hatched second juveniles were raised and used for inoculums. Plants were grown carefully under supervision weeding was done and were regularly watered and were kept free of another pest invasion. On observing Table 3.4 it was observed that all rootstocks used showed high resistance to nematodes and showed no gall formation on roots except for PNR-7 and Hisar Lal which observed resistant to nematode and recorded a little bit gall formation. Both scions used were highly susceptible to nematode and recorded a value of 4 on the scale.

Table 3.4 Number of Galls recorded at time of harvest (Taylor and Sasser 1978)

Sr. no	Rootstock	Number of galls	Reaction
1	NR-5	0	HR*
2	PNR-7	1	R*
3	NR-10	0	HR*
4	L-0272	0	HR*
5	L-0275	0	HR*
6	L-097	1	R*
7	Hisar Lal	1	R*
8	EC-531804	0	HR*
9	EC-119197	0	HR*
10	Pb Sartaj	4	HS*
11	Pb. Ratta	4	HS*

HR*: Highly Resistant; R*: Resistant; HS*: Highly Susceptible

3.5.3.4 Grafting success rate

The overall success of grafted plants after 2 weeks of transplanted seedlings was calculated and expressed in percentage.

$$\text{Graft success (\%)} = \frac{\text{Number of successfully established plants}}{\text{Total number of grafted plants}} \times 100$$

3.2.5 Grafting

The scions were grafted on various rootstocks using three grafting techniques i.e. tongue, cleft and slant cut as and when tomato plants attained graftable height (15-20 cm) and stem thickness (5-10 mm). The graft unions were secured with plastic grafting clips wherever required to ensure good vascular contact and successful healing of the grafted components.

3.2.6 Aftercare and healing

Grafted plants were sprayed with water immediately after grafting with the help of a hand held sprayer. After grafting the grafted plants were put in the grafting chamber. Water was sprayed in the day time in order to avoid wilting and accelerate the healing process. Successful healing of grafts in vegetables requires a reduced light intensity, high relative humidity (85-90%) and moderate temperature (25-30°C) following grafting to reduce transpiration of the scion until rootstock and scion vascular tissues are healed together and water transport gets restored. Under these conditions a total of 5-7 days were sufficient so that the rootstock and scion establish a good vascular connection and continue normal growth as a single plant. On an average in all grafted plants it took a total of 5-7 days to establish a good vascular connection and to continue normal growth when such conditions were maintained for the specified period. After successful healing the plastic clips were removed from the graft union.

3.2.7 Acclimatization

For acclimatization grafted seedlings were kept outside the healing chamber under sunlight just to give hardening prior to transplanting, to prevent leaf burning and wilting of just healed seedlings. Grafted plants took 3 to 4 days for acclimatization as hardening treatment.

3.2.8 Bed preparation and transplanting

The width of the bed was kept at 90 cm, whereas length was kept at 2 m. The plants were planted at 90 cm row to row and 30 cm plant to plant spacing thus accommodating 12 plants per bed. Vermicompost @ 1 kg/m² and chemical fertilizers 12: 32: 16 @ 0.02 kg/m², M.O.P. @ 0.008 kg/m² and Urea @ 0.012 kg/m² were applied in beds before of transplanting. The beds were covered by plastic mulch and 12 plants in each control plot (one plot in every replication) were transplanted at inter row distance of 70 cm and plant to plant distance of 30 cm.

3.2.9 Fertilizer application

Fertilizers were initiated after three weeks of transplanting with water soluble fertilizer N:P:K (19:19:19) @ 2.2 g/m² twice a week through drip irrigation. Fertigation was stopped 15 days prior to final harvesting of tomato fruits.

3.2.10 Cultural practices

Recommended package of practices were followed to raise a healthy crop under polyhouse conditions. Irrigation was applied through drip on alternate day during the cropping period. The plants were trained on single stem through nylon twines by retaining one primary stems per plant. Proper staking and pruning was done at regular interval to remove unwanted shoots arising from main stem to ensure proper growth of two main stems trained on twines. Desuckering was also done simultaneously along with pruning to remove unwanted suckers/shoots growing from the crown region especially from the rootstock of the plant to ensure proper growth of the grafted plants.

3.2.11 Statistical analysis

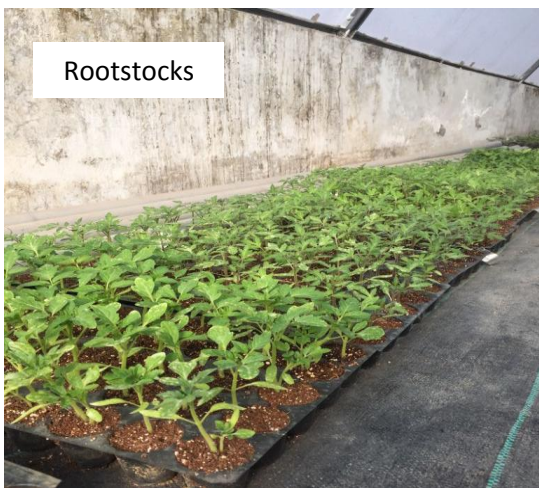
The data recorded in respect to various parameters were statistically analyzed according to the procedure outlined by Steel and Torrie (1981) using CPCS1 software (Factorial CRD) developed by the Department of Math, Stat and Physics P.A.U Ludhiana. Comparison of the mean values of different treatment was made at 5% level of significance.



Grafting chamber



Healing chamber



Rootstocks



Scion

Healthy nursery prepared for grafting



Grafted plants inside the chamber

Plate 1 : Grafting and healing chambers



Plants ready for acclimatization



Fully healed plants ready for transplantation

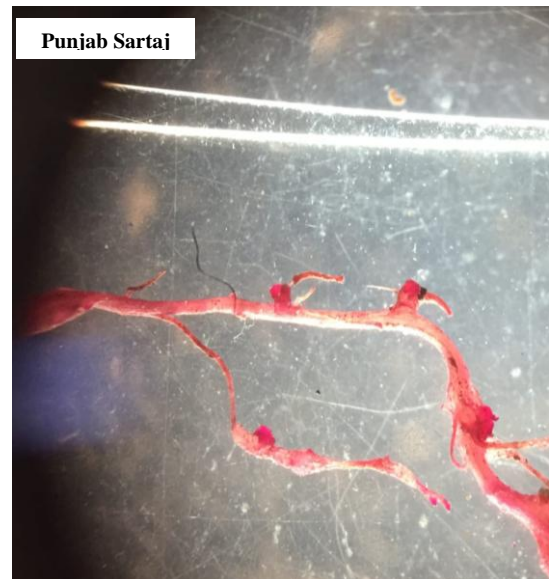


Healthy grafted plants at field

Plate 2 : Acclimatization of plants



Roots of susceptible scion at 30 days



Infestation of nematode egg mass at 15 days on susceptible scion

Plate 3: Disease reaction on roots of susceptible scion



Roots of resistant rootstock at 30 days



Infestation of nematode egg mass at 15 days on susceptible scion

Plate 4: Disease reaction on roots of resistant rootstocks

CHAPTER – IV

RESULTS and DISCUSSION

The present investigation entitled “Imparting root knot nematode resistance through grafting in tomato (*Solanum lycopersicum* L.)” was carried out during autumn season of 2015-2016 and 2016-17 at Vegetable Research Farm, Department of Vegetable Science, Punjab Agricultural University, Ludhiana (Punjab). In this chapter an attempt has been made to present and discuss the experimental results obtained from the present investigation with possible scientific explanation and supportive evidences based on the available literature. From the results it has been studied that *Solanum torvum* did not show any compatibility with scions so it was not used in the research experiment. The following trait has been discussed under different experiment heads.

4.1 Experiment 1: Evaluation of different rootstock and scion combination for yield and quality traits by using tongue graft method

4.1.1 Plant Height (cm)

Grafted plants generally do have high vigor and possess more plant height than self rooted plants and is further enhanced with supplementing stem diameter. More plant height may help in producing more branches which help in increasing yield of plants. The data pertaining to the effect of different rootstocks on plant height is presented in Table 4.1.1.

Punjab Sartaj

On scrutinizing pooled data of nematode free plots grafted plants showed a significant effect on plant height over non-grafted plants. EC-119197 recorded a height of 331.9 cm which was significantly higher among all the rootstocks in both years of experiment followed by NR-10 (329.2 cm) which is at par with EC-119197. Non-grafted plants recorded a height of 291.8 cm which was significantly lower than EC-119197 and NR-10. Similar pattern was recorded in both the years of experiment. These results were in line with the results of Lee (1994) and Ioannou *et al* (2002) who found that grafted tomato plants were taller and more vigorous than self-rooted plants. It generally occurs due to vigorous root system, which helps in improved uptake of water and minerals in plants which tend to become more vigorous.

While observing the Nematode infested plots pooled data, it was observed that plants grafted on rootstock EC-119197 (328.8 cm) recorded maximum plant height which was significantly higher than non-grafted (74.2 cm) as well as other grafted plants. While computing data year wise it revealed that EC-119197 recorded significantly higher plant height but was statistically at par with NR-10 (324.1 cm) in year 2016-17 but was significantly lower in year 2015-16 which recorded a plant height of 311.8 cm. It may be due to favorable temperature which may help plant to grow at higher extent. Height of non-grafted plants was highly reduced because of disease infestation hindering growth of plant as roots get galled and nutrition is itself absorbed by the pathogen suppressing uptake of plants.

Table 4.1.1 Effect of different rootstock's on plant height (cm) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Plant height (cm) Punjab Sartaj						Plant height (cm) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	295.1	309.0	302.0	293.4	296.5	294.9	69.5	68.8	69.2	67.4	70.1	68.8
T ₂	PNR-7	303.2	295.1	298.2	301.0	292.7	297.9	68.8	67.6	68.2	67.7	65.1	66.4
T ₃	NR-10	326.5	332.0	329.2	311.8	324.1	317.9	70.3	65.3	67.8	65.9	66.9	66.4
T ₄	L-0272	285.4	265.9	275.6	267.5	262.9	265.2	66.7	69.2	67.6	64.6	68.2	66.9
T ₅	L-0275	299.4	303.1	301.2	298.9	301.0	299.9	63.5	62.2	62.9	61.0	60.9	61.0
T ₆	L-097	294.1	298.5	296.3	293.2	294.7	293.9	65.9	61.8	63.9	62.5	61.5	62.0
T ₇	Hisar Lal	298.6	283.8	291.2	288.6	293.2	290.9	65.2	63.9	64.6	61.7	63.4	62.6
T ₈	EC-531804	300.2	297.7	298.9	287.2	289.8	288.5	68.5	69.2	70.7	68.3	69.2	68.9
T ₉	EC-119197	328.5	338.3	331.9	325.1	329.6	328.8	70.5	66.1	68.3	65.9	66.5	66.2
T ₁₀	Control (NG)*	284.1	299.5	291.8	77.7	70.6	74.2	56.3	54.7	55.5	34.5	33.3	33.9
	CD(P=0.05) (P=0.05)	13.7	16.0	10.1	11.7	13.5	8.6	6.4	5.7	4.1	5.8	6.4	4.1

(NG)*: Non-Grafted

Punjab Ratta

Non-Grafted plants of Punjab Ratta are determinate in nature. Grafting has a positive effect on plant height. While observing nematode free plots, pooled data revealed that maximum plant height was obtained when plants were grafted on rootstock EC-531804 (70.7 cm) and was significantly higher than non-grafted plants (55.5 cm). Further it was seen from the data that it was statistically at par with plants grafted on rootstocks NR-5 (69.2 cm), EC-119197 (68.3cm), PNR-7 (68.2 cm), NR-10 (67.8 cm) and L-0272 (67.6 cm). Similar data was observed in both the years of experiment except in year 2015-16 where grafted plants of EC-531804 (70.5 cm) was statistically at par with plants grafted on rootstock L-097 (65.9 cm). Further in year 2016-17, rootstock L-097 (61.8cm) recorded significantly lower plant height from EC-531804 (69.2 cm) which may be due to favorable environmental conditions.

On observing Nematode infested plots of Punjab Ratta, it was revealed that maximum plant height was recorded by EC-531804 (68.9 cm) rootstock which was significantly higher than non-grafted control plants. It was further observed that rootstock EC-531804 was also statistically at par with NR-5 (68.8 cm), PNR-7 (66.2 cm), L-0272 (66.9 cm), NR-10 (66.4 cm) and EC-119197 (66.2 cm). Non-grafted plants of Punjab Ratta recorded minimum plant height of 33.9 cm which was due to heavy infestation of disease which suppressed the plant height by restricting water and mineral uptake of roots. Similarly these results also coincide with the results of Khah *et al* (2006) in which he concluded that vigor of grafted tomato was significantly higher than non-grafted plants.

4.1.2 Days to flowering

Day to first flowering is a desirable character for farmers as it helps to attain early yield which fetches more returns to the farmers. Data pertaining to the effect of different rootstocks on days to flowering is presented in Table 4.1.2

Punjab Sartaj

In case of nematode free plots pooled data revealed that plants grafted on rootstock PNR-7 recorded minimum days to flowering (85.8 days) which was lowest in all grafted plants but was significantly higher than non-grafted plants of Punjab Sartaj (80.0 days) due to effect of grafting on seedlings of tomato which causes initial stress at the stage of grafting which may delay the flowering of grafted plants. In year wise data, it was examined that non-grafted plants were statistically at par with plants grafted on PNR-7 in year 2015-16 (86.3 days) and 2016-17 (85.3 days).

While investigating pooled data for infested plots, there was significant difference among grafted and non-grafted plants. Plants grafted on PNR-7 took minimum days to flower (87.2) which were statistically at par with other rootstocks like L-097 (87.8 days), L-0275 (88.9 days), NR-10 (89.9 days), Hisar Lal (90.3 days) and L-0272 (90.7 days). Whereas non-grafted plants of Punjab Sartaj took more days (112.0 days) to first bloom due to infestation

Table 4.1.2 Effect of different rootstock's on days to flowering of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Days to Flowering Punjab Sartaj						Days to flowering Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	93.8	94.0	93.9	93.7	95.3	94.4	104.2	105.3	104.8	106.2	104.1	105.2
T ₂	PNR-7	86.3	85.3	85.8	86.5	87.0	87.2	105.4	103.2	104.3	104.2	103.0	103.6
T ₃	NR-10	87.9	89.4	88.7	90.7	89.0	89.9	107.2	106.8	107.0	104.3	103.1	103.7
T ₄	L-0272	89.9	88.9	89.4	90.9	90.5	90.7	103.3	103.1	103.2	101.6	103.6	102.6
T ₅	L-0275	87.6	87.0	87.3	88.4	89.4	88.9	103.2	102.7	103.0	101.5	99.5	100.5
T ₆	L-097	86.0	87.3	86.7	86.7	87.8	87.8	104.2	103.8	104.0	103.1	102.6	102.9
T ₇	Hisar Lal	89.7	90.2	90.0	90.2	90.3	90.3	106.1	105.1	105.6	104.2	103.2	103.7
T ₈	EC-531804	93.7	94.1	93.9	96.3	96.0	96.2	105.3	106.3	105.8	106.2	104.2	105.2
T ₉	EC-119197	93.0	93.2	93.1	93.9	94.2	94.1	107.2	107.3	107.3	108.2	107.5	107.9
T ₁₀	Control (NG)*	79.7	80.3	80.0	113.0	111.0	112.0	102.4	104.2	103.3	126.3	126.7	126.5
	CD(P=0.05)	6.9	5.7	4.5	7.0	8.2	5.1	NS	NS	NS	7.4	8.2	5.3

(NG)*: Non-grafted

of disease. Whereas, plants of Punjab Sartaj when grafted on rootstock EC-119197, EC-531804 and NR-5 also took more number of days (viz. 93.1, 93.4 and 93.9 respectively) to flower than other grafted plants but recorded significantly less number of days than non-grafted plants. Similar trends were obtained in both years of experiment. The reason for delay in flowering was due to the stress caused grafting and healing of grafted plants, which altered physiological response of rootstocks and scion interactions. Similar results were quoted by Ibrahim *et al* (2001) and Khah *et al* (2006). Delay in flowering of non-grafted plants was due to susceptibility to disease whereas plants grafted on resistance rootstocks demonstrated resistance towards disease.

Punjab Ratta

The plants of Punjab Ratta have dense foliage cover and are dark green in color. There was no significant difference among the grafted plants and non-grafted plants of Punjab Ratta when observed for days required to flowering in nematode free plots. While under the infested plots, data revealed that grafted plants showed significantly less number of days for flowering than non-grafted plants of Punjab Ratta. Grafted plants have more ability to flower under infested conditions as plants grafted on rootstock L-0275 showed comparative less number of days to flower in pooled data (100.5) and were statistically at par with rest of the rootstocks except for rootstocks EC-119197 which recorded 107.9 numbers of days and was significantly higher among other grafted plants. While computing for year-wise data, L-0275 rootstock took less number of days for first flowering but was statistically at par with plants grafted on rootstocks Hisar Lal, PNR-7, NR-10, L-0272, NR-5, EC-531804, L-097 and EC-119197. When plants are grafted, there is an initial stress on plants, which may delay the flowering. Under infested conditions plants grafted on resistant rootstocks confer resistance and are able to produce early flowering.

4.1.3 Days to picking

Days to picking is having a direct relation to early yield of tomato. Data on effect of different rootstock on days to first picking was represented in Table 4.1.3.

Punjab Sartaj

On observing nematode free plots of Punjab Sartaj data revealed that plants grafted on rootstock PNR-7 (108.2) demonstrated least number of days which were significantly lower than non-grafted plants (121.6). Further it was statistically at par with L-097 (109.1), L-0275 (111.7) and NR-10 (114.1).

In year-wise data it was recorded that PNR-7 took significantly lower days in both years i.e 2015-16 (106.0) and 2016-17 (109.3). While during 2016-17, PNR-7 rootstock was significantly at par with plants grafted on rootstock NR-5 which took 116.3 days to first picking. It may be due to effect of high temperature which shoots up plant vigor to higher extent. In general early picking in grafting may be achieved because of enhanced mineral and

Table 4.1.3 Effect of different rootstock's on days to picking of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Days to Picking Punjab Sartaj						Days to Picking Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	118.3	116.3	117.1	118.2	116.1	117.0	124.8	125.0	124.9	125.7	126.8	126.3
T ₂	PNR-7	106.0	109.3	108.2	108.3	110.3	109.8	117.0	118.3	117.7	124.0	125.7	124.9
T ₃	NR-10	114.1	114.0	114.1	115.0	113.4	114.2	118.9	120.4	119.7	126.5	124.8	125.7
T ₄	L-0272	117.0	119.7	118.4	114.7	113.7	114.2	120.9	119.9	120.4	124.1	125.2	124.7
T ₅	L-0275	111.0	112.3	111.7	112.0	114.3	113.2	118.6	118.0	118.3	123.6	124.1	123.9
T ₆	L-097	108.7	109.9	109.1	108.7	112.7	110.7	117.3	116.3	116.8	119.3	120.2	119.8
T ₇	Hisar Lal	113.5	115.8	114.7	113.7	114.7	114.2	120.7	121.2	121.0	127.7	128.4	128.1
T ₈	EC-531804	134.0	136.0	135.0	134.0	136.0	135.0	120.3	125.0	123.2	125.0	126.0	125.5
T ₉	EC-119197	126.4	129.9	128.2	126.9	128.5	127.7	122.9	120.2	122.1	127.5	127.2	127.4
T ₁₀	Control (NG)*	122.1	121.0	121.6	141.3	141.7	141.5	120.7	121.3	121.0	145.3	143.3	144.3
	CD(P=0.05)	9.3	10.6	6.2	9.0	8.9	5.4	NS	NS	NS	8.0	6.4	4.4

(NG)*: Non-Grafted

water uptake which may help plants to form more flower cluster and improve fruit setting of plants. Similar results were obtained by Khah *et al* (2006) which recorded that graft combinations have more number of fruits and were able to have early picking as well.

While observing the Nematode infested plots, pooled data revealed that grafted plants recorded significantly less number of days to picking than control plants of Punjab Sartaj which took 141.5 days to flower which was significantly higher. Delay in picking of susceptible control plants was due to the stress caused by nematode, which lead to poor and late flowering as well as fruit setting of plants. While investigating grafted plants similar results were observed as in nematode free plots where rootstock PNR-7 took minimum days to picking (109.8) which was significantly lesser than grafted as well as non-grafted plants.

Punjab Ratta

Correspondingly while investigating pooled data in nematode free plots for days to picking, non-grafted plants of Punjab Ratta recorded a value 121.0 days which was significantly at par with other grafted plants. While plants grafted on rootstock L-097 which took minimum days for picking (116.8) but were at par with non-grafted plants of Punjab Ratta.

Although on investigating Nematode infested plots, pooled data revealed that there was significant difference among grafted and non-grafted plants. Non-grafted plants took significantly more number of days (144.3) to picking under infested conditions. Whereas plants grafted on rootstock L-097 significantly took less number of days to picking (119.8). This was due to infestation of disease which hinders uptake flow of water and nutrients in roots of plant causing high stress and decreasing water use efficiency of plants further affecting both yield as well as vigor of plants (Schwarz *et al* 2013). Similar results were recorded in both years of experiment where plants grafted on rootstock L-097 took less number of days for picking than non-grafted plants in infested plots.

4.1.4 Fruit width (cm)

Solutes associated with fruit shape and quality are translocated in the scion through the xylem so presumably rootstock and scion interactions are prior most factors in shaping and development of fruit (Oda *et al* 2005). Effect of different rootstock on scion for fruit width was presented in Table 4.1.4.

Punjab Sartaj

A significant difference was observed among grafted plants when same scion was grafted on different rootstocks. Pooled data in nematode free plots revealed that rootstock EC-119197 recorded maximum fruit width of 6.2 cm which was significantly higher than non-grafted plants (5.3 cm). It was further followed by EC-531804 (5.7 cm) and was at par with each other.

Similarly while observing data of year-wise (2015-16 and 2016-17), plants grafted

Table 4.1.4 Effect of different rootstock's on fruit width (cm) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Fruit width (cm) Punjab Sartaj						Fruit width (cm) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	5.5	5.7	5.6	5.5	5.2	5.4	5.7	5.8	5.7	5.6	5.4	5.5
T ₂	PNR-7	5.0	4.8	4.9	4.9	4.9	4.7	5.2	5.0	5.1	4.9	5.0	5.0
T ₃	NR-10	4.5	4.7	4.6	4.6	4.5	4.5	4.9	4.9	4.9	4.5	4.5	4.5
T ₄	L-0272	4.1	4.2	4.1	4.1	4.1	4.2	5.0	5.0	5.0	4.3	4.4	4.4
T ₅	L-0275	4.6	4.0	4.3	4.2	4.2	4.1	4.1	4.0	4.0	4.1	3.8	3.9
T ₆	L-097	4.1	3.9	4.0	4.0	3.8	3.9	4.1	4.0	4.0	3.9	3.9	3.9
T ₇	Hisar Lal	5.5	5.4	5.4	5.4	5.2	5.3	4.7	4.9	4.8	4.7	4.8	4.7
T ₈	EC-531804	5.5	5.7	5.7	5.6	5.5	5.4	5.8	5.8	5.8	5.7	5.8	5.6
T ₉	EC-119197	6.1	6.3	6.2	6.1	6.1	6.1	6.0	6.2	6.1	6.0	6.0	6.0
T ₁₀	Control (NG)*	5.2	5.5	5.3	4.2	4.2	4.3	5.6	5.5	5.5	4.7	4.6	4.7
	CD(P=0.05)	0.7	0.9	0.5	0.6	0.8	0.5	0.7	0.8	0.5	0.8	0.9	0.5

(NG)*: Non-grafted

on rootstock NR-5 (5.5 and 5.7 cm) and Hisar Lal (5.5 cm and 5.4 cm) was also significantly at par with plants grafted on rootstock EC-119197 in year 2015-16 (6.1 cm) and 2016-17 (6.3 cm) of experiment.

On evaluating pooled data in infested plot it was revealed that non-grafted plants demonstrated a lower fruit width (4.3 cm) in plants which was significantly lower than grafted plants. Rootstock EC-119197 had maximum fruit width (6.1 cm) which was significantly higher than other grafted and non-grafted plants. In year wise data, EC-119197 (6.1 cm) was statistically at par with plants grafted on rootstock EC-531804 (5.6 cm) and NR-5 (5.5 cm) in year 2015-16. Similar results were found in year 2016-17 but EC-119197 (6.1 cm) was statistically at par with EC-531804 (5.5 cm) only. Non-grafted plants recorded lower fruit width because of high stress caused to roots of plant by nematodes which stunted overall growth of plants hence drastically reducing physiological activities of plants. Pogonyi *et al* (2005) revealed that same scion of tomato when grafted on different rootstock combinations altered fruit sizes but under infested conditions grafted plants observed higher fruit sizes than non-grafted plants.

Punjab Ratta

It was concluded from the pooled data of nematode free plots that different rootstocks had different effects on same scion and there were significant differences in fruit width among grafted as well as non-grafted plants of Punjab Ratta. Therefore on analyzing pooled data, plants when grafted on rootstocks EC-119197 recorded maximum fruit width (6.1 cm) which was significantly higher than non-grafted plants of Punjab Ratta (5.5cm). It was further followed by EC-531804 (5.8 cm) and NR-5 (5.7 cm). Plants grafted on rootstocks L-0275 and L-0272 recorded lesser fruit width that was 4.0 cm respectively. Similar, trends were observed in both the years in which different rootstocks modified fruit width of grafted plants and had a major role in effecting the shape of fruit.

While computing year-wise data, it was observed that EC-119197 besides being statistically at par with EC-531804 and NR-5 was further also statistically at par with non-grafted plants of Punjab Ratta in year 2015-16 (5.6 cm) and 2016-17 (5.5 cm).

While investigating infested plots of Punjab Ratta pooled data revealed that there was higher effect of disease on self rooted plants of Punjab Ratta (4.7 cm) rather than plants grafted on resistant rootstocks. Similar result were observed as in nematode free plots where EC-119197 recorded maximum fruit width (6 cm) which was at par with EC-531804 (5.6 cm) and NR-5 (5.5 cm). They were significantly higher than non-grafted plants. Rivard *et al* (2010) had recorded similar results in which grafted plants of tomato showed better fruit shape than non-grafted plants when they were subjected under nematode infested soil but some combinations of grafted plants had higher fruit widths which was purely due to the effect of different rootstocks.

4.1.5 Fruit length (cm)

Fruit length is directly proportioned to fruit size which is related to overall yield of plant. Fruit length improves fruit index of plant. The data pertaining to the effect of different fruit length has been presented in Table 4.1.5.

Punjab Sartaj

It is evident while observing pooled data that grafting effects fruit length appreciably, while observing Table 4.1.5 plants grafted on rootstock EC-119197 recorded significantly higher fruit lengths (6.1 cm) as compared to other rootstocks followed by rootstocks EC-531804 (5.6 cm) and PNR-7 (5.5 cm) and were at par with non-grafted plants of Punjab Sartaj which recorded a fruit length of 5.2 cm. On observing data among other grafted plants rootstock NR-5 and Hisar Lal recorded a fruit length of 5.0 cm and 5.2 cm respectively which were again at par with non-grafted plants of Punjab Sartaj. Whereas plants grafted on rootstocks L-0272 (3.9 cm), L-0275 (4.0 cm), L-097 (4.2 cm) and NR-10 (4.6 cm) recorded reduced fruit lengths among all grafted treatments. Similar trend of data was recorded in both the years of experiment.

Alike data was observed in infested plots where again plants grafted on rootstocks EC-119197 (6 cm) had higher fruit length followed by EC-531804 (5.4 cm), PNR-7 (5.2 cm) and Hisar Lal (4.9 cm). These rootstocks conferred high resistance to nematodes and performed better under stress conditions. Rootstock L-0275 (3.9 cm) and L-0272 (3.7 cm) showed lesser fruit length which was purely due to interactions between scion and rootstocks combinations and were at par with non-grafted plants which recorded a value of 4.4 cm.

Punjab Ratta

Grafting plays an imperative role in effecting shape and size of fruit. It is evident from pooled data of Table 4.1.5 that plants grafted on rootstock EC-119197, EC-531804 and NR-5 showed significantly higher fruit lengths in nematode free plots (6.4 cm, 6.3 cm and 5.9 cm resp.) as compared to control plants of Punjab Ratta (5.5 cm) where as EC-119197 was significantly higher among them in both the years of experiment. Rootstocks NR-5, PNR-7, NR-10, L-0272 and Hisar Lal were statistically at par with control plants. Above data authenticates that there was significant effect of different rootstocks on fruit length of scion which alters fruit shape and size.

In infested plots, pooled data revealed that self rooted plants of Punjab Ratta showed significantly reduced fruit length (4.3 cm) as compared to grafted plants. EC-119197 recorded a maximum fruit length of 6.5 cm followed by EC-531804 (6.3 cm) whereas rootstocks L-097 recorded least fruit length (4.4 cm) and was at par with control plants. Plants grafted on rootstocks NR-5, PNR-7, NR-10, Hisar Lal and L-0272 recorded a significant higher fruit length than non-grafted plants (4.3 cm). Higher fruit length attained in grafted plants was due to improved water and nutrient uptake helping in improved fruit size and shape of plant

Table 4.1.5 Effect of different rootstock's on fruit length (cm) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Fruit length (cm) Punjab Sartaj						Fruit length (cm) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	5.0	4.9	5.0	4.8	4.7	4.8	5.8	6.1	5.9	5.7	5.9	5.8
T ₂	PNR-7	5.5	5.4	5.5	5.1	5.2	5.2	5.5	5.7	5.6	5.7	5.7	5.7
T ₃	NR-10	4.7	4.4	4.6	4.5	4.2	4.4	5.2	5.4	5.3	5.2	5.1	5.1
T ₄	L-0272	3.8	4.0	3.9	3.7	3.7	3.7	5.3	5.5	5.4	5.4	5.3	5.4
T ₅	L-0275	4.1	3.9	4.0	3.8	4.1	3.9	4.8	4.9	4.8	4.9	4.9	4.9
T ₆	L-097	3.9	4.4	4.2	3.8	4.2	4.0	4.9	4.2	4.6	4.6	4.1	4.4
T ₇	Hisar Lal	5.1	5.2	5.2	4.7	5.1	4.9	5.2	5.1	5.1	5.4	5.0	5.2
T ₈	EC-531804	5.5	5.7	5.6	5.4	5.3	5.4	6.3	6.3	6.3	6.5	6.1	6.3
T ₉	EC-119197	6.2	6.1	6.1	6.1	5.9	6.0	6.3	6.6	6.4	6.5	6.4	6.5
T ₁₀	Control (NG)*	5.4	5.1	5.2	4.6	4.3	4.4	5.6	5.5	5.5	4.4	4.1	4.3
	CD(P=0.05)	0.6	0.6	0.5	0.9	0.7	0.6	0.6	0.8	0.5	0.8	0.8	0.5

(NG)*: Non-Grafted

(Rivard *et al* 2010). But in non-grafted plants reduction in fruit length was recorded only due to affect of nematode disease which decreases the intake of water and minerals from the roots of plants by forming galls on roots.

4.1.6 Harvest duration (Number of days)

Punjab Sartaj

Indeterminate tomato plants generally produce more flush of fruits than determinate tomatoes. When grafted on vigorous rootstocks, tomatoes generally allow longer duration of harvest due to increased water and mineral uptake which help in maintaining prolonged harvest duration even in infested conditions. While inspecting Table 4.1.6 in nematode free plots there was no significant difference among grafted and non-grafted plants. Although rootstocks EC-531804 (126), EC-119197 (122) and PNR-7 (123) recorded more number of days for duration to harvest but were somehow non-significant among all the treatments.

On other hand while inspecting Nematode infested plot similar trends were observed as in nematode free plot. Grafted plants recorded higher harvest duration and were at par among themselves except for control plants (Non-Grafted) which showed high susceptibility to nematode and had a drastic reduction in duration of harvest which recorded 52 number of day only. It had a severe effect on yield of plants. King *et al* (2010) reported prolonged duration of harvest when plants were grafted on different rootstock.

Punjab Ratta

Generally determinate varieties show heavy flushes of fruit but determinate varieties stop growing when fruit sets on top bud. Grafting improves prolonged duration of harvest. Plants grafted with rootstocks EC-119197 showed enhanced duration with average days of 82 which was significantly higher than non-grafted plants when computed for pooled data but in yearly data EC-531804 recorded significantly lower duration (77 days) than NR-10 (78 days) in year 2016-17 further followed by NR-5 (76 days), PNR-7 (74 days), L-0272 (73 days) and L-0275 (71 days). All above grafted plants were also at par with control plants (72 days). Prolong duration of harvest generally occurs due to increased uptake of water and nutrients which provides more ability to plants for fruiting for longer time.

While inspecting Nematode infested plot, self rooted plants (control) were severely affected by disease and had reduced duration of harvest (42 days) but grafted plants of EC-119197 showed exceptionally superior results with a maximum average of 84 days. Rootstocks EC-119197 and EC-531804 had significantly extended harvest duration among other rootstock and were at par among each other. These rootstocks performed best in both years 2015-16 and 2016-17 further followed by NR-10, NR-5, PNR-7, L-0272 and L-0275. These results were in line with King *et al* (2010) who also reported prolonged duration of harvest by different combinations of grafted plants.

Table 4.1.6 Effect of different rootstock's on harvest duration of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Harvest duration Punjab Sartaj						Harvest duration Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	123	123	123	120	121	121	75	76	76	74	71	73
T ₂	PNR-7	124	122	123	121	122	121	75	72	74	70	74	72
T ₃	NR-10	121	121	121	122	122	122	74	78	76	76	78	77
T ₄	L-0272	121	120	120	121	122	121	74	72	73	70	72	71
T ₅	L-0275	123	124	123	121	120	121	71	71	71	69	69	69
T ₆	L-097	119	120	119	117	118	117	73	70	72	68	71	70
T ₇	Hisar Lal	121	122	122	120	121	121	70	70	70	71	73	72
T ₈	EC-531804	125	126	126	123	124	123	76	77	77	79	74	77
T ₉	EC-119197	122	122	122	123	122	122	81	82	82	81	86	84
T ₁₀	Control (NG)*	124	122	123	51	54	52	74	72	73	44	40	42
	CD(P=0.05)	NS	NS	NS	9	8	7	5	7	5	8	7	7

(NG)*: Non-Grafted

4.1.7 Average fruit weight (g)

Punjab Sartaj

While observing Table 4.1.7, nematode free plots indicated that rootstocks had a significant effect on average fruit weight of plants. In pooled data of plots it revealed that plants grafted on EC-119197 showed exceptionally higher fruit weight of 94.8 g which were significantly higher followed by EC-531804 with an average of 89.1 g which was statistically at par with non-grafted plants and recorded similar data in both years. On further investigating the data rootstocks NR-5 recorded a fruit weight of 86.0 g which was significantly lower than EC-119197 and EC-531804 when analyzed in pooled data but was statistically at par when recorded for yearly data. PNR-7 and Hisar Lal which were statistically at par with non-grafted plants of Punjab Sartaj having average fruit weight of 83.9g. While, rootstocks NR-10, L-0272, L-0275 and L-097 showed exceptionally lower fruit weight which was significantly lower among grafted plants as well as from non-grafted control plants of Punjab Sartaj recording a similar data in both years of experiment. Varied average fruit weight was recorded only due to interactions between different scions and rootstocks.

On inspecting infested plots of experiment it revealed that fruit weight of control plants was drastically reduced under influence of root knot nematode disease and showed an average weight of 34.7 g which was significantly less than rest of the rootstocks. A similar pattern of average fruit weight was observed in grafted plants as observed in nematode free plots of experiment, where EC-119197 (94.5g) and EC-531804 (87.1g) showed exceptionally higher fruit weights followed by NR-5, PNR-7 and Hisar Lal (84.4g, 81.7g and 81.8g). Similar results were reported by Djidonou *et al* (2013), Mahmoud (2014), Wahb-Allah (2014) and Kumar *et al* (2015).

Punjab Ratta

On observing Table 4.1.7 in nematode free plots pooled data revealed that rootstocks EC-119197, EC-531804 and NR-5 showed exceptional higher fruit weight that was 88.7 g, 84.2g and 83.2 g respectively where as EC-119197 was higher among all the treatments and was at par with EC-531804 and NR-5. Further while comparing with non-grafted plants, EC-119197, EC-531804 and NR-5 were statistically higher than non-grafted plants of Punjab Sartaj (75.3g) but were at par with PNR-7, NR-10, L-0272 and Hisar Lal.

On scrutinizing Nematode infested plots of experiment pooled data revealed that self rooted plants of Punjab Ratta (control) showed exceptionally low average weight of fruits (33.2g) which was significantly less than grafted plants. In grafted plants rootstock EC-119197 and EC-531804 had more average weight of fruits among other rootstocks in range of 88g to 83.5g succeeded by NR-5, PNR-7, NR-10 and Hisar Lal. Pogonyi *et al* (2005) reported that when Lemance F1 was grafted onto Beaufort rootstock, increased yield mainly due to higher average fruit weight.

Table 4.1.7 Effect of different rootstock's on average fruit weight (g) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Average fruit weight (g) Punjab Sartaj						Average fruit weight (g) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	86.5	85.6	86.0	83.3	85.6	84.4	82.6	83.9	83.2	81.2	82.1	81.6
T ₂	PNR-7	83.5	84.0	84.3	81.2	82.3	81.7	78.4	77.5	77.9	77.5	75.4	76.5
T ₃	NR-10	67.2	65.5	65.8	66.2	64.2	65.7	74.2	75.6	74.9	73.3	74.5	73.9
T ₄	L-0272	68.5	69.3	68.9	68.3	68.9	68.7	71.2	70.2	70.7	70.1	69.3	69.7
T ₅	L-0275	65.3	66.5	65.4	64.1	66.2	65.1	69.3	68.5	68.9	65.3	64.5	64.9
T ₆	L-097	68.2	67.8	68.0	67.2	65.2	66.2	64.1	65.2	64.7	63.2	62.2	62.7
T ₇	Hisar Lal	82.5	84.5	83.5	82.3	81.2	81.8	79.2	80.2	80.0	78.5	77.3	77.9
T ₈	EC-531804	88.9	89.4	89.1	86.8	87.5	87.1	83.8	84.5	84.2	83.5	83.5	83.5
T ₉	EC-119197	95.3	94.7	94.8	94.3	94.2	94.3	88.2	89.2	88.7	87.5	88.6	88.0
T ₁₀	Control (NG)*	82.9	83.0	83.9	35.2	34.2	34.7	76.5	74.2	75.3	34.2	32.3	33.2
	CD(P=0.05)	10.6	10.3	6.0	8.1	9.3	7.4	8.5	10.1	5.7	8.3	9.9	5.6

(NG)*: Non-Grafted

4.1.8 Number of fruits

Grafting has a noticeable increase in yield and has significant effect on number of fruits per plant and it is one of major factor in favoring the yield of plants. Effect of different rootstock on number of fruits of two scions that was Punjab Sartaj and Punjab Ratta has been presented in Table 4.1.8

Punjab Sartaj

Observing Table 4.1.8 in nematode free plots of experiment, rootstocks L-097 (74.4), L-0275 (72.6), L-0272 (71.6), Hisar Lal (65.7) and NR-10 (65.4) has significantly more number of fruits than other grafted as well as non-grafted plants (60.8). While critically investigating the data it was revealed that Hisar Lal (64.8) in year 2015-16 recorded significant lower number of fruits than L-097 (75.6) but was statistically at par in year 2016-17. Increased number of fruits on grafted plants generally recorded a lower fruit weight as well as fruit size, similar results were quoted by Mahmoud (2014) that there were more of clusters of flower and increase in flower count per cluster which also helped in increase in number of fruits. While further investigating grafted plants EC-531804, EC-119197, NR-5 and PNR-7 had significantly less number of fruits than L-097. Khah *et al* (2006) also reported that grafted plants have more number of fruits per truss than non-grafted plants.

While investigating pooled data of Nematode infested plots non-grafted plants of Punjab Sartaj were severely infested by nematodes and recorded a significant low value (27.2). Whereas grafted plants conferred resistance against disease and recorded similar values as in nematode free plots where rootstocks L-097 (72.9) recorded highest fruit count followed by L-0275 (71.2) and L-0272 (71.1) which were statistically at par among grafted plants. While investigating yearly data it was revealed that plants grafted on NR-10 (65.1) recorded statistically at par data with L-097 (72.2) in year 2016-17 but in year 2015-16 it recorded significantly lower fruit count than L-097 (73.5). In infested plots plants recorded lower fruit count because of heavy infestation of nematodes which hinders plants growth as well as other physiological activities of plants.

Punjab Ratta

In nematode free plots of Punjab Ratta, pooled data revealed that non-grafted plants of Punjab Ratta (control) recorded 29.3 fruits per plant whereas grafted plants recorded significantly higher number. Rootstocks L-097 L-0275, L-0272 and NR-10 have a tally of 37.6, 36.8, 32.8 and 31.3 numbers of fruits respectively on analyzing data they recorded a non-significant effect on number of fruits.

While observing pooled data in infested plots of experiment, non-grafted plants had significantly lesser number of fruits (10.4) where as rootstock L-097 (36.7) recorded highest number of fruits which was followed by L-0275 (34.2) and L-0272 (32.0) had significantly higher number of fruits. While observing yearly data rootstocks in year 2015-16 all grafted

Table 4.1.8 Effect of different rootstock's on number of fruits on Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Number of fruits Punjab Sartaj						Number of fruits Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	58.6	60.1	59.4	55.3	59.5	57.4	27.1	26.1	26.6	26.2	28.2	27.2
T ₂	PNR-7	62.7	62.1	62.4	62.5	60.2	61.4	29.5	30.6	30.1	28.0	27.3	27.7
T ₃	NR-10	64.5	66.2	65.4	62.5	65.1	63.6	32.0	30.6	31.3	31.5	29.5	30.5
T ₄	L-0272	72.0	71.2	71.6	71.3	70.8	71.1	33.0	32.5	32.8	32.8	31.2	32.0
T ₅	L-0275	71.8	73.3	72.6	70.2	72.2	71.2	36.2	37.3	36.8	34.9	33.5	34.2
T ₆	L-097	75.6	73.3	74.4	73.5	72.2	72.9	38.8	36.3	37.6	38.2	35.2	36.7
T ₇	Hisar Lal	64.8	66.6	65.7	62.3	61.2	61.8	27.0	28.2	27.6	27.3	26.2	26.8
T ₈	EC-531804	59.7	59.3	59.5	57.8	58.5	58.2	29.8	30.6	30.2	28.2	27.5	27.9
T ₉	EC-119197	59.3	60.1	59.7	58.2	58.8	58.5	27.8	28.2	28.0	26.2	28.2	27.2
T ₁₀	Control (NG)*	60.4	61.2	60.8	25.2	29.2	27.2	29.9	30.1	29.3	11.3	9.5	10.4
	CD(P=0.05)	8.0	10.3	9.6	9.6	9.7	6.0	NS	NS	NS	11.2	9.0	5.6

(NG)*: Non-Grafted

plants recorded at par data with L-097 (38.2) except for plants grafted on rootstock NR-5 (26.2) and EC-119197 (28.2) which were significantly lower in fruit count but in year 2016-17 all grafted plants recorded at par data with L-097 (35.2) Grafted plants confirm their ability to fruit under infested conditions as nematode resistant rootstock provided resistance against diseases. Similar, results were quoted by Louws *et al* (2012) in which grafted tomato plants recorded higher plant yield as compared to non-grafted plants due to increase in number of fruit.

4.1.9 Total yield (q/ha)

Grafting is mainly done to provide resistance from soil borne disease but sometime it is having a complementing effect on yield. Data for total yield in grafted and non-grafted has been presented in Table 4.1.9.

Punjab Sartaj

In pooled data of nematode free plots revealed that plants grafted on rootstock EC-119197 yielded significantly higher among grafted as well as non-grafted plants of Punjab Sartaj with an average yield of 2115 q/ha which was further followed by Hisar Lal, EC-531804 and PNR-7 with an average yield of 2024 q/ha, 2003 q/ha and 1995 q/ha respectively. Plants yielded in a similar trend in 2016-17 year. While during 2015-16 year, grafted plants of EC-531804 (2011 q/ha) recorded more yield than grafted plants of Hisar Lal (2001 q/ha). It may be due to the effect of favourable temperature conditions which may have elevated yield of EC-531804 assuring yield increment in grafted plants. Similar results were obtained by Chung and Lee (2007) confirming yield increase in grafted fruit bearing vegetables.

While investigating Nematode infested plot it was revealed that self rooted plants of Punjab Sartaj were severely affected by the nematode and formation of galls were intense recording a yield of 322q/ha which was significantly lower than other grafted plants. Grafted plants illustrate high resistance and did not have any detrimental effect on yield of plants hence showing a maximum yield of 2070 q/ha when plants were grafted on rootstock EC-119197 which was significantly higher among other rootstocks followed by Hisar Lal with a mean yield of 1983 q/ha, EC-531804 with a yield of 1980 q/ha and PNR-7 with a mean yield of 1924 q/ha. In yearly data it was revealed that plants of Hisar Lal (2003 q/ha) yielded more than EC-531804 (1975 q/ha) in year 2015-16 but in year 2016-17 it recorded yield of 1963 q/ha which was lower than EC-531804 (1985 q/ha) but were statistically at par among themselves. These results were in-line with Di Gioia *et al* (2010).

Plants grafted on to vigorous rootstocks have an ability to respond more towards nutrient and water uptake hence making them more vigorous and hence help in improving yield of plant either by complimenting with overall average fruit weight or by increasing number of fruits per plant even it helps in supplementing more number of flowers per cluster

Table 4.1.9 Effect of different rootstock's on total yield (q/ha) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Total yield (q/ha) Punjab Sartaj						Total yield (q/ha) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	1,951	1,931	1,941	1,922	1,925	1,924	503	514	504	483	504	499
T ₂	PNR-7	1,958	2,031	1,995	1,915	1,933	1,924	526	510	518	486	508	497
T ₃	NR-10	1,751	1,753	1,752	1,721	1,635	1,678	532	534	533	519	504	512
T ₄	L-0272	1,823	1,755	1,789	1,795	1,787	1,791	511	517	514	502	479	491
T ₅	L-0275	1,791	1,840	1,816	1,788	1,791	1,790	521	528	525	513	498	506
T ₆	L-097	1,889	1,900	1,895	1,874	1,892	1,883	492	495	494	488	474	482
T ₇	Hisar Lal	2,001	2,050	2,024	2,003	1,963	1,983	520	503	512	489	514	501
T ₈	EC-531804	2,011	1,995	2,003	1,975	1,985	1,980	599	601	601	587	569	578
T ₉	EC-119197	2,090	2,140	2,115	2,075	2,065	2,070	600	603	602	587	575	581
T ₁₀	Control (NG)*	1,975	2,000	1,988	340	304	322	530	533	532	59	71	65
	CD(P=0.05)	56	47	36	53	47	34	53	47	34	48	46	33

(NG)*: Non-Grafted

(Al-Harbi *et al* 2016).

Punjab Ratta

On investigating pooled data of Punjab Ratta it was revealed that grafting successfully enhances the yield of plant. In pooled data EC 119197 and EC-531804 yielded exceptionally well and were significantly higher among different rootstocks with a yield of 602 q/ha and 601 q/ha followed by non-grafted plants with an average yield of 532 q/ha which was further at par with plants grafted on rootstocks NR-10, L-0275 and L-0272. Rootstocks NR-5, Hisar Lal, PNR-7 and L-097 yield significantly lower than rest of the grafted and non-grafted plants. Similar trend were obtained in both of the years 2015-16 and 2016-17.

Sometimes a negative effect of grafting may also be seen with lower yield (Nina and Joze 2004). On other hand grafting has a positive effect which is mainly due to presence of vigorous root system of rootstocks which enhances water and mineral nutrient uptake of plants hence improving vigour and fruit yield of plants and even helps to confer disease in plant. Similar results were quoted by Lee and Oda (1995).

In case of Nematode infested plot plants with resistant rootstock showed high resistant to diseases and had significantly higher yield than self rooted plants (65 q/ha). Rootstock EC-119197 and EC-531804 distinguishingly yielded better among other rootstock making an average yield of 581 q/ha and 578 q/ha respectively. Similar trends were obtained in nematode free plots but there was a drastic decrease in yield of self rooted plants of Punjab Ratta which recorded an average yield of 65 q/ha which was due to formation of nematode galls on self rooted plants hence decreasing yield of plants on other hand plants grafted on resistance rootstocks showed high resistance to disease and yielded significantly higher which also improved marketable yield. Same results were reported by Nina and Joze (2004).

4.1.10 Marketable Yield (q/ha)

Punjab Sartaj

Pooled data presented in Table 4.1.10 in nematode free plots revealed that grafted plants has a significant effect on marketable yield than non-grafted plants. Rootstock EC-119197 significantly recorded higher yield which is around 1800 q/ha and recorded similar trend in both years followed by EC-531804 and Hisar Lal which recorded a yield of 1723 q/ha and 1654 q/ha respectively. On further observing data PNR 7, NR-5 and L-097 recorded a yield of 1641 q/ha, 1617 q/ha and 1594 q/ha which were significantly lower than EC-119197, EC-531804, Hisar Lal and non grafted plants of Punjab Sartaj. NR-10, L-0275 and L-0272 were overall low yielders and NR-10 recorded a minimum yield of 1526 q/ha yield. Similar trends were observed in both the years 2015-16 and 2016-17.

On accounting data for Nematode infested plot similar trend was observed as in nematode free plot except for Non-grafted plants of Punjab Sartaj that yielded significantly

Table 4.1.10 Effect of different rootstock's on marketable yield (q/ha) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Marketable yield (q/ha) Punjab Sartaj						Marketable yield (q/ha) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	1608	1626	1617	1546	1585	1551	462	458	460	447	444	446
T ₂	PNR-7	1626	1655	1641	1583	1596	1589	461	461	461	455	447	451
T ₃	NR-10	1523	1528	1526	1473	1467	1470	495	491	493	477	474	476
T ₄	L-0272	1520	1540	1530	1505	1490	1498	477	471	474	460	466	463
T ₅	L-0275	1537	1568	1552	1475	1486	1480	480	488	484	471	463	467
T ₆	L-097	1591	1596	1594	1456	1490	1473	460	457	459	438	443	441
T ₇	Hisar Lal	1610	1698	1654	1585	1643	1614	462	463	462	446	441	444
T ₈	EC-531804	1739	1708	1723	1635	1650	1642	569	562	566	545	531	538
T ₉	EC-119197	1812	1787	1800	1729	1744	1736	571	570	571	545	544	545
T ₁₀	Control (NG)*	1697	1672	1632	220	210	215	491	493	492	42	47	44
	CD(P=0.05)	60	51	39	60	57	33	43	47	30	34	33	18

(NG)*: Non-Grafted.

lower than grafted plants as these were susceptible to root knot nematode. Severe gall formation was observed on roots of non-grafted plants hindering plant growth and lowering yield of plants drastically to 200 q/ha in year 2015-16 and 210 q/ha in year 2016-17 giving a pooled value of 215 q/ha. Plants grafted on rootstock EC-119197 yielded maximum with a mean yield of 1736 q/ha which was significantly higher in both the years of experiment followed by EC-531804 which recorded a value of 1642 q/ha and Hisar Lal with a value of 1614 q/ha while further accompanied by PNR-7 and NR-5.

In general plants with superior and resistance root system have higher resistance to soil borne disease. Grafted plants were acquainted with nematode resistant roots showing higher resistance to nematode which hindered gall formation in roots moreover improved water and nutrient uptake of plants effectively, providing more vigour as well as more number fruits per plant and supplementing average fruit weight which helped in increasing marketable yield of plants both in Nematode infested and nematode free plots. Similar, findings were reported by Di Gioia *et al* (2010), Turkmen *et al* (2010) and Al-Harbi *et al* (2016).

Punjab Ratta

Profit of farm produce directly depends on the marketable yield of crop. Marketable yield is generally affected by both biotic and abiotic stresses, grafting helps in improving marketable yield of crop. On scrutinising Table 4.1.10 it was revealed that grafting improved yield over self rooted plants, where plants grafted on rootstocks EC-119197 yielded significantly higher with a maximum mean yield of 571 q/ha further followed by EC-531804 with a mean yield of 566 q/ha which was significantly higher among rest of the rootstocks. Plants grafted on rootstock L-097 yielded significantly lower among other rootstocks as well as non-grafted plants.

Increase in yield is generally supplemented by vigour of rootstock by enhancing movement of nutrients and minerals from roots to scion as investigating Nematode infested plot. Non-grafted plant were highly susceptible to disease and yielded significantly lower than grafted plants with an mean yield of 44 q/ha which was a drastic shrink where as grafted plants yielded higher with nearly no signs of disease stress or no gall formation on roots. Rootstock EC-119197 recorded maximum yield of 545 q/ha which was significantly higher among grafted plants further followed by EC-531804 which recorded a value of 538 q/ha which was also significantly higher among other rootstocks. Similar trends were followed in both the years 2015-16 and 2016-17. Results were in line with Turkmen *et al* (2010) and Al-Harbi *et al* (2016) which recorded higher yield of grafted tomato under stress conditions.

4.1.11 Pericarp Thickness

Punjab Sartaj

Grafting has conflicting reports on altering fruit quality in vegetables. On scrutinising Table 4.1.11 it revealed that grafting had both positive and negative effect on pericarp

Table 4.1.11 Effect of different rootstock's on pericarp thickness of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Pericarp Thickness (mm) Punjab Sartaj						Pericarp Thickness (mm) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	7.01	7.00	7.00	6.99	6.93	6.98	6.80	6.98	6.94	6.68	6.65	6.66
T ₂	PNR-7	7.15	7.05	7.11	7.13	7.10	7.11	7.13	7.03	7.08	7.05	7.10	6.91
T ₃	NR-10	6.09	6.22	6.14	6.19	6.10	6.14	6.16	6.00	6.11	6.08	6.05	6.06
T ₄	L-0272	6.38	6.42	6.39	6.42	6.34	6.38	6.15	6.00	6.11	6.14	6.01	6.07
T ₅	L-0275	5.95	5.91	5.82	5.65	5.76	5.70	5.83	5.65	5.74	5.68	5.54	5.61
T ₆	L-097	5.23	5.21	5.22	5.22	5.21	5.22	4.43	4.57	4.50	4.14	4.08	4.11
T ₇	Hisar Lal	6.32	6.41	6.36	6.27	6.32	6.29	5.33	5.29	5.31	5.01	4.83	4.98
T ₈	EC-531804	7.83	7.73	7.78	7.77	7.67	7.72	8.16	8.45	8.31	7.93	8.15	8.04
T ₉	EC-119197	8.27	8.18	8.22	8.18	8.20	8.19	8.52	8.63	8.58	8.36	8.04	8.20
T ₁₀	Control (NG)*	7.04	6.94	7.02	5.11	5.09	5.05	6.91	6.51	6.74	4.95	5.01	4.95
	CD(P=0.05)	0.9	1.2	0.6	0.7	1.4	0.7	0.7	0.5	0.4	1.3	0.7	1.0

(NG)*: Non-Grafted

thickness of fruit. Although final fruit characteristics clearly depends upon scion but can be altered due to interactions with rootstock (Yetisir *et al* 2003). Rootstocks EC-119197 recorded maximum thickness of 8.22 mm which was significantly higher among other rootstocks followed by EC-531804 with a thickness of 7.78 mm which were somehow significantly higher than non-grafted plants. On further investigating rootstocks PNR-7 and NR-5 recorded a thickness of 7.11 mm and 7.00 mm which was also at par with control plants but recorded a higher pericarp thickness than rootstocks NR-10, L-0272 and L-0275. Similar trends were obtained in both of the years of experiment that is year 2015-16 and 2016-17 where grafted plants recorded at par data with non-grafted. Whereas Non-grafted plants had a thickness of 7.04 mm which was significantly less than some of the grated plants that is EC-119197 and EC-531804, when investigated in pooled data but on yearly data basis it was statistically at par with EC-531804 in year 2015-16 and 2016-17.

While investigating Nematode infested plot there was comprehensible decrease in pericarp thickness of control plots that is non-grafted plants, which were susceptible to disease hence decreasing fruit size as well as average fruit weight of plants. Plants grafted on different rootstocks showed resistance to disease and followed same trend of result as in nematode free plot were plants grafted on rootstock EC-119197 recorded a maximum thickness of 8.19 mm which was higher among all rootstocks and control plants when investigated for pooled data but on observing year-wise data EC-119197 was at par with EC-531804. L-097 plants recorded lowest pericarp thickness and were at par with non-grafted plants. Parallel results were followed in both the years 2015-16 and 2016-17. Above results have relevance with the research of Kumar *et al* (2015).

Punjab Ratta

Being a perishable commodity shelf life plays a high role in quality of tomato. While investigating Table 4.1.11 in nematode free plot it revealed that grafting has significant effect on pericarp thickness of fruit. Plants grafted on EC-119197 and EC-531804 which have higher pericarp thickness of 8.58 mm and 8.31 mm correspondingly and were significantly higher among rest of the treatments in both consecutive years of experiment followed by PNR-7 (7.08 mm) and NR-5 (6.94 mm) which were at par with each other as well as with non-grafted plants of Punjab Ratta illustrating a pericarp thickness of 6.74 mm which was significantly higher among rest of the treatments and had similar results in both years. Change in pericarp thickness is generally due to scion and rootstock interactions which may alter fruit characters as well as shape and size of fruits.

While examining Table 4.1.11 Nematode infested plots it discloses that grafted plants having highly resistant roots proves to be good alternative for controlling nematode disease. Rootstocks EC-119197 and EC-531804 exhibit maximum fruit thickness with an average mean of 8.20 mm and 8.04 mm which was significantly higher than other rootstocks followed

by PNR-7 and NR-5. Self rooted plants or control plants of Punjab Ratta were highly susceptible to nematode which has significant less thickness with an average of 4.95 mm. Over both the years 2015-16 and 2016-17 it showed similar results. Hence grafting confirming resistance against nematodes and improved fruit quality both under infested as well as nematode free conditions these result were also substantiated by Kumar *et al* (2016).

4.1.12 TSS (Total Soluble Solids) °Brix

Punjab Sartaj

Being one of the most important traits of quality Total soluble solids (TSS) plays major role for industrial purpose use of tomato. Grafting is surrounded by contradictions of affecting TSS in fruits while scrutinizing Table 4.1.12 there was a significant effect of different rootstocks. Plants grafted on L-097 showed maximum TSS content with 6.4 °Brix and is significantly higher than other rootstocks even in both years of experiment followed by L-0275, Punjab Sartaj (non-grafted), Hisar Lal and L-0272 which approximately had an average of 5.9, 5.6, 5.6 and 5.5 °Brix respectively. On further investigating plants grafted on rootstocks NR-5, PNR-7, EC-531804 and EC-119197 recorded least TSS as compared to other grafted plants and non-grafted plants and were at par among them-self. Similar trend was followed in both the years of experiment except in yearly data L-097 was statistically at par with L-0275.

Likewise while inspecting Nematode infested plots self rooted plants recorded a reduction in TSS of fruits which may be due to infestation of disease. Self rooted plants recorded least TSS of 4.5 °Brix as compared to grafted plants. L-097 recorded maximum TSS followed by L-0275, Hisar Lal and L-0272. Alteration in TSS of grafted tomato has been reported by many authors, various rootstocks decrease or increase soluble solids in fruit (Alexopoulos *et al* 2007) due to scion and rootstocks interactions they have influence on TSS which may be reduce by grafting (Pogonyi *et al* 2005; Qaryouti *et al* 2007) or may increase by grafting Mohammed *et al* (2009). These results are parallel to findings of other authors.

Punjab Ratta

While inspecting Table 4.1.12 nematode free plot it was revealed that grafting had a noteworthy effect on Total Soluble Solids of fruit, being one of the major character for flavor and processing industry high TSS favors processing industries. Rootstock L-097, L-0275 and Hisar Lal significantly showed higher TSS values as compared among other rootstocks and control plants. Non grafted control plants recorded a value of 4.8 °brix which was significantly lower than L-097, L-0275 and Hisar Lal but was significantly higher than other rootstocks. NR-5, NR-10 and EC-119197 recorded least TSS. Similar results were obtained in both years except for PNR-7 which recorded a higher TSS value in first year of experiment with value of 4.13 °brix which was at par with control plants but was non-significant when recoded for second year as well as for pooled data.

Table 4.1.12 Effect of different rootstock's on TSS ⁰Brix (total soluble solids) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	TSS (⁰ Brix) Punjab Sartaj						TSS (⁰ Brix) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	4.7	4.6	4.7	4.7	4.5	4.6	3.7	3.8	3.8	3.7	3.8	3.8
T ₂	PNR-7	4.6	4.6	4.6	4.5	4.5	4.5	4.2	4.1	4.2	4.1	4.1	4.1
T ₃	NR-10	5.0	5.1	5.1	5.1	5.0	5.1	3.8	3.8	3.8	3.7	3.7	3.7
T ₄	L-0272	5.4	5.6	5.5	5.5	5.3	5.4	4.0	4.0	4.0	4.0	4.0	4.0
T ₅	L-0275	5.9	5.9	5.9	5.7	5.7	5.7	5.9	6.2	6.0	5.9	6.0	5.9
T ₆	L-097	6.4	6.4	6.4	6.2	6.4	6.3	6.2	6.3	6.3	6.1	6.3	6.2
T ₇	Hisar Lal	5.6	5.5	5.6	5.6	5.6	5.6	5.8	5.9	5.9	5.7	5.7	5.7
T ₈	EC-531804	4.1	4.0	4.1	4.1	4.1	4.1	4.0	4.1	4.1	4.0	4.0	4.0
T ₉	EC-119197	4.3	4.3	4.3	4.3	4.1	4.2	4.0	4.0	4.0	3.7	3.7	3.7
T ₁₀	Control (NG)*	5.5	5.6	5.6	4.4	4.6	4.5	4.8	4.8	4.8	4.1	4.5	4.3
	CD(P=0.05)	0.6	0.6	0.4	0.5	1.2	0.6	0.8	0.7	0.4	0.5	1.0	0.5

(NG)*: Non-Grafted

Looking over Nematode infested plots it revealed that rootstocks showing high resistance to disease were able to preserve the quality of fruits. L-097, L-0275 and Hisar Lal recorded higher TSS that is 6.2, 5.9 and 5.7 °brix correspondingly which is significantly higher than control plants of Punjab Ratta (Non-grafted). Similar results were recorded in both years of experiment. Grafting alters TSS value as per interactions between scion and different rootstocks used, which may alter levels of hormonal production in plants so it may carry both negative and positive effect on quality of fruit. Parallel results have been reported by many authors like Lopez-Galarza *et al* (2004) and Alexopoulos *et al* (2007).

4.1.13 Lycopene content (mg/ 100g of fresh weight)

Punjab Sartaj

Lycopene is a bright red carotenoid pigment and phytochemical found in tomatoes and other red fruits. Lycopene in tomato soup and tomato paste is more bio-available than in fresh tomatoes (Tepic *et al* 2006). On observing Table 4.1.13 nematode free plots different rootstocks were used but did not show any significant effect on scion and statistically data was non-significant. In fresh tomato juice maximum lycopene content was observed in rootstock NR-10 with a mean of 5.78 mg/ 100 g but was statistically at par with each other. Turhan *et al* (2011) recorded similar results where there was no significant difference in lycopene among grafted and Non-grafted plants.

On analyzing Nematode infested plots there was a significant difference among control (non-grafted) and grafted plants. Grafted plants illustrated higher lycopene content, rootstocks NR-10 recorded maximum lycopene content of 5.60 mg/100g and was at par with all other grafted plants and were significantly higher than non-grafted plants, which recorded a value of 5.41 mg/100g. Augment of lycopene content was due to resistance imparted by rootstock, which aided better fruit growth and superior fruit quality that helped in perpetuating high lycopene. Liana *et al* (2009) observed similar results, where highest lycopene content was observed in grafted plants.

Punjab Ratta

Lycopene content is fundamentally determined by the genetics of variety as well as environmental factors. In our experiment while observing data of Table 4.1.13 nematode free plots there was no significant difference in lycopene both in grafted as well as non-grafted plants. Although data is non-significant but still lower ranges of lycopene was reported in grafted plants as compared to self-rooted plants this may be due to overall higher yield of grafted plants and late maturity of fruits on grafted plants. Turhan *et al* (2011) also reported that lycopene content did not differ significantly between the grafted and non-grafted plants and in contrast, Mohammed *et al* (2009) found a decrease for lycopene in grafted tomato plants. Many authors have reported that qualitative characters of fruits are not altered by grafting (Khah *et al* 2006).

Table 4.1.13 Effect of different rootstock's on lycopene content (mg/ 100g) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Lycopene content Punjab Sartaj						Lycopene content Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	5.18	5.10	5.14	5.14	5.12	5.13	8.10	8.17	8.13	8.14	8.11	8.12
T ₂	PNR-7	5.13	5.10	5.12	5.07	5.12	5.09	8.11	8.21	8.16	7.90	7.98	7.94
T ₃	NR-10	5.70	5.85	5.78	5.64	5.56	5.60	8.70	8.63	8.67	8.47	8.43	8.45
T ₄	L-0272	5.60	5.16	5.38	5.28	5.25	5.27	8.60	8.67	8.63	8.59	8.58	8.58
T ₅	L-0275	5.53	5.50	5.52	5.41	5.33	5.37	8.77	8.87	8.82	8.65	8.72	8.69
T ₆	L-097	5.57	5.60	5.58	5.46	5.49	5.48	8.45	8.45	8.45	8.37	8.44	8.41
T ₇	Hisar Lal	5.43	5.38	5.40	5.28	5.15	5.21	7.85	7.85	7.85	7.76	7.82	7.79
T ₈	EC-531804	4.83	4.75	4.79	4.65	4.75	4.70	7.77	7.67	7.72	7.57	7.57	7.57
T ₉	EC-119197	4.98	4.79	4.89	4.94	4.70	4.81	7.91	7.86	7.89	7.85	7.85	7.85
T ₁₀	Control (NG)*	5.66	5.56	5.61	5.32	5.50	5.41	8.10	8.10	8.10	7.85	7.90	7.88
	CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

(NG)*: Non-Grafted

While investigating Nematode infested plot grafted plants recorded higher lycopene content where as non-grafted plants Punjab Ratta where highly affected by nematode and recorded a lesser amount of yield, fruit weight as well as lycopene content. Further while investigating data EC-531804 and EC-119197 demonstrated less lycopene as compared to other rootstocks whereas L-0272 and L-0275 recorded maximum lycopene content. Liana *et al* (2009) observed similar results having higher lycopene in grafted plants than non-grafted plants.

4.2 Experiment No. 2: Evaluation of different rootstocks and scions combination for yield and quality traits by using tube graft method.

4.2.1 Plant Height (cm)

In grafted plants height and vigor is enhanced as compared to non-grafting plants (Ioannou *et al* 2002). The data pertaining to the effect of different rootstocks on two scions Punjab Sartaj and Punjab Ratta for plant height was presented in Table 4.2.1.

Punjab Sartaj

In case of pooled data of nematode free plots, maximum plant height was observed in grafted rootstocks EC-119197 (358.7 cm) which was significantly higher from all other grafted and non-grafted rootstocks followed by NR-10 (317.5 cm). Whereas, minimum plant height was recorded in the grafted rootstock L-0272 (280.4 cm) which was significantly lower from all other grafted rootstocks but was at par with non-grafted plants. On analyzing yearly data, same rootstock EC-119197 showed significantly higher plant height (355.3 cm and 362.1 cm) from all other rootstocks in both years respectively (2015-16 and 2016-17) as well as from the non-grafted plants.

In case of pooled data of Nematode infested plants, highest plant height was observed in the rootstock EC-119197 (350.7 cm) which was significantly higher from all other rootstocks. Lowest plant height was observed in the non-grafted plants of Punjab Sartaj (84.7 cm) which was due to infestation of nematode disease which forms galls on roots further which hinders the uptake of minerals, nutrients and water. In yearly data (2015-16 and 2016-17) maximum plant height was achieved in the rootstock EC-119197 (351.1 cm and 350.2 cm respectively) which was significantly higher from all other grafted as well as non grafted plants. Similar results were reported by Ibrahim *et al* (2001) in tomato that grafted plants has more plant height than non-grafted plants under nematode free and Nematode infested soils might be due to the use of nematode resistant rootstock of tomato.

Punjab Ratta

Grafting significantly impacts height of plants. Pooled data showed that rootstocks EC-531804 (71.6 cm), L-097 (71.0 cm), NR-5 (69.8 cm), NR-10 (68.7 cm), EC-119197 (68.6 cm), Hisar Lal (68.4 cm), PNR-7 (68.3 cm), L-0272 (67.3 cm) and NR-10, recorded statistically at par plant height. These all rootstocks were significantly higher from the plants

Table 4.2.1 Effect of different rootstock's on plant height (cm) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Plant height (cm) Punjab Sartaj						Plant height (cm) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	299.7	302.9	301.3	297.3	294.8	294.4	70.4	69.8	69.8	70.1	69.1	69.8
T ₂	PNR-7	300.1	304.2	302.2	299.8	291.1	295.5	68.8	69.7	68.3	69.3	66.8	68.1
T ₃	NR-10	314.2	320.7	317.5	314.4	316.3	315.4	69.1	69.1	68.7	68.4	68.9	68.7
T ₄	L-0272	280.6	280.2	280.4	280.9	273.3	277.1	66.1	68.4	67.3	64.5	65.4	64.9
T ₅	L-0275	309.0	318.7	313.9	305.0	312.6	308.8	66.2	66.5	66.4	59.7	56.4	58.1
T ₆	L-097	301.0	305.5	303.3	297.4	290.7	294.1	70.1	71.9	71.0	65.2	65.5	65.4
T ₇	Hisar Lal	287.9	290.7	289.3	282.6	285.3	284.0	66.4	70.3	68.4	62.4	68.6	65.5
T ₈	EC-531804	287.5	285.6	286.2	279.0	280.7	279.9	72.0	71.1	71.6	67.7	71.6	68.7
T ₉	EC-119197	355.3	362.1	358.7	351.1	350.2	350.7	67.3	69.8	68.6	67.2	68.4	67.8
T ₁₀	Control (NG)*	279.4	275.6	277.5	86.5	82.9	84.7	57.9	52.8	55.4	31.4	32.4	31.9
	CD(P=0.05)	7.2	6.5	4.7	6.6	6.0	6.0	6.4	7.2	4.6	7.0	6.3	4.5

(NG)*: Non-Grafted

grafted on rootstock L-0275 (66.4 cm) and non-grafted plant (55.4 cm). In case of yearly data, maximum plant height was observed in the rootstock EC-531804 (72.0 cm) during 2015-16 and in the rootstock L-097 (71.9 cm) during 2016-17 respectively which was statistically at par with all other rootstocks except non-grafted plants in both the years.

In case of infested plots, highest plant height was observed in the rootstock EC-531804 (68.7 cm) which was significantly higher from the rootstock L-0275 (58.1 cm) and from non-grafted plants (31.9 cm) and statistically at par with all other grafted rootstocks. Similar results were observed under 2015-16 and 2016-17 yearly trials.

Overall, grafting enhances the plant height by reducing the nematode disease forming galls and providing the protection to plants by activating the scavenging enzymes in the roots. Similar results were reported by Khah *et al* (2006) in which grafted plants acquired more plant height than non-grafted plants due to accelerated xylem and phloem movements in the plant by secondary metabolites stored in vigorous root system.

4.2.2 Days to flowering

Days to flowering has direct association with early fruit yield and yield related traits in the tomato crop. This parameter is responsible for the earliness of the crop which favors more marketable yield and farmers may fetch more returns. The data related to the effect of different rootstock on two scions namely Punjab Sartaj and Punjab Ratta for days to first flowering was presented in Table 4.2.2.

Punjab Sartaj

Farmers' desire earliness of crop as early yield fetches more profit. There was no significant difference was observed among the different rootstocks in pooled data under the nematode free plots. Whereas, minimum number of days for flowering were observed in PNR-7 rootstock (82.6) and maximum number of days for flowering was observed in rootstock EC-531804 (91.4). In case of yearly data of 2015-16 and 2016-17, similar results were noticed.

While observing the data of infested plots, non-grafted plants of Punjab Sartaj were susceptible to disease and recorded a delayed flowering, which took 114.7 days to flowering. Among grafted plants rootstocks, PNR-7 recorded minimum number of days (83.9 days), which was statistically at par with L-0275 (84.0 days), NR-10 (84.5 days), L-097 (85.5 days), L-0272 (85.8 days) and Hisar Lal (86.7 days) and significantly lower from all other rootstocks. In case of yearly data similar results were observed for 2015-16 and 2016-17 except for L-097, where it was also statistically at par with NR-5 and recorded 91.3 days in year 2015-16 and 90.3 days in year 2016-17.

These results were in line with Khah *et al* (2006) who reported that grafted plants were able to flower early than non-grafted plants under infested conditions due to nematode resistant rootstock.

Table 4.2.2 Effect of different rootstock's on days to flowering of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Days to flowering Punjab Sartaj						Days to flowering Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	89.2	90.5	89.9	91.3	90.3	90.8	99.0	101.3	100.2	103.6	104.1	103.9
T ₂	PNR-7	82.3	82.9	82.6	83.4	84.3	83.9	101.3	99.7	100.5	103.2	101.7	102.5
T ₃	NR-10	82.7	84.9	83.8	83.7	85.3	84.5	102.3	99.6	101.0	104.3	102.7	103.5
T ₄	L-0272	85.7	84.8	85.3	85.7	85.8	85.8	98.9	100.3	99.5	100.2	102.5	101.4
T ₅	L-0275	84.3	83.3	83.8	83.6	84.3	84.0	98.4	97.0	98.6	100.7	101.7	101.2
T ₆	L-097	83.1	83.0	83.1	84.4	86.5	85.5	99.7	99.3	99.5	102.0	104.2	103.1
T ₇	Hisar Lal	84.8	85.6	85.2	86.4	86.9	86.7	102.1	99.0	100.6	103.1	104.2	103.7
T ₈	EC-531804	92.7	90.0	91.4	94.6	92.3	93.5	101.3	101.7	101.5	104.2	107.6	105.9
T ₉	EC-119197	88.1	91.9	90.0	92.7	92.2	92.5	103.1	102.3	102.7	104.9	108.6	106.8
T ₁₀	Control (NG)*	81.7	81.0	81.4	115.3	113.0	114.7	99.5	98.0	98.8	126.7	127.3	127.0
	CD(P=0.05)	NS	NS	NS	9.1	6.5	4.9	NS	NS	NS	10.3	9.2	6.1

(NG)*: Non-grafted

Punjab Ratta

In case of pooled data in nematode free plots it revealed that when plants of Punjab Ratta were grafted on different rootstocks it did not show any significant difference among grafted as well as non-grafted plants for days to flower. Minimum days to flowering, was observed in plants grafted on rootstock L-0275 (98.6 days). On comparing yearly data of 2015-16 and 2016-17 also not recorded any significant difference among grafted as well as non-grafted plants for days to flower.

While comparing for infested plots grafted plants recorded a significant difference with non-grafted plants. Plants grafted on rootstock L-0275 recorded minimum days (101.2) to flower while plants grafted on rootstock EC-119197 took maximum number days to flower (106.8) which were significantly lower from non-grafted plants (127.0 days) and statistically at par with rest of grafted plants. Similar, results were reported by Ibrahim *et al* (2001) that grafted plants of tomato were able to flower earlier than non-grafted plants due to the reason that resistant rootstocks provides higher movement of growth hormones like auxin through the union which improves the flower budding strength.

4.2.3 Days to picking

Days to first picking are responsible for earliness in tomato. Lesser the number of day's earlier yield can be fetched from the plants. Effect of different nematode resistant rootstock on two nematode susceptible scions named Punjab Sartaj and Punjab Ratta for days to first picking was analyzed and presented in Table 4.2.3.

Punjab Sartaj

From the data it was observed that in case of nematode free plots, minimum number of days for first picking was noticed in the rootstock PNR-7 (105.7 days) followed by L-097 (106.2 days), L-0275 (108.7 days), Hisar Lal (111.8 days) and NR-10 (112.8 days) which was significantly lower from rest of the rootstocks. Further the study reported that during the year 2015-16 and 2016-17, rootstock PNR-7 took minimum number of days for first picking (105.1 and 106.3 respectively) which was statistically at par with all other grafted rootstocks except EC-531804 (132.6 and 133.5 days), EC-119197 (126.2 and 123.5 days) and non grafted plants (116.0 and 119.2 days respectively).

On the other hand, pooled data under the Nematode infested plot revealed that minimum number of days for first picking was noticed in the rootstock PNR-7 (107.5 days) which was significantly lower from all other grafted and non grafted rootstocks except L-097 (109.1 days), L-0275 (110.5 days), Hisar Lal (112.8 days) and NR-10 (113.9 days) rootstocks. During the 2015-16 and 2016-17, rootstock PNR-7 took minimum number of days for first picking (106.8 and 108.2 days respectively) which was statistically at par with all other grafted rootstocks except EC-531804 (136.4 and 132.6 days), EC-119197 (124.4 and 127.8 days) and non grafted plants (140.5 and 142.6 days). Similar results were reported by Khah *et*

Table 4.2.3 Effect of different rootstock's on days to picking of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Days to Picking Punjab Sartaj						Days to Picking Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	112.2	114.6	113.4	115.7	116.8	116.2	120.6	121.7	121.2	123.6	122.5	123.1
T ₂	PNR-7	105.1	106.3	105.7	106.8	108.2	107.5	122.2	119.3	120.8	122.3	119.5	120.9
T ₃	NR-10	113.6	112.0	112.8	114.4	113.4	113.8	120.2	122.5	121.4	125.7	121.0	123.4
T ₄	L-0272	114.1	113.0	113.3	112.9	115.0	114.9	116.2	117.7	117.0	119.3	117.4	118.4
T ₅	L-0275	106.3	111.0	108.7	109.7	111.3	110.5	117.9	119.4	118.7	119.3	118.5	118.9
T ₆	L-097	105.3	107.0	106.2	108.9	109.2	109.1	115.1	117.0	116.1	116.7	118.0	117.4
T ₇	Hisar Lal	110.7	112.9	111.8	112.1	113.4	112.8	116.9	119.7	118.3	122.4	120.3	121.4
T ₈	EC-531804	132.6	133.5	133.1	136.4	132.6	134.5	124.7	124.5	124.6	128.8	125.1	127.0
T ₉	EC-119197	126.2	123.5	124.9	124.4	127.8	126.1	123.2	119.6	121.4	123.2	121.3	122.3
T ₁₀	Control (NG)*	116.0	119.2	117.1	140.5	142.6	141.6	118.0	123.0	120.5	147.2	150.3	148.8
	CD(P=0.05)	10.7	11.9	7.3	7.5	8.5	6.8	NS	NS	NS	11.2	11.4	7.0

(NG)*: Non-Grafted

al (2006) that grafted plant took lesser number of days for picking than non-grafted plants due to susceptibility of non-grafted plants to nematodes, which hindered growth of plants while resistant rootstock of grafted plants helped to confer resistance against disease.

Punjab Ratta

In case of nematode free plots pooled data revealed that there was no significant effect on days to first picking of grafted as well as non-grafted plants of Punjab Ratta. Minimum days to first picking was noticed in plants grafted on rootstock L-097 (116.1) while non-grafted plants of Punjab Ratta took 120.5 days for picking but recorded a statistically at par data with each other. Similar data was observed in both the years of trial which recorded a non-significant data.

On other hand while investigating Nematode infested plots of Punjab Ratta pooled data revealed that all grafted plants recorded a significant lower number of days for picking as compared to non-grafted plants (148.8). Plants grafted on rootstocks L-097 (117.4) took minimum days for picking followed by L-0272 (118.4), L-0275 (118.9), PNR-7 (120.9), Hisar Lal (121.4), NR-5 (123.1), NR-10 (123.4) and EC-119197 (122.3) which was statistically at par with each other. Similar results were obtained in both experimental trials that is in year 2015-16 and 2016-17 where plants grafted on rootstock L-097 recorded minimum number of days to picking (116.7 and 118 respectively). Similar, results were obtained by Khah *et al* (2006), which stated that early yield was obtained in infested plots where grafted plants increased overall vigor of plants due to enhanced physiological activity of grafted plants as increased uptake of water and minerals enhanced yield of plants compared to non-grafted plants.

4.2.4 Fruit width (cm)

Fruit width is an important parameter that determines the health of the fruits. Fruit width also influences the shape index of tomato. Data related to effect of different rootstock on scion for fruit width was presented in Table 4.2.4.

Punjab Sartaj

Different rootstocks may influence fruit characters of scion while ongoing investigation recorded a significant effect of rootstocks on fruit width of scion. Maximum fruit width was obtained by rootstock EC-119197 (6.2 cm) which was significantly higher from PNR-7 (4.9 cm), NR-10 (4.6 cm), L-0275 (4.3 cm), L-0272 (4.2 cm), L-097 (4.1 cm) and non-grafted plant (5.3 cm) and statistically at par with rest of all grafted rootstocks. Similar trend for fruit width was observed in both years of experiment that confirms the influence of different rootstocks on scion.

While observing data of infested plots pooled data, maximum fruit width was observed in EC-119197 rootstock (6.1 cm) which was statistically at par with NR-5 (5.5 cm), Hisar Lal (5.5 cm), EC-531804 (5.6 cm) and significantly higher from all other rootstocks. In

Table 4.2.4 Effect of different rootstock's on fruit width (cm) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Fruit width (cm) Punjab Sartaj						Fruit width (cm) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	5.6	5.8	5.7	5.3	5.8	5.5	5.7	5.6	5.6	5.4	5.6	5.5
T ₂	PNR-7	4.9	4.8	4.9	4.7	4.6	4.6	5.2	4.9	5.1	4.9	5.0	5.0
T ₃	NR-10	4.7	4.5	4.6	4.7	4.4	4.6	4.8	4.8	4.8	4.6	4.4	4.5
T ₄	L-0272	4.1	4.3	4.2	4.1	4.2	4.2	4.9	5.1	5.0	4.6	4.8	4.7
T ₅	L-0275	4.4	4.2	4.3	3.9	4.3	4.1	3.9	4.1	4.0	3.9	3.8	3.9
T ₆	L-097	4.2	4.1	4.1	4.1	3.9	4.0	4.2	4.1	4.1	3.9	3.8	3.8
T ₇	Hisar Lal	5.8	5.4	5.6	5.7	5.4	5.5	4.7	5.0	4.9	4.4	4.8	4.6
T ₈	EC-531804	5.8	6.1	5.9	5.4	5.7	5.6	6.0	5.9	6.0	5.7	5.8	5.7
T ₉	EC-119197	6.1	6.3	6.2	6.1	6.1	6.1	6.1	6.3	6.2	6.0	6.1	6.1
T ₁₀	Control (NG)*	5.3	5.3	5.3	4.2	4.5	4.5	5.0	5.3	5.1	4.4	4.7	4.6
	CD(P=0.05)	0.7	0.9	0.6	0.9	0.9	0.6	0.6	0.9	0.5	0.9	1.0	0.6

NG*: Non-Grafted

case of yearly data, same genotype EC-119197 showed highest fruit width (6.1 cm and 6.1 cm respectively) which was statistically at par with NR-5 (5.3 and 5.8 cm), Hisar Lal (5.7 and 5.4 cm) and EC-531804 (5.4 and 5.7 cm) rootstocks. Grafted plants possessed more fruit width than non-grafted plants due to infestation of disease, which hindered growth of non-grafted plants. Different rootstocks possessed different fruit sizes on scion, although key characters of scion fruit possesses total characters of fruit but sometimes there may be minor effect of rootstocks on shape as well as on quality characters of fruits (Rivard *et al* 2010).

Punjab Ratta

While investigating nematode free plots of Punjab Ratta pooled data revealed that fruit width of grafted plants was influenced by rootstocks and had significant results. Plants grafted on rootstocks EC-119197 recorded maximum fruit width (6.2 cm) and was significantly higher from all the treatments. It was further followed by EC-531804 (6.0) which was at par with EC-119197. While rootstocks NR-5 (5.6 cm), PNR-7 (5.1 cm), L-0272 (5.0 cm), Hisar Lal (4.9 cm) and NR-10 (4.8 cm) were at par with the non-grafted plants of Punjab Ratta (5.1 cm). Similar results were followed in both the years of experiment except for rootstock EC-119197 (6.1 and 6.3 cm) which were also statistically at par with NR-5 in year 2015-16 (5.7 cm) and 2016-17 (5.6 cm) in addition to EC-531804 (6.0 and 5.9 cm). Although fruit characters of scion are highly dependent on genetic architecture of scion but it may have a little effect of rootstocks which is purely due to the interactions between scion and rootstocks, which altered the transport of growth hormones through the union hence fruit characters may vary accordingly.

On the other hand while investigating Nematode infested plots, pooled data revealed that plants grafted on rootstock EC-119197 (6.1 cm) recorded maximum fruit width followed by EC-531804 (5.7 cm) which was statistically at par with each other. Non-grafted plants of Punjab Ratta (4.4 and 4.7 cm) recorded significantly lower fruit width from EC-119197 (6.0 and 6.1 cm) and EC-531804 (5.7 and 5.8 cm). Reduced fruit width in grafted plants was due to effect of nematode infestation which hinders plants growth hence decreasing overall vigor of plants as well as fruit width. Rivard *et al* (2010) acknowledged that grafted plants of tomato show high tolerance to nematodes when grafted on nematode resistant lines and were able to perform better over non-grafted plants.

4.2.5 Fruit length (cm)

Fruit length has influence the fruit shape index. More the fruit length more will be the fruit yield. Fruit length determines the size index and fruit pulp ratio of tomato. Data regarding the effect of different rootstocks on scions for fruit length was analyzed and summarized in Table 4.2.5.

Punjab Sartaj

Pooled data of nematode free plots showed that maximum fruit length was

Table 4.2.5 Effect of different rootstock's on fruit length (cm) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Fruit length (cm) Punjab Sartaj						Fruit length (cm) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	5.1	5.0	5.0	5.0	4.8	4.9	5.8	6.1	5.9	5.8	5.7	5.8
T ₂	PNR-7	5.3	5.6	5.5	5.1	5.4	5.3	5.4	5.5	6.0	5.9	5.7	5.8
T ₃	NR-10	4.4	4.6	4.7	4.2	4.4	4.3	5.8	5.8	5.8	5.7	5.9	5.7
T ₄	L-0272	3.8	4.1	3.9	3.8	3.8	3.8	5.4	5.3	5.3	5.3	5.2	5.3
T ₅	L-0275	3.8	4.1	4.0	3.9	3.8	3.8	4.9	5.1	5.0	4.8	4.9	4.9
T ₆	L-097	3.7	4.0	4.0	3.8	4.0	3.9	4.8	4.9	4.8	4.4	4.8	4.6
T ₇	Hisar Lal	5.7	5.9	5.8	5.6	5.7	5.6	5.8	6.0	5.9	5.7	5.9	5.7
T ₈	EC-531804	5.7	5.9	5.8	5.4	5.8	5.6	6.0	6.1	6.0	5.8	6.0	5.9
T ₉	EC-119197	6.2	6.5	6.3	6.2	6.4	6.3	6.5	6.2	6.3	6.1	6.3	6.2
T ₁₀	Control (NG)*	5.1	5.3	5.2	4.6	4.2	4.4	5.8	5.5	5.6	4.7	4.4	4.6
	CD(P=0.05)	0.6	0.7	0.5	0.9	0.9	0.5	0.8	0.9	0.5	1.0	0.9	0.6

(NG)*: Non-Grafted

observed under EC-119197 rootstock (6.3 cm) which was statistically at par with Hisar Lal and EC-531804 (5.8 cm) rootstocks and significantly higher from all other rootstocks. In case of yearly data of 2015-16 and 2016-17, similar trend for fruit length was observed where plants grafted on EC-119197 recorded significantly higher fruit length than non-grafted plants (6.2 cm and 6.5 cm resp.).

While observing the data for Nematode infested plots, EC-119197 (6.3 cm) recorded a significant higher fruit length among other grafted and non-grafted rootstocks. Minimum fruit length was observed in the rootstock L-0272 (3.8 cm). In case of yearly data, maximum fruit width was observed in the rootstock EC-119197 (6.2 cm and 6.4 cm) during 2015-16 and 2016-17 years respectively which was statistically at par with Hisar Lal (5.6 and 5.7 cm) and EC-531804 (5.4 and 5.8 cm) rootstocks and significantly higher from all other rootstocks. Non-grafted plants recorded a reduction in fruit length due to harsh effect of infested disease but grafted plants easily escaped the effect of nematodes. Reduction of fruit length observed in grafted plants is was due to interaction between scion and rootstocks. Pogonyi *et al* (2005) reported that different combination of graft behave differently and observed both higher and lower fruit lengths of plants than non-grafted control plants due to improved secondary metabolites and xylem flow movements between the stems for the grafted plants. Results were in line with Rivard *et al* (2010).

Punjab Ratta

On observing data for fruit length of Punjab Ratta pooled data of nematode free plots revealed that plants grafted on rootstocks EC-119197 (6.3 cm) recorded maximum fruit length and was statistically higher than non-grafted plants (5.6 cm). Further it was followed by EC-531804 (6.0 cm), NR-5 (5.9 cm), Hisar Lal (5.9 cm), PNR-7 (6.0 cm), and NR-10 (5.8 cm) rootstocks which were at par with EC-119197. Higher fruit length in grafted plants was due to effect of rootstocks and scion interactions which had significant effect in fruit length of plants. Similar results were obtained in both the years of experiment and were in line with the findings of Rivard *et al* (2010).

Identical testimony was obtained in Nematode infested plots as obtained in nematode free plots except for non-grafted plants as they recorded a reduced fruit length of 4.7 cm and 4.4 cm in year 2015-16 and 2016-17 further 4.6 cm in pooled data which was significantly lesser than EC-119197, EC-531804 and NR-5 which recorded a length of 6.2 cm, 5.9 cm and 5.8 cm. Non-grafted plants recorded lesser fruit length due to stress caused by nematodes which caused galling in roots of plants and hindered absorption capability of roots which decreased overall vigor of fruits in plant. These results were in line with Rivard *et al* (2010) which stated that higher fruit length was observed in grafted plants as compared to non-grafted plants.

4.2.6 Harvest duration (Number of days)

Prolonged harvest duration enhances over all yield of plants. The data for the effect of different rootstock on scions for harvest duration was presented in Table 4.2.6.

Punjab Sartaj

In case of pooled data of nematode free trial, maximum harvest duration was observed in the EC-119197 and EC-531804 rootstocks but all the rootstocks showed non-significant difference for the harvest duration. Similarly, on analysis of year wise data of 2015-16 and 2016-17 it was also observed that data harvest duration was not significantly affected.

While observing data in Nematode infested plots, highest harvest duration was observed under the rootstock EC-531804 (123) which was significantly higher from non-grafted plants and statistically at par with all other rootstocks. Similar trend for harvest duration was observed in both the years (2015-16 and 2016-17). Duration of harvest was drastically reduced in non-grafted plants might be due to the impact of disease, which reduced overall vigor of plants. Similar results were reported by King *et al* (2010).

Punjab Ratta

In case of nematode free plots it was observed that plants grafted on rootstocks EC-119197 (84) recorded maximum days of harvest duration which was significantly higher than all the treatments further followed by rootstock EC-531804 (81) and NR-10 (80) and were at par among themselves. Similar data was observed in both the years of experiment where EC-119197 recorded higher number of days for harvest and was at par with EC-531804 and NR-10 Grafted plants do have an increased uptake of minerals, nutrients and water, which helps in enhancing overall vigor of plants hence enhancing yield as well as harvest duration of plants.

Similarly while observing infested plots maximum effect of disease was observed on non-grafted plants which recorded harvest duration of 46 days and was significantly lower among all the treatments. Plants grafted on rootstock EC-119197 recorded maximum duration of harvest that is 82 days was significantly higher among other grafted plants. These results were in line with King *et al* (2010) who also reported prolonged duration of harvest when scion used was grafted on different rootstock combinations which increased harvesting duration of grafted plants over non-grafted plants.

4.2.7 Average fruit weight (g)

Fruit weight has direct and positive association with fruit yield. Fruit weight expresses the total health status of plant. The data pertaining to the effect of different rootstocks on scions for average fruit weight was noticed in Table 4.2.7.

Punjab Sartaj

The pooled data of nematode free trial showed that, maximum average fruit weight was observed in the rootstock EC-119197 (97.2 g) which was significantly higher from all

Table 4.2.6 Effect of different rootstock's on harvest duration of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Harvest duration Punjab Sartaj						Harvest duration Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	121	121	121	119	121	120	72	71	72	69	68	69
T ₂	PNR-7	127	122	124	127	122	124	73	77	76	70	75	73
T ₃	NR-10	123	122	122	123	122	122	79	81	80	76	78	77
T ₄	L-0272	119	122	120	118	122	120	72	72	72	69	69	69
T ₅	L-0275	120	120	120	118	120	119	72	67	70	70	64	67
T ₆	L-097	120	119	119	117	119	118	72	72	72	69	69	69
T ₇	Hisar Lal	123	121	122	122	121	122	76	75	76	73	72	73
T ₈	EC-531804	125	124	124	123	122	123	81	81	81	78	78	78
T ₉	EC-119197	125	124	124	122	122	122	84	85	84	81	82	82
T ₁₀	Control (NG)*	123	122	122	50	54	53	74	76	75	42	49	46
	CD(P=0.05)	NS	NS	NS	10	9	7	5	7	4	9	9	7

(NG)*: Non-Grafted

Table 4.2.7 Effect of different rootstock's on average fruit weight (g) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Average fruit weight (g) Punjab Sartaj						Average fruit weight (g) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	86.7	88.4	87.5	85.6	87.5	86.5	82.1	80.3	81.2	81.2	80.1	80.7
T ₂	PNR-7	83.3	84.5	83.4	82.3	83.2	82.1	78.5	77.3	77.9	75.3	77.5	76.9
T ₃	NR-10	66.3	67.3	66.7	66.5	65.1	65.8	73.2	72.2	72.7	72.1	71.2	71.7
T ₄	L-0272	67.9	66.5	67.2	65.2	66.3	65.8	70.4	69.3	69.9	69.3	68.5	68.9
T ₅	L-0275	66.1	65.3	65.7	63.2	64.3	63.8	70.3	68.5	69.4	66.3	65.0	65.7
T ₆	L-097	67.3	68.5	67.4	66.4	67.3	66.4	67.2	66.5	67.1	64.2	63.4	63.0
T ₇	Hisar Lal	82.2	83.8	82.8	82.2	82.3	81.9	80.1	81.9	81.0	79.7	80.1	79.9
T ₈	EC-531804	88.3	88.2	88.4	85.4	88.7	87.5	85.5	87.0	86.3	84.5	82.2	82.9
T ₉	EC-119197	96.6	97.9	97.2	94.1	96.3	95.2	88.2	88.0	88.1	87.3	87.5	87.4
T ₁₀	Control (NG)*	83.6	84.3	82.9	34.6	33.7	34.1	76.5	75.3	75.9	35.2	33.3	34.3
	CD(P=0.05)	7.1	8.4	5.8	8.1	9.5	6.3	10.0	10.3	7.2	8.9	9.1	5.5

(NG)*: Non-Grafted

other grafted and non-grafted rootstocks (82.9 g). Further it was followed by rootstock EC-531804 (88.4 g) and NR-5 (87.5 g) which was significantly lower than EC-119197. Minimum average fruit weight was observed in the rootstock L-0275 (65.7 g). In case of yearly data of 2015-16 and 2016-17, maximum average fruit weight was observed in the rootstock EC-119197 (96.6 g and 97.9 g respectively) which was significantly superior from all other rootstocks but was statistically at par with EC-531804 (88.3 g) in year 2015-16.

In case of Nematode infested plots, maximum average fruit weight was observed in EC-119197 (95.2 g) rootstock which was significantly higher from all other grafted as well as non-grafted rootstocks but was followed by EC-531804 and NR-5 and in year 2016-17 they were at par with EC-119197. Minimum average fruit weight was observed in the rootstock L-0275 (63.8 g). Similar trends for average fruit weight was observed in both the years (2015-16 and 2016-17). These results show a similar pattern as recorded by Wahb-Allah (2014) and Kumar *et al* (2015) in grafted tomatoes.

Punjab Ratta

In case of nematode free plots pooled data revealed that plant of Punjab Ratta had significant effect on average fruit weight when grafted with different combinations of rootstock. Plants grafted on rootstock EC-119197 recorded higher fruit weight (88.1 g) and was significantly higher than non-grafted plants of Punjab Ratta (75.9 g). Further it was followed by plants grafted on rootstock EC-531804 (87.0 g), NR-5 (81.2 g) and Hisar Lal (81.0 g) which were statistically at par with EC-119197. Similar data was recorded in both the years of experiment in which EC-119197 recorded a highest value of 88.2 g in year 2015-16 and 88.0 g in year 2016-17 respectively but was statistically at par with PNR-7 (78.5) in year 2015-16. Enhanced fruit weight recorded in grafted plant was due to robust rootstock used which responds more likely to nutrients and were able to promote growth in aerial parts of the plant increasing stomatal conductance and photosynthetic activity in plant hence improving dry matter content of plant

Further while going through data for infested plots non-grafted plants recorded decline in average fruit weight of plants and recorded a value of 34.3 g, which was significantly lower from grafted plants. It was due to the impact of nematodes, which damaged roots of plant disturbing uptake of plants hence reducing overall yield of non-grafted plants. Grafted plants recorded a similar trend of result as in nematode free plots where rootstocks EC-119197 significantly recorded a higher fruit weight (87.4 g) followed by EC-531804 (82.9 g) which were at par among themselves. These results were in line with results of Pogonyi *et al* (2005) who reported that when Lemance (F1) grafted onto Beaufort rootstock, increased over all yield of plants and which mainly was due to higher average fruit weight of plants hence increasing fruit size and overall yield of plants.

4.2.8 Number of fruits

Number of fruits per plant has direct association with fruit yield. More the number of fruits per plant more will be the yield. The data pertaining to the effect of different rootstock on scion for number of fruits per plant was discussed in Table 4.2.8.

Punjab Sartaj

Fruit yield get enhanced when plants are grafted on different rootstocks. Data revealed that under the nematode free plots, maximum number of fruits per plant was observed in the grafted rootstock L-097 (72.8) which was statistically at par with NR-10 (66.7), L-0272 (71.6) and L-0275 (72.7) and significantly higher from all other rootstocks. On analysis of yearly data of 2015-16 and 2016-17, similar trend for number of fruits per plant was observed in which maximum fruit number was observed on L-097.

In Nematode infested plots, maximum number of fruits per plant was observed in grafted rootstock L-097 (71.8) which was statistically at par with NR-10 (64.8), L-0272 (70.4) and L-0275 (70.8) and significantly higher from all other grafted and non grafted rootstocks. In case of year 2015-16, maximum number of fruits per plant was observed in the grafted rootstock L-097 (72.2) which was significantly higher from all other grafted and non-grafted plants except NR-10 (65.3), L-0275 (70.3) and L-0272 (71.2). Whereas during 2016-17, highest number of fruits per plant was observed in L-097 and L-0275 (71.3) which was statistically at par with NR-10 (63.2), L-0272 (69.5) and significantly higher from all other grafted and non grafted rootstocks. Similar, results were reported by Khah *et al* (2006) that number of fruits per plant was more in grafted plants because of disease free rootstock.

Punjab Ratta

While scrutinizing data for nematode free plots it revealed that there was no significant effect of rootstocks on number of fruits per plant. While maximum number of fruits were observed on rootstock L-097 (43.7) which was statistically at par with all the treatments.

On other hand while analyzing pooled data for Nematode infested plots it revealed that there was significant effect of rootstocks. Plants grafted on rootstocks L-097 recorded maximum number of fruit (43.3) which was significantly higher from non-grafted plants (11.8). L-097 was also at par with plants grafted on rootstock L-0272 (38.5), L-0275 (38.4) and NR-10 (37.1). In year 2015-16 and 2016-17 Similar data was recorded where L-097 recorded 42.3 and 44.2 numbers of fruits respectively which significantly higher than non-grafted plants in both the years of trial. Reduced number of fruits in non-grafted plants was due to susceptibility to nematodes which deterred growth of plant due to suppression of nutrient uptake causing stunted growth, decreasing overall height of plant, decreasing number of branches and reducing overall fruit number. Similar results were given by Lowus *et al* (2010) in which higher yield of grafted plants was observed mainly due to increase in overall

Table 4.2.8 Effect of different rootstock's on number of fruits on Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Number of fruits Punjab Sartaj						Number of fruits Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	59.3	57.9	58.6	58.5	56.2	57.4	31.2	32.2	31.7	30.2	31.9	31.1
T ₂	PNR-7	60.1	59.2	59.7	61.5	60.1	60.8	34.3	33.3	33.8	32.2	33.1	32.7
T ₃	NR-10	68.2	65.2	66.7	65.3	63.2	64.8	38.5	37.2	37.9	36.8	37.3	37.1
T ₄	L-0272	71.1	72.0	71.6	71.2	69.5	70.4	38.5	39.4	39.0	38.0	39.0	38.5
T ₅	L-0275	73.2	72.2	72.7	70.3	71.3	70.8	41.2	40.2	40.7	39.3	37.4	38.4
T ₆	L-097	72.3	73.2	72.8	72.2	71.3	71.8	43.2	44.2	43.7	42.3	44.2	43.3
T ₇	Hisar Lal	63.1	64.5	63.8	62.2	60.5	61.4	33.3	31.2	32.3	32.4	31.2	31.8
T ₈	EC-531804	59.3	60.1	59.7	59.3	58.7	59.0	34.2	35.4	34.8	33.2	34.3	33.8
T ₉	EC-119197	61.2	60.5	60.9	58.5	59.6	59.1	31.2	32.2	31.7	31.3	32.2	31.8
T ₁₀	Control (NG)*	61.5	60.2	60.9	24.2	25.5	24.9	35.3	37.3	36.3	12.0	12.1	11.8
	CD(P=0.05)	8.8	9.1	6.6	9.5	10.6	7.2	NS	NS	NS	8.6	9.3	6.1

(NG)*: Non-Grafted

fruit number of plants which was due to increase in flower clusters of tomato plant.

4.2.9 Total yield (q/ha)

Total yield of the plant describes the potentially of the crop plant. Success or failure of any variety or genotype depends on the total and marketable yield of that variety in the adopted area. The data pertaining to the effect of different rootstock on scion for total yield was presented in Table 4.2.9.

Punjab Sartaj

The pooled data of nematode free trial showed that, maximum total yield was observed in the rootstock EC-119197 (2159 q/ha) which was significantly higher from all other grafted and non-grafted rootstocks (2015 q/ha). It was further followed by plants grafted on rootstock EC-531804 (2047 q/ha), PNR-7 (2032 q/ha) and NR-5 (2017 q/ha) which recorded significantly lower yield than EC-119197 but were statistically at par with non-grafted plants of Punjab Sartaj. Minimum total fruit yield was observed in the rootstock NR-10 (1775 q/ha). In case of yearly data of 2015-16 and 2016-17, maximum total fruit yield was observed in the rootstock EC-119197 (2167 q/ha and 2151 q/ha respectively) which was significantly superior from all other rootstocks.

In case of Nematode infested plots, maximum total fruit yield was observed in EC-119197 (2114 q/ha) rootstock which was significantly higher from all other grafted and non-grafted rootstocks and minimum total fruit yield was observed in the rootstock NR-10 (1767 q/ha). Similar trends for total fruit yield were observed in both the years (2015-16 and 2016-17). Similar results were observed by Di Gioia *et al* (2010). Results were in contrast with (Nina and Joze 2004) that there was a negative effect of grafting with lower yield.

Plants grafted on to vigorous rootstocks have an ability to respond more towards nutrient and water uptake hence making them more vigorous and hence help in improving yield of plant either by complimenting with overall average fruit weight of fruit or by increasing number of fruits per pant even help in supplementing more number of flowers per cluster (Al-Harbi *et al* 2016).

Punjab Ratta

On investigating nematode free plots pooled data revealed that plants grafted on rootstocks EC-119197 recorded maximum yield (642 q/ha) which was significantly higher from few grafted rootstocks as well as non-grafted plants of Punjab Ratta (557 q/ha) followed by EC-531804 (619 q/ha) which is at par with EC-119197. Minimum yield was recorded by plants grafted on rootstock L-097 which recorded a yield of 530 q/ha and was also at par with non-grafted plants. Sometimes a negative effect of grafting may also be seen with lower yield similar results were obtained by Nina and Joze (2004) and concluded that it was due to effect of different rootstock, vigorous root morphology does not indicate higher growth of grafted plants but also cell to cell interaction in union and genotype of scion/rootstock have a major

Table 4.2.9 Effect of different rootstock's on total yield (q/ha) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Total yield (q/ha) Punjab Sartaj						Total yield (q/ha) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	1,999	2,035	2,017	1,976	1,970	1,973	530	547	539	515	531	523
T ₂	PNR-7	2,019	2,045	2,032	1,987	1,977	1,982	546	556	551	524	537	531
T ₃	NR-10	1,797	1,753	1,775	1,797	1,736	1,767	548	541	545	538	534	536
T ₄	L-0272	1,850	1,894	1,872	1,817	1,804	1,811	538	555	547	531	513	522
T ₅	L-0275	1,784	1,812	1,798	1,884	1,806	1,845	535	533	534	504	533	519
T ₆	L-097	1,954	1,953	1,954	1,886	1,982	1,934	525	535	530	499	467	483
T ₇	Hisar Lal	1,995	1,975	1,985	1,988	1,969	1,978	540	535	538	534	508	521
T ₈	EC-531804	2,070	2,023	2,047	2,020	2,041	2,031	623	615	619	600	602	601
T ₉	EC-119197	2,167	2,151	2,159	2,079	2,149	2,114	640	644	642	636	628	632
T ₁₀	Control (NG)*	2,008	2,022	2,015	343	292	318	546	567	557	62	70	66
	CD(P=0.05)	39	53	33	57	46	48	48	44	40	52	42	36

(NG)*: Non-Grafted

role in enhancing growth in grafted plants (Pina *et al* 2012). Grafting has a positive effect mainly due to presence of vigorous root system of rootstocks which enhances water and mineral nutrient uptake of plants hence improving vigour and fruit yield of plants and even helps to confer disease in plant.

While interpreting data of infested plots pooled data revealed that grafted plants yielded significantly higher than non-grafted plants. Plants grafted on rootstock EC-119197 and EC-531804 recorded a yield of 632 q/ha and 601 q/ha which was significantly higher among all the grafted and non-grafted plants. There was decrease in yield of non-grafted plants and recorded a value of 66 q/ha which was due to infestation of nematodes in roots which formed galls damaging root system of plants. Similar results were recorded in both the years of experiment in which grafted plants EC-119197 and EC-531804 yielded significantly higher than non-grafted plants. These results were also confirmed by Turhan *et al* (2011) in which he demonstrated that grafted plants performing better and yielding more than non-grafted plants under stress conditions.

4.2.10 Marketable Yield (q/ha)

Marketable yield determines the success or failure of any crop plant. Marketable yield is the end product which was delivered to consumers from farmer field. Therefore for the farmer point of view it was important to increase the income. The data pertaining to the effect of different rootstock on scion for marketable yield was presented in Table 4.2.10.

Punjab Sartaj

The pooled data of nematode free trial showed that, maximum marketable yield was observed in the rootstock EC-119197 (1882 q/ha) which was significantly higher from all other grafted and non-grafted rootstocks. It was further followed by plants grafted on rootstock EC-531804 (1771 q/ha) and PNR-7 (1744 q/ha) but were statistically lower than plants grafted on rootstock EC-119197. Minimum marketable fruit yield was observed in the rootstock NR-10 (1548 q/ha). In case of yearly data of 2015-16 and 2016-17, maximum marketable fruit yield was observed in the rootstock EC-119197 (1911 q/ha and 1853 q/ha respectively) which was significantly superior from all other rootstocks.

In case of Nematode infested plots, maximum marketable fruit yield was observed in EC-119197 (1805 q/ha) rootstock which was significantly higher from all other grafted and non-grafted rootstocks and minimum total fruit yield was observed in the rootstock NR-10 (1496 q/ha). Similar trends for marketable fruit yield were observed in both the years (2015-16 and 2016-17).

Punjab Ratta

On going through case of nematode free plots pooled data revealed that plants grafted on rootstocks EC-119197 yielded maximum with a yield 606 q/ha which were significantly higher in both the years further followed by EC-531804 with yield of 575 q/ha which was at

Table 4.2.10 Effect of different rootstock's on marketable yield (q/ha) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Marketable yield (q/ha) Punjab Sartaj						Marketable yield (q/ha) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T₁	NR-5	1710	1690	1702	1702	1652	1677	510	505	508	478	445	462
T₂	PNR-7	1748	1741	1744	1635	1710	1672	513	517	515	475	476	476
T₃	NR-10	1557	1540	1548	1499	1487	1496	500	501	500	498	452	475
T₄	L-0272	1599	1562	1581	1552	1538	1545	478	474	476	447	471	459
T₅	L-0275	1594	1535	1565	1540	1510	1525	513	515	514	490	477	484
T₆	L-097	1589	1562	1576	1505	1499	1502	480	475	477	444	465	455
T₇	Hisar Lal	1677	1671	1674	1628	1635	1632	503	510	507	450	458	454
T₈	EC-531804	1792	1749	1771	1689	1712	1701	574	575	575	549	563	556
T₉	EC-119197	1911	1853	1882	1783	1806	1805	608	603	606	600	578	589
T₁₀	Control (NG)*	1642	1682	1662	216	284	250	505	498	502	48	51	49
	CD(P=0.05)	48	57	37	59	51	33	52	56	40	59	61	36

(NG)*: Non-Grafted

par with EC-119197. Non-grafted plants of Punjab Ratta recorded a yield of 502 q/ha and was also at par with plants grafted on rootstock PNR-7 (515 q/ha) and L-0275 (514 q/ha). Similar results were highlighted by Khah *et al* (2006) which reported enhanced yield of grafted plants than non-grafted plants.

On investigating Nematode infested plots non-grafted plants were highly suppressed by disease and recorded a yield of 49 q/ha which was significantly lower than grafted plants. Similar trend of result was followed by grafted plants as in nematode free plots where rootstocks EC-119197 yielded maximum (589 q/ha) followed by EC-531804 (556 q/ha) and were at par among themselves. In both years of experiment results were alike. These results were in also in line with Turkmen *et al* (2010) and Al-Harbi *et al* (2016) which reported higher yield of grafted tomato over non-grafted tomato plants.

In general plants with superior and resistance root system have higher resistance to soil borne disease. Grafted plants were acquainted with nematode resistant roots showing higher resistance to nematode which hindered gall formation in roots moreover improved water and nutrient uptake of plants effectively, providing more vigour as well as more number fruits per plant and supplementing average fruit weight which helped in increasing marketable yield of plants both in Nematode infested and nematode free plots. Similar, findings were reported by Di Gioia *et al* (2010), Turkmen *et al* (2010) and Al-Harbi *et al* (2016).

4.2.11 Pericarp Thickness (mm)

Pericarp thickness is an important parameter for the fruit firmness. It is positively correlated with fruit firmness. The data pertaining to the effect of different rootstock on scion for pericarp thickness was observed in Table 4.2.11.

Punjab Sartaj

The pooled data of nematode free trial showed that, maximum pericarp thickness was observed in the rootstock EC-119197 (8.13 mm) which was significantly higher from all other grafted and non-grafted rootstocks. In case of yearly data of 2015-16 and 2016-17, maximum pericarp thickness was observed in the rootstock EC-119197 (8.08 mm and 8.19 mm respectively) which was significantly superior from all other rootstocks.

In case of Nematode infested plots, maximum pericarp thickness was observed in EC-119197 (8.09 mm) rootstock which was significantly higher from all other grafted and non-grafted rootstocks. Minimum pericarp thickness was observed in the L-097 rootstock (5.21 mm). Similar trends for pericarp thickness were observed in both the years (2015-16 and 2016-17). Similar, results were reported by Yetisir *et al* (2007) and Kumar *et al* (2015) in tomato that grafted plants has more pericarp thickness as compared to non grafted tomato due to disease resistant rootstock which enhances the water and mineral uptake from the vigorous roots.

Table 4.2.11 Effect of different rootstock's on pericarp thickness of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Pericarp thickness (mm) Punjab Sartaj						Pericarp thickness (mm) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	6.99	6.88	6.94	6.98	6.74	6.86	7.03	6.89	6.96	6.74	6.77	6.75
T ₂	PNR-7	7.03	7.10	7.07	6.84	7.06	6.95	7.15	7.08	7.12	7.08	7.01	7.04
T ₃	NR-10	6.45	6.53	6.49	6.34	6.31	6.14	6.60	6.87	6.85	6.62	6.59	6.75
T ₄	L-0272	6.56	6.39	6.48	6.50	6.51	6.39	6.10	6.34	6.22	6.15	5.98	6.07
T ₅	L-0275	6.25	6.11	6.18	5.67	6.00	5.82	5.82	5.73	5.78	5.53	5.24	5.39
T ₆	L-097	5.50	5.97	5.71	5.48	4.90	5.21	4.12	4.47	4.30	4.20	4.10	4.14
T ₇	Hisar Lal	6.47	6.43	6.45	6.45	6.64	6.36	5.84	5.76	5.80	5.51	5.75	5.63
T ₈	EC-531804	7.44	7.90	7.69	7.39	7.69	7.54	7.96	7.98	7.95	7.89	7.90	7.94
T ₉	EC-119197	8.08	8.19	8.13	8.04	8.14	8.09	8.39	8.16	8.27	8.02	8.24	8.13
T ₁₀	Control (NG)*	6.99	7.04	7.02	5.65	5.73	5.93	6.94	6.62	6.58	4.83	4.79	4.81
	CD(P=0.05)	0.7	0.9	0.6	1.1	0.8	0.6	0.8	0.8	0.8	0.6	0.4	0.3

(NG)*: Non-Grafted

Punjab Ratta

While investigating pooled data for nematode free plot it revealed that rootstocks EC-119197 (8.27 mm) recorded maximum pericarp thickness which was significantly higher than non-grafted plants (6.58 mm). It was further followed by EC-531804 (7.95 mm) and was at par with EC-119197. Minimum pericarp thickness was recorded by plants grafted on L-097 (4.30 mm). Both positive and negative effect was observed by grafting on pericarp thickness which was due to cell to cell interaction of rootstock and scion combinations which alter the concentration of growth hormones through the union and may influence fruit character.

Similarly on analysing data of Nematode infested plots pooled data revealed that non-grafted plants were highly susceptible to disease and recorded a poor growth hence decreasing fruit size as well as pericarp thickness of fruit. Non-grafted plants of Punjab Ratta computed a value of 4.81 mm which was significantly lower than rootstocks EC-119197 (8.13 mm) and EC-531804 (7.94 mm) which were at par among each other. Minimum pericarp thickness was observed in L-097 (4.14 mm) and was at par with non-grafted plants of Punjab Ratta. Hence, grafting confirms resistance against nematode and had an positive effect on improving fruit quality both under infested as well as nematode free conditions these result were also confirmed by Kumar *et al* (2015).

4.2.12 TSS ⁰Brix (Total Soluble Solids)

TSS is an important parameter in tomato that will describes the presence of total natural sugars in tomato. Effect of different rootstock on scion for TSS content was presented in Table 4.2.12.

Punjab Sartaj

The pooled data of nematode free trial showed that, maximum TSS content was observed in the rootstock L-097 (6.8 ⁰Brix) which was significantly higher from all other grafted and non-grafted rootstocks except L-0275 (6.3 ⁰Brix). In case of yearly data of 2015-16 and 2016-17, maximum TSS content was observed in the rootstock L-097 (6.7 ⁰Brix and 7.0 ⁰Brix respectively) which was significantly superior from all other rootstocks.

In case of Nematode infested plots, maximum TSS content was observed in L-097 (6.2 ⁰Brix) rootstock which was significantly higher from all other grafted and non-grafted rootstocks. Minimum TSS content was observed in the EC-531804 rootstock (3.7 ⁰Brix). A similar trend for TSS was observed in 2015-16 year. During 2016-17, maximum TSS was observed in L-097 rootstock (6.2 ⁰Brix) which was statistically at par with L-0272 (5.5 ⁰Brix) and L-0275 (6.0 ⁰Brix) and significantly higher from all other rootstocks.

Various rootstocks decrease or increases soluble solids in fruit (Lopez-Galarza *et al* 2004; Alexopoulos *et al* 2007) due to scion and rootstocks interactions as they have influence on TSS of fruits which may be decreased by grafting (Pogonyi *et al* 2005; Qaryouti *et al* 2007) or may be increased by grafting Mohammed *et al* (2009). These results are parallel to

our findings.

Punjab Ratta

On analyzing pooled data of nematode free plots it revealed that plants grafted on rootstock L-097 recorded higher TSS (6.2⁰brix) which was significantly higher than non-grafted plants (4.8⁰brix). It was followed by rootstock L-0275 which recorded a value of 6.1⁰brix and was at par with L-097. Minimum TSS was obtained by plants grafted on rootstock NR-5 (3.8⁰brix). Similar results were documented in both years 2015-16 and 2016-17 (4.8 and 4.9⁰brix respectively).

On other hand while investigating pooled data of Nematode infested plots it revealed that rootstocks showing high resistance to disease were able to maintain TSS of fruits. Non-grafted plants recorded a reduced level of TSS with the value of 4.1⁰brix, which was significantly lower than rootstocks L-097 (6.1⁰brix) and L-0275 (6.1⁰brix). Grafting alters TSS value as per interactions between scions and rootstock. When grafted on different rootstocks, it may alter levels of hormonal production in plants. So, it may carry both negative and positive effect on quality of fruit. Parallel results; have been reported by many authors like Lopez-Galarza *et al* (2004) and Alexopoulos *et al* (2007).

4.2.13 Lycopene content (mg/ 100g)

Lycopene content gives colour to the tomato fruit. More the lycopene pigment, more will be the color and more beneficial for processing as well as for raw material. Due to its strong color and non-toxicity, lycopene is a useful food coloring. Lycopene in tomato soup and tomato paste is considered more nutritious in comparison to fresh salad (Tepic *et al* 2006). The data pertaining to the effect of different rootstocks on scion for lycopene content was presented in Table 4.2.13.

Punjab Sartaj

It was observed from the data that lycopene content in various rootstocks was not significantly different among the two scions under the nematode free environment and as well as under the Nematode infested field. Similar results were observed by Liana Maria Alda *et al* (2009) in tomato.

Punjab Ratta

Lycopene content greatly depends upon genetic structure of scion but sometimes it gets alter due to interactions of rootstocks with scion. Similarly while observing pooled data of nematode free plots no significant difference was obtained in grafted and non-grafted plants. Similar results were also found in Nematode infested plots where no significant difference was generated among grafted and non-grafted palnst of tomato. Turhan *et al* (2011) also reported that lycopene content did not differ significantly between the grafted and non-grafted plants.

Table 4.2.12 Effect of different rootstock's on TSS⁰Brix (Total Soluble Solids) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	TSS ⁰ Brix Punjab Sartaj						TSS ⁰ Brix Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	4.8	5.0	4.9	4.8	4.6	4.7	3.9	3.8	3.8	3.8	3.5	3.7
T ₂	PNR-7	4.6	4.8	4.7	4.2	4.5	4.4	4.2	4.1	4.2	4.0	4.1	4.1
T ₃	NR-10	5.4	5.4	5.4	5.1	5.0	5.1	4.1	4.3	4.2	3.9	4.0	3.9
T ₄	L-0272	5.5	5.7	5.6	5.4	5.5	5.4	5.1	5.0	5.1	4.8	4.9	4.8
T ₅	L-0275	6.0	6.1	6.3	5.9	6.0	6.0	6.0	6.1	6.1	6.1	6.0	6.1
T ₆	L-097	6.7	7.0	6.8	6.2	6.3	6.2	6.3	6.2	6.2	6.1	6.1	6.1
T ₇	Hisar Lal	5.7	5.8	5.8	4.8	5.6	5.2	5.8	5.8	5.8	5.8	5.6	5.7
T ₈	EC-531804	4.1	4.1	4.1	3.7	3.7	3.7	4.0	3.9	3.9	4.1	3.7	3.8
T ₉	EC-119197	4.4	4.3	4.4	4.5	3.9	4.2	4.0	3.9	3.9	3.8	3.9	3.9
T ₁₀	Control (NG)*	5.3	5.3	5.3	4.5	4.7	4.6	4.8	4.9	4.8	4.1	4.2	4.1
	CD(P=0.05)	0.4	0.6	0.6	0.8	1.0	0.6	0.6	0.5	0.5	0.6	0.6	0.4

(NG)*: Non-Grafted

Table 4.2.13 Effect of different rootstock's on lycopene content (mg/ 100g) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Lycopene content Punjab Sartaj						Lycopene content Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	5.10	5.14	5.12	5.10	4.95	5.03	8.10	8.15	8.13	8.08	8.12	8.10
T ₂	PNR-7	5.20	5.10	5.15	4.95	5.08	5.02	8.11	8.14	8.12	8.09	8.11	8.10
T ₃	NR-10	5.50	5.64	5.57	5.50	5.60	5.55	8.60	8.55	8.58	8.50	8.55	8.53
T ₄	L-0272	5.50	5.40	5.56	5.35	5.50	5.43	8.70	8.60	8.65	8.40	8.50	8.45
T ₅	L-0275	5.50	5.46	5.48	5.25	5.35	5.30	8.75	8.70	8.73	8.60	8.65	8.63
T ₆	L-097	5.60	5.65	5.63	5.60	5.50	5.55	8.55	8.60	8.58	8.50	8.60	8.55
T ₇	Hisar Lal	5.35	5.40	5.38	5.10	5.15	5.13	7.95	7.81	7.87	7.90	7.80	7.85
T ₈	EC-531804	5.70	5.65	5.68	5.40	5.10	5.20	6.60	6.55	6.58	6.50	6.45	6.48
T ₉	EC-119197	4.80	4.80	4.80	4.65	4.75	4.70	6.80	6.75	6.78	6.75	6.65	6.70
T ₁₀	Control (NG)*	5.50	5.52	5.51	5.10	5.20	5.10	8.00	7.90	7.95	6.88	7.75	7.30
	CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

(NG)*: Non-Grafted

4.3 Experiment No. 3: Evaluation of different rootstocks and scions combination for yield and quality traits by using cleft graft method.

4.3.1 Plant Height (cm)

Plant height is an important parameter which determines the actual health of plant from visual observations. Good plant height ensures that plant is healthy and free from insect-pest and diseases. The data pertaining to the effect of different rootstocks on two scions Punjab Sartaj and Punjab Ratta for plant height was presented in Table 4.3.1.

Punjab Sartaj

In pooled data of nematode free plots, maximum plant height was observed in grafted rootstocks EC-119197 (354.9 cm) which was significantly higher from all other grafted and non-grafted rootstocks. Whereas, minimum plant height was recorded in the grafted rootstock L-0272 (276.1 cm) which was significantly lower from the non-grafted as well as other grafted rootstocks. On analysis of yearly data, rootstock EC-119197 showed significantly higher plant height (357.0 cm and 350.8 cm) as compared to all other rootstocks and non-grafted plants in both years i.e. 2015-16 and 2016-17 respectively.

In case of pooled data of Nematode infested plants, highest plant height was observed in the rootstock EC-119197 (351.3 cm) which was significantly higher from all other rootstocks. Lowest plant height was observed in the non-grafted plants of Punjab Sartaj (73.5 cm) which was due to nematode disease which reduced the plant height. During year 2015-16 and 2016-17, maximum plant height was achieved in the rootstock EC-119197 i.e. 353.0 cm and 349.7 cm respectively which were significantly higher from all other grafted as well as non-grafted plants. Similar results were reported by Fullana-Pericas *et al* (2018) in which, tomato plants were grafted on different rootstock improves xylem and phloem solute movement in plant which results in greater plant height as compared to non-grafted plants.

Punjab Ratta

While observing nematode free plots, it was revealed in pooled data that rootstocks EC-531804 recorded a maximum height of 70.95 cm which was further followed by L-097 (69.07 cm), EC-119197 (68.65 cm), NR-10 (68.50 cm), PNR-7 (66.79 cm) and NR-5 (66.56 cm) which were significantly at par with EC-531804. Non-grafted plant recorded a height of 61.7 cm which was significantly lower than EC-531804. Similar data was recorded in both years of experiment where it recorded height of 72.60 cm in year 2015-16 and 69.30 cm in year 2016-17. Grafted plants recorded higher plant height due to vigorous root system of rootstock which helped in increased uptake of water and nutrients by improved flow of assimilates through graft junction.

Further investigating for infested plots, pooled data for highest plant height was observed in the rootstock EC-531804 (68.40 cm) which was significantly higher from non-grafted plants of Punjab Ratta (32.04 cm). It was observed that EC-531804 was also

Table 4.3.1 Effect of different rootstock's on plant height (cm) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Plant height (cm) Punjab Sartaj						Plant height (cm) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	299.3	299.7	299.5	295.1	297.9	296.5	67.80	66.32	66.56	64.70	65.32	65.51
T ₂	PNR-7	310.6	307.3	308.9	295.7	289.7	292.7	66.04	67.54	66.79	62.80	64.52	63.66
T ₃	NR-10	321.1	314.8	317.9	316.4	312.1	314.2	69.30	67.60	68.50	64.30	62.35	63.33
T ₄	L-0272	279.3	273.0	276.1	273.0	268.7	270.8	66.90	63.80	65.35	61.60	64.12	63.36
T ₅	L-0275	317.3	318.0	317.6	316.3	315.7	316.0	62.40	65.23	63.82	61.00	62.70	61.85
T ₆	L-097	303.1	299.1	301.1	293.2	292.7	292.9	69.90	68.23	69.07	65.70	67.40	67.05
T ₇	Hisar Lal	289.9	297.7	293.8	280.9	285.3	283.1	67.80	68.90	68.35	63.90	64.60	64.25
T ₈	EC-531804	289.5	285.8	287.6	284.4	283.4	283.9	72.60	69.30	70.95	70.10	67.70	68.40
T ₉	EC-119197	357.0	350.8	354.9	353.0	349.7	351.3	68.60	68.70	68.65	66.01	67.60	66.80
T ₁₀	Control (NG)*	291.3	289.9	290.6	73.0	74.0	73.5	62.40	61.00	61.7	32.55	31.52	32.04
	CD(P=0.05)	6.7	7.5	4.8	7.4	7.0	4.9	6.9	8.9	5.4	6.6	5.6	4.4

(NG)*: Non-Grafted

statistically at par with all other grafted plants except for L-0275 (61.85 cm). Similar results were observed in both the year (2015-16 and 2016-17) where EC-531804 recorded higher plant heights (70.10 and 67.70 cm respectively). Minimal galls were reported in grafted plants which showed high resistance against nematodes and providing the protection to plants by activating the secondary metabolites providing resistance in the roots. Alike results were quoted by Kyriacou *et al* 2017 in which grafted plants acquired more plant height under stress conditions than non-grafted plants.

4.3.2 Days to flowering

The data related to the effect of different rootstock on two scions namely Punjab Sartaj and Punjab Ratta for days to first flowering was presented in Table 4.3.2.

Punjab Sartaj

It was seen from the pooled data under nematode free plots that minimum days to first flowering was reported in non-grafted plants of Punjab Sartaj (82.1) which was statistically at par with grafted PNR-7 rootstock and significantly lower from all other rootstocks because effect of grafting on union formation exerts initial stress on plants which may delay flowering in grafted plants. In case of yearly data of 2015-16 and 2016-17, similar results were noticed.

While observing the data of infested plots, among grafted rootstocks, PNR-7 recorded minimum number of days for flowering (86.7) which was statistically at par with L-097 (87.4), L-0272 (87.6), L-0275 (88.1), NR-10 (90.2), Hisar Lal (89.2) and EC-531804 (92.5) and significantly less days from all other rootstocks. In case of yearly data similar results were observed for 2016-17. While during 2015-16, minimum number of days for first flowering was reported in PNR-7 (86.0) which was statistically at par with all other rootstocks except non-grafted plants (112.6).

These results were in line with Fullana-Pericas *et al* (2018) that more number of flowers emerged with in few numbers of days from transplanting in grafted plants due to less incidence of nematode on grafted plants as compared to non-grafted plants.

Punjab Ratta

In case of nematode free plots of Punjab Ratta pooled data revealed that there was no significant effect of days to flowering on grafted plants as well as non-grafted plants. Although non-grafted plant took least number of days (99.5) and plants grafted on rootstock EC-531804 took more number of days (102.7) but were statically non significant.

On observing pooled data of Nematode infested plots grafted plants recorded a significant difference with non-grafted plants. Plants grafted on rootstock L-097 recorded minimum days (100.4) to flower which was significantly lower from non-grafted plants (123.9). It also revealed that L-097 was statistically at par with rest of grafted plants, except from EC-119197 (107.4) and EC-531804 (106.0) which recorded significantly higher number

Table 4.3.2 Effect of different rootstock's on days to flowering of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Days to Flowering Punjab Sartaj						Days to flowering Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	91.3	91.3	91.9	92.0	92.3	92.2	101.3	103.0	102.2	106.6	103.0	104.8
T ₂	PNR-7	85.0	85.7	85.5	86.00	86.0	86.7	99.8	99.3	99.6	102.1	103.9	103.0
T ₃	NR-10	86.0	86.0	86.6	90.3	90.0	90.2	100.0	101.6	101.2	102.7	104.4	103.6
T ₄	L-0272	87.1	86.4	86.8	88.30	88.3	87.6	99.3	101.3	100.3	101.2	103.5	102.4
T ₅	L-0275	88.0	88.0	88.0	88.3	87.8	88.1	99.6	100.3	99.9	102.3	101.6	102.0
T ₆	L-097	86.6	86.6	86.3	86.4	88.3	87.4	99.3	99.9	99.6	101.0	99.8	100.4
T ₇	Hisar Lal	88.3	88.3	87.8	86.8	89.2	88.0	100.0	100.0	100.0	101.1	104.5	102.8
T ₈	EC-531804	92.0	92.0	93.0	93.3	91.6	92.5	102.0	103.3	102.7	104.4	107.6	106.0
T ₉	EC-119197	92.3	92.3	93.3	93.6	94.0	93.8	102.6	102.6	102.6	109.0	105.8	107.4
T ₁₀	Control (NG)*	82.9	81.6	82.1	112.6	114.0	113.3	100.0	99.0	99.5	122.5	125.2	123.9
	CD(P=0.05)	5.1	5.4	3.4	9.9	6.1	5.8	NS	NS	NS	8.2	7.9	5.2

(NG)*: Non-grafted

of days in pooled data.

While computing yearly data in year 2015-16 L-097 was statistically at par with EC-531804 (104.4) and further in year 2016-17 it was statistically at par with EC-119197 (105.8). Similar, results were reported by Kokalis-Burelle *et al* (2016) that grafted plants of tomato were able to flower earlier than non-grafted plants due to the reason that resistant rootstocks provides growth hormones like gibberelic acid and auxin which improves the flower budding strength.

4.3.3 Days to picking

The effect of different rootstock on scion for days to first picking was summarized in Table 4.3.3.

Punjab Sartaj

From the data it was observed that in case of nematode free plots, minimum number of days for first picking was noticed in the rootstock PNR-7 (111.6) followed by L-097 (111.8), NR-10 (112.7) and NR-5 (116.1) which was significantly lower from rest of the rootstocks. Further the study reported that during the year 2015-16 and 2016-17, rootstock PNR-7 took minimum number of days for first picking (110.7 and 112.5 respectively) which was significantly lower from Hisar Lal (121.0 and 120.2), EC-531804 (128.0 and 129.6), EC-119197 (124.7 and 128.1) and non grafted plant of Punjab Sartaj (120.0 and 118.0 respectively) and were further statistically at par with rest of grafted rootstocks.

On the other hand, pooled data under the Nematode infested plot revealed that minimum number of days for first picking was noticed in the rootstock PNR-7 (114.1) which was statistically at par with all other grafted rootstocks except from EC-531804 (131.2), EC-119197 (128.5) and non-grafted plants (142.3). During the 2015-16 and 2016-17, rootstock PNR-7 took minimum number of days for first picking (113.3 and 115.8 respectively) which was statistically at par with all other grafted rootstocks except EC-531804 (132.3 and 130.0), EC-119197 (127.9 and 129.0) and non grafted plants a (143.0 and 141.6). Similar results were reported by Gilardi *et al* (2013) that grafted plant took lesser number of days for picking than non-grafted plants in infested soils due to vigorous root system which utilizes the nutrient from different layers of soil and enhances their uptake potential. This improved uptake potential of plant improve the storage of secondary metabolites which enhances the gases exchange between stomata's and ultimately improves the respiration and photosynthesis.

Punjab Ratta

On observing pooled data of nematode free plots it revealed that grafted plants and non-grafted plants of Punjab Ratta did not show any significant difference among themselves. Minimum number of days to picking was observed in plants grafted on rootstock L-097 (118.8) which statistically at par with grafted and non-grafted plants.

While investigating for Nematode infested plots pooled data revealed that non-grafted

Table 4.3.3 Effect of different rootstock's on days to picking of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Days to Picking Punjab Sartaj						Days to Picking Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	115.2	117.0	116.1	119.3	117.3	118.3	126.3	127.3	126.8	127.3	128.2	127.8
T ₂	PNR-7	110.7	112.5	111.6	113.3	115.8	114.1	124.5	125.5	125.0	125.0	126.0	125.5
T ₃	NR-10	113.3	112.0	112.7	118.0	116.4	117.2	123.0	124.5	123.8	126.3	127.4	126.9
T ₄	L-0272	117.0	117.6	117.3	117.6	118.9	118.3	122.7	124.3	123.5	124.5	123.5	124.0
T ₅	L-0275	116.0	118.6	117.3	122.2	118.6	120.4	120.5	123.4	122.0	122.0	124.6	123.3
T ₆	L-097	112.6	110.9	111.8	114.3	113.8	114.6	119.3	118.2	118.8	120.8	119.5	119.7
T ₇	Hisar Lal	121.0	120.2	120.6	121.9	119.6	120.8	122.3	126.3	124.3	124.0	128.0	126.0
T ₈	EC-531804	128.0	129.6	128.8	132.3	130.0	131.2	121.4	123.6	122.5	126.5	123.5	124.0
T ₉	EC-119197	124.7	128.1	126.4	127.9	129.0	128.5	122.6	123.7	123.2	125.2	122.2	123.7
T ₁₀	Control (NG)*	120.0	118.0	119.0	143.0	141.6	142.3	122.1	121.3	121.7	149.2	146.2	147.7
	CD(P=0.05)	8.7	5.3	4.8	5.1	9.1	8.1	NS	NS	NS	5.4	6.3	4.3

(NG)*: Non-Grafted.

plants of Punjab Ratta took more number of days to picking (147.7) which was due to infestation of disease. Flow of assimilates were deterred from roots to shoot area due to formation of galls choking xylem and phloem vessels of plants. While plants grafted on resistant rootstocks took less number of days to picking. Plants grafted on L-097 took minimum number of days to picking (119.7) and was at par with L-0275 and L-0272 which took 123.3 and 124.0 days respectively. Increase in number of days in grafted plants was purely due to the interactions between scion and rootstocks which altered days to production of growth hormones in grafted plants which changes the behavior of cell to cell interaction in graft junction hence altering days to picking in grafted plants. Similar data was recorded by Gilardi *et al* (2013) in which grafted tomato plants were able to produce more number of fruits per cluster and took less number of days to picking.

4.3.4 Fruit width (cm)

Fruit width actually describes the fruit health. Fruit width improves the shape index of tomato. Data related to effect of different rootstock on scion for fruit width was presented in Table 4.3.4.

Punjab Sartaj

In case of nematode free trial, Maximum fruit width was obtained by rootstock EC-119197 (6.2 cm) which was significantly higher from all other grafted and non-grafted rootstocks except EC-531804 (5.9 cm) and NR-5 (5.7 cm). On further investigating it was observed that minimum fruit width was observed on rootstock L-097 (4.2 cm). Similar trend for fruit width was observed in both the years of experiment where plants grafted on EC-119197 recorded a maximum fruit width of 6.3 cm and 6.2 cm in year 2015-16 and 2016-17 respectively and significantly higher from non-grafted plants of Punjab Sartaj (5.2 cm and 5.3 cm).

While observing infested plots pooled data revealed that maximum fruit width was observed in EC-119197 rootstock (6.2 cm) which was significantly higher from all other rootstocks. On analyzing yearly data, during 2015-16 and 2016-17, rootstock EC-119197 showed highest fruit width (6.2 cm and 6.1 cm respectively) which was statistically at par with NR-5 (5.6 cm and 5.4 cm) and EC-531804 (5.5 cm and 5.4 cm) rootstocks but significantly higher from all other rootstocks. Due to disease appearance on non-grafted plants, fruit width was less as compared to grafted plants because it reduces the growth potential of the plants (Rivard *et al* 2012).

Punjab Ratta

Going through the nematode free plots of Punjab Ratta pooled data revealed plants grafted on rootstocks EC-119197 recorded maximum fruit width of 6.2 cm followed by EC-531804 which recorded a value of 5.9 cm which were at par. They were also significantly higher from all other grafted and non-grafted plants (5.0 cm). Similar data was observed in

Table 4.3.4 Effect of different rootstock's on fruit width (cm) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Fruit width (cm) (Punjab Sartaj)						Fruit width (cm) (Punjab Ratta)					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	5.8	5.6	5.7	5.6	5.4	5.5	4.6	4.6	4.6	4.7	4.6	4.7
T ₂	PNR-7	5.4	4.9	4.9	5.1	4.7	4.8	4.9	5.0	4.9	4.9	5.0	5.0
T ₃	NR-10	4.6	4.5	4.6	4.3	4.5	4.4	4.7	4.6	4.7	4.5	4.4	4.5
T ₄	L-0272	4.3	4.3	4.2	4.0	4.2	4.2	4.3	4.6	4.4	4.3	4.5	4.4
T ₅	L-0275	4.4	4.2	4.3	4.3	4.1	4.2	4.0	4.0	4.0	3.9	3.8	3.9
T ₆	L-097	4.2	4.3	4.2	4.1	3.9	4.0	4.0	3.8	3.9	4.0	3.8	3.8
T ₇	Hisar Lal	5.1	5.2	5.2	5.4	5.0	5.1	4.7	4.9	4.8	4.5	4.8	4.6
T ₈	EC-531804	5.7	5.9	5.9	5.5	5.4	5.5	5.9	6.0	5.9	5.7	5.8	5.7
T ₉	EC-119197	6.3	6.2	6.2	6.2	6.1	6.2	6.1	6.3	6.2	6.0	6.1	6.1
T ₁₀	Control (NG)*	5.2	5.3	5.2	4.2	4.4	4.3	5.0	4.9	5.0	4.2	4.3	4.6
	CD(P=0.05)	0.8	0.8	0.5	0.8	0.9	0.6	0.8	0.7	0.4	0.8	1.0	0.6

(NG*: Non-Grafted)

both years of experiment that is 2015-16 and 2016-17. Minimum fruit width was observed in plants grafted on rootstock L-097 (4.0 cm).

On other hand while investigating pooled data for Nematode infested plots similar trend of result was recorded as in nematode free plots. Plants grafted on rootstocks EC-119197 recorded highest fruit width (6.1 cm) followed by EC-531804 (5.7 cm) which were statistically higher than non-grafted plants of Punjab Ratta (4.6 cm). Non-grafted plants recorded a lower fruit width due to impact of disease which stunted plant height and decreased overall physiological activity triggering over production of free radicals and scavenging enzymes of plants hence decreasing plant vigor.

4.3.5 Fruit length

Fruit length has direct association with fruit yield. Shape size and fruit skin: pulp ratio depends upon the fruit length of tomato. Data regarding the effect of different rootstocks on scions for fruit length was analyzed and summarized in Table 4.3.5.

Punjab Sartaj

Pooled data of Nematode infested free plots showed that maximum fruit length was observed under EC-119197 rootstock (6.2 cm) which was statistically at par with EC-531804 (5.7 cm) rootstocks and significantly higher from all other rootstocks. Minimum fruit length was observed in the L-0272 grafted rootstock (4.0). In case of yearly data of 2015-16 and 2016-17, similar trend for fruit length was observed.

In case of Nematode infested plots, EC-119197 (6.1 cm) recorded a significant higher fruit length among other grafted and non-grafted rootstocks. Minimum fruit length was observed in the rootstock L-0272 (3.8 cm). In case of yearly data, maximum fruit width was observed in the rootstock EC-119197 (6.0 cm and 6.2 cm) during 2015-16 and 2016-17 years respectively which was statistically at par with EC-531804 rootstocks (5.7 cm and 5.4 cm respectively) and significantly higher from all other rootstocks. Higher fruit lengths were attained in grafted plants which may be due to improved water and nutrient uptake of plant hence helping plants for better fruit setting as well as improved fruit size and shape of plant Flores *et al* (2010).

Punjab Ratta

Varied sizes of tomato fruit was observed when plants grafted on different rootstocks. On investigating nematode free plots pooled data revealed that there was significant difference in grafted and non-grafted plants. Plants grafted on rootstock EC-119197 recorded maximum fruit length (6.3 cm) which was significantly higher than non-grafted plants (5.0 cm) further it was followed by EC-531804 with a fruit length of 6.2 cm and were at par among them.

On computing year wise data it further revealed that EC-119197 was also at par with NR-5 in year 2015-16 (5.8 cm) and in year 2016-17 (5.7 cm). Non-grafted plants of Punjab

Table 4.3.5 Effect of different rootstock's on fruit length (cm) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Fruit length (cm) Punjab Sartaj						Fruit length (cm) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	5.2	5.3	5.2	5.3	5.1	5.2	5.8	5.7	5.8	5.6	5.4	5.5
T ₂	PNR-7	4.6	4.9	4.8	4.4	4.5	4.5	5.7	5.6	5.6	5.4	5.4	5.4
T ₃	NR-10	4.5	4.3	4.4	4.4	4.2	4.3	5.1	5.0	5.1	4.9	4.9	5.0
T ₄	L-0272	3.9	4.0	4.0	3.7	3.8	3.8	5.4	5.3	5.4	4.5	4.4	4.8
T ₅	L-0275	3.9	4.1	4.1	4.2	3.8	3.9	4.7	4.6	4.6	4.3	4.4	4.4
T ₆	L-097	3.8	4.2	4.1	3.7	3.9	3.9	4.3	4.2	4.2	4.3	4.2	4.2
T ₇	Hisar Lal	4.8	5.0	4.9	4.7	5.1	4.8	5.0	5.2	5.1	4.7	4.9	4.8
T ₈	EC-531804	5.5	5.7	5.7	5.7	5.4	5.5	6.3	6.1	6.2	5.9	6.0	5.9
T ₉	EC-119197	6.2	6.3	6.2	6.0	6.2	6.1	6.5	6.3	6.3	6.4	6.2	6.3
T ₁₀	Control (NG)*	5.1	5.2	5.1	4.6	4.4	4.4	5.0	5.1	5.0	4.4	4.3	4.3
	CD(P=0.05)	0.7	0.8	0.5	0.8	0.9	0.5	0.7	0.8	0.4	0.5	0.5	0.4

(NG)*: Non-Grafted

Ratta recorded a value of 5.1 cm and 5.0 cm in year 2015-16 and 2016-17 which was significantly lower than EC-119197 and EC-531804. Increase of fruit length in grafted plants was due to enhanced water and mineral uptake of roots further improving overall physiological efficiency of plants which increases photosynthetic activity of plants increasing activity of photosynthates and promoting action growth hormones in plant. Similar results were recorded by Khak *et al* (2006) which also recorded different sizes of fruit of same scion when grafted on different rootstocks.

Further while investigating Nematode infested plots pooled data was computed and it revealed that non-grafted plants recorded a reduced fruit length of 4.3 cm which was significantly lower than plants grafted on rootstock EC-119197 (6.3 cm) and EC-531804 (5.9 cm) and were at par with each other. Decrease in fruit size was due to the effect of nematodes which hinder flow of water and nutrients in xylem and phloem vessels of roots by forming galls. Hence, decreasing normal physiological activity of plants.

4.3.6 Harvest duration (Number of days)

Fruit yield of tomato plants depends upon the harvest numbers. More the number of harvesting, more will be the fruit and more will be the fruit yield. The data for the effect of different rootstock on scions for harvest duration was presented in Table 4.3.6.

Punjab Sartaj

It was observed from pooled data of nematode free plots that maximum harvest duration was observed in the EC-119197, EC-531804, PNR-7 and NR-10 (125 days) rootstocks but all the rootstocks showed non-significant difference for the harvest duration. In case of yearly data harvest duration was also not significantly affected.

While observing data in Nematode infested plots, highest harvest duration was observed under the rootstock EC-119197 (124 days) which was significantly higher from L-097 (116 days) and non-grafted plants of Punjab Sartaj (51 days) and statistically at par with all other rootstocks. Similar trend for harvest duration was observed in both the years (2015-16 and 2016-17). Plant vigor was reduced due to nematode attack on non-grafted plants which enlarge the harvest duration period of tomato (King *et al* 2010).

Punjab Ratta

While observing nematode free plots it was observed that plants grafted on rootstocks EC-119197 (89) recorded maximum days of harvest duration further followed by rootstock EC-531804 (80) and NR-10 (79) but recorded a non-significant data among all the treatments as well as from non-grafted plants.

Similarly while observing infested plots maximum effect of disease was observed on non-grafted plants which recorded harvest duration of 42 days and was significantly lower among all the treatments. Plants grafted on rootstock EC-119197 recorded maximum duration of harvest that is 86 days which was significantly higher among other grafted and non-grafted

Table 4.3.6 Effect of different rootstock's on harvest duration of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Harvest duration Punjab Sartaj						Harvest duration Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	122	122	122	120	120	120	72	72	72	70	72	71
T ₂	PNR-7	125	124	125	121	125	123	73	73	73	67	73	70
T ₃	NR-10	122	129	125	121	125	123	79	79	79	78	79	79
T ₄	L-0272	122	120	121	119	120	119	72	72	72	73	72	73
T ₅	L-0275	122	120	121	120	117	118	72	72	72	76	72	74
T ₆	L-097	119	120	119	116	117	116	72	74	73	71	74	73
T ₇	Hisar Lal	122	126	124	119	124	122	78	79	79	75	79	77
T ₈	EC-531804	127	123	125	124	123	123	80	80	80	72	80	76
T ₉	EC-119197	127	124	125	123	125	124	90	88	89	84	88	86
T ₁₀	Control (NG)*	121	124	122	50	52	51	78	76	77	41	43	42
	CD(P=0.05)	NS	NS	NS	9	10	6	NS	NS	NS	10	9	5

(NG)*: Non-Grafted

plants. Grafted plants possess a vigorous root system which supplement increased uptake of minerals, nutrients and water, which helps in enhancing overall vigor of plants hence enhancing yield as well as harvest duration of plants. These results were in line with King *et al* (2010) who also reported prolonged duration of harvest when scion used was grafted on different rootstock combinations which increased harvesting duration of grafted plants over non-grafted plants.

4.3.7 Average fruit weight (g)

Fruit weight expressed the total health status of plant. More the weight of fruit more will be the fruit yield. The data pertaining to the effect of different rootstocks on scions for average fruit weight was noticed in Table 4.3.7.

Punjab Sartaj

In case of pooled data of nematode free trial, maximum average fruit weight was observed in the rootstock EC-119197 (96.0 g) which was significantly higher from all other grafted and non-grafted rootstocks. Minimum average fruit weight was observed in the rootstock L-0275 (65.0 g). In case of yearly data of 2015-16 and 2016-17, maximum average fruit weight was observed in the rootstock EC-119197 (96.3 g and 95.6 g respectively) which was significantly superior from all other rootstocks but was at par with EC-531804 in year 2016-17 (88.3g).

Among the Nematode infested plots, maximum average fruit weight was observed in EC-119197 (94.3 g) rootstock which was significantly higher from all other grafted and non-grafted rootstocks and minimum average fruit weight was observed in the rootstock L-0275 (64.3 g). In yearly data it was investigated that EC-531804 (87.4g and 86.5g) was also significantly at par with EC-119197 in both the years of experiment while NR-5 was also significantly at par in year 2015-16 (85.6g). These results show a similar pattern as recorded by Wahb-Allah (2014) and Kumar *et al* (2015) which enhances the production of more growth hormones like gibberelic acid and auxin for respiration and mineral requirements of enlarged fruits of grafted plants.

Punjab Ratta

On observing nematode free plots pooled data revealed that plants grafted on rootstock EC-119197 recorded maximum fruit weight (88.1 g) which was significantly higher than non-grafted plants (74.4 g). It was further followed by EC-531804 (86.1 g), NR-5 (82.3 g) and Hisar Lal (81.9g) which were significantly at par with EC-119197 in pooled data. Further while investigating year wise data it revealed that EC-119197 was also significantly at par with PNR-7 in year 2015-16 (80.3 g) and 2016-17 (79.8 g) as well as with Hisar Lal in year 2015-16 (81.5 g) and 2016-17 (82.2 g).

While further computing data for infested plots non-grafted plants recorded least average fruit weight and recorded a value of 32.2 g which was significantly lower than all the

Table 4.3.7 Effect of different rootstock's on average fruit weight (g) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Average fruit weight (g) Punjab Sartaj						Average fruit weight (g) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	83.2	84.5	83.9	85.6	81.3	83.4	83.3	80.4	82.3	82.3	80.3	81.8
T ₂	PNR-7	82.3	83.7	83.0	81.2	82.4	81.8	80.3	79.8	80.1	78.8	80.3	79.5
T ₃	NR-10	68.3	67.3	67.8	65.3	66.4	65.3	74.3	73.8	74.1	73.4	74.3	73.8
T ₄	L-0272	68.3	67.1	67.7	66.5	68.5	67.5	71.3	70.5	69.9	68.5	69.3	69.4
T ₅	L-0275	64.5	65.6	65.0	63.3	65.3	64.3	69.4	70.8	70.1	67.5	69.3	68.4
T ₆	L-097	69.4	68.5	69.0	68.5	67.2	67.9	68.3	69.7	69.0	65.3	66.2	65.8
T ₇	Hisar Lal	82.2	83.3	82.2	81.3	80.3	81.8	81.5	82.2	81.9	81.1	80.5	80.8
T ₈	EC-531804	86.5	88.3	87.4	87.4	86.5	87.0	86.7	85.6	86.1	83.3	85.7	84.5
T ₉	EC-119197	96.3	95.6	96.0	95.4	93.3	94.3	87.5	88.6	88.1	88.1	87.2	87.7
T ₁₀	Control (NG)*	84.5	82.2	83.4	32.5	33.3	32.9	75.3	73.5	74.4	34.2	30.2	32.2
	CD(P=0.05)	9.1	10.9	6.2	10.4	10.2	6.4	10.8	10.1	6.4	9.3	11.5	6.4

(NG)*: Non-Grafted

grafted plants. It was due to the high incidence of nematode disease which hindered growth of plants suppressing physiological activity of vascular bundles in plants. Rootstocks EC-119197 significantly recorded higher fruit weight (87.7 g) among all the treatments but was also at par with EC-531804 (84.5g) and NR-5 (81.8g) in pooled data. While yearly data revealed that EC-119197 recorded maximum fruit weight that is 88.1g and 87.2g respectively but was also at par with EC-531804, NR-5, Hisar Lal and PNR-7. Similar results were quoted by Pogonyi *et al* (2005) who reported that when Lemance (F1) when grafted onto Beaufort rootstock, increased over all yield and was caused mainly by higher average fruit weight

4.3.8 Number of fruits

Number of fruits per plant has direct association with fruit yield. The data pertaining to the effect of different rootstock on scion for number of fruits per plant was discussed in Table 4.3.8.

Punjab Sartaj

Pooled data of nematode free plots revealed that maximum number of fruits per plant was observed in the grafted rootstock L-097 (72.8) which was statistically at par with L-0272 (70.3) and L-0275 (71.9) which was significantly higher from all other rootstocks. In yearly data, similar trend for number of fruits per plant was observed for 2015-16 and 2016-17.

Under the infested plots, maximum number of fruits per plant was observed in grafted rootstock L-097 (71.8) which was statistically at par with L-0272 (69.8) and L-0275 (69.3) rootstocks which was significantly higher from all other grafted and non grafted rootstocks. In case of year 2015-16, maximum number of fruits per plant was observed in the grafted rootstock L-097 (71.2) which was significantly higher from all other grafted and non-grafted plants except NR-10 (63.4), L-0275 (69.3) and L-0272 (70.3). Whereas during 2016-17, highest number of fruits per plant was observed in L-097 (72.4) which was statistically at par with NR-10 (64.2), L-0272 (69.3) and L-0275 (69.3) and was significantly higher from all other grafted and non grafted rootstocks. Similar, results were reported by Khah *et al* (2006) that number of fruits per plant was high in grafted plants because of enhanced secondary metabolites which improve the xylem and phloem movements.

Punjab Ratta

While observing data for nematode free plots it revealed that there was no significant effect of rootstocks on number of fruits per plant. While maximum number of fruits were observed on rootstock L-097 (42.3) which was statistically at par with all the treatments.

On other hand while analyzing pooled data for Nematode infested plots it revealed that there was significant effect of rootstocks. Maximum numbers of fruits were observed in plants grafted on rootstocks L-097 (41.2) which was significantly higher from non-grafted plants (10.7). Where as L-097 was also at par with plants grafted on rootstock L-0275 (35.8) and L-0272 (35.6). Similar data was recorded in the both years of experiment where L-097

Table 4.3.8 Effect of different rootstock's on number of fruits on Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Number of fruits Punjab Sartaj						Number of fruits Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	57.5	56.5	57.0	57.1	56.2	56.7	31.2	32.2	31.7	30.4	29.1	29.8
T ₂	PNR-7	60.5	60.2	60.4	58.1	59.1	58.6	32.5	34.6	33.6	30.2	31.3	30.8
T ₃	NR-10	66.6	64.3	65.6	63.4	64.2	63.8	34.6	33.6	34.1	34.2	32.3	33.3
T ₄	L-0272	70.2	70.3	70.3	70.3	69.3	69.8	36.6	37.6	37.1	36.5	34.7	35.6
T ₅	L-0275	71.3	72.4	71.9	69.3	69.3	69.3	41.2	40.2	40.7	35.4	36.2	35.8
T ₆	L-097	71.3	74.3	72.8	71.2	72.4	71.8	43.2	41.3	42.3	42.2	40.2	41.2
T ₇	Hisar Lal	63.5	62.3	62.9	61.2	60.5	60.9	33.3	31.4	32.4	32.4	31.7	32.1
T ₈	EC-531804	58.3	61.3	59.8	56.3	57.6	57.0	32.3	33.5	32.9	31.2	34.6	32.9
T ₉	EC-119197	59.2	58.3	58.8	57.3	56.6	57.0	31.3	32.3	31.8	31.3	33.2	32.3
T ₁₀	Control (NG)*	61.3	60.2	60.8	24.2	23.3	23.8	35.5	31.0	33.3	11.0	10.3	10.7
	CD(P=0.05)	8.5	9.7	5.3	8.5	8.4	5.2	NS	NS	NS	10.0	9.7	6.1

(NG)*: Non-Grafted

recorded 42.2 numbers of fruits in year 2015-16 and 40.2 number of fruits in year 2016-17 which significantly higher than non-grafted plants in both the years of trial but were at par with all other grafted plants in year 2016-17 except from NR-5 (29.1). Similarly in year 2015-16, L-097 was at NR-10, L-0272, L-0275 and Hisar lal. It may be due to feasible temperature which enhances growth of crop.

Non-grafted plants recorded a reduced number of fruits because of high susceptibility to nematodes of non-grafted plants which suppressed nutrient uptake of plant causing stunted growth hence decreasing overall height of plant decreasing number of branches hence reducing over fruit number on plants. Similar results were given by Lauws *et al* (2010) in which higher yield of grafted plants was observed mainly due to increase in overall fruit number of plants which was due to increase in flower clusters of tomato plant.

4.3.9 Total yield (q/ha)

Punjab Sartaj

Farmers always prefer a variety which has great yield potential. It is the main criteria to determine the success of any crop in the adopted area. The data pertaining to the effect of different rootstock on scion for total yield was presented in Table 4.3.9.

Punjab Sartaj

Maximum total yield in the nematode free trial was observed in the rootstock EC-119197 (2078 q/ha) which was significantly higher from all other grafted and non-grafted rootstocks. Minimum total fruit yield was observed in the rootstock NR-10 (1718 q/ha). Maximum total fruit yield was observed in the rootstock EC-119197 (2078 q/ha and 2078 q/ha) which was significantly superior from all other rootstocks during 2015-16 and 2016-17 years respectively.

Maximum total fruit yield in Nematode infested trial was observed in EC-119197 (1934 q/ha) rootstock which was significantly higher from all other grafted and non-grafted rootstocks and minimum total fruit yield was observed in the rootstock NR-10 (1619 q/ha). During both the years 2015-16 and 2016-17, similar trends for total fruit yield were observed. Similar results were observed by Di Gioia *et al* (2010). Fruit yield and yield related traits were improved with the grafting plants as compared to non-grafted plants might be due to vigorous rootstocks which enhances the nutrient and water uptake (Al-Harbi *et al* 2016).

Punjab Ratta

Plants grafted on vigorous rootstocks have an ability to respond more towards nutrient and water uptake hence making them more vigorous and hence help in improving yield of plant. While going through nematode free plots pooled data revealed that plants grafted on rootstock EC-119197 recorded maximum yield that is 635 q/ha which was significantly higher among all the treatments further followed by EC-531804 which recorded a value of 627 q/ha and were significantly at par among themselves. Non-grafted plants

Table 4.3.9 Effect of different rootstock's on total yield (q/ha) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Total yield (q/ha) Punjab Sartaj						Total yield (q/ha) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	1,953	1,932	1,943	1,881	1,874	1,878	504	538	521	488	495	492
T ₂	PNR-7	1,960	1,941	1,951	1,890	1,915	1,903	526	550	538	512	501	507
T ₃	NR-10	1,732	1,704	1,718	1,630	1,607	1,619	528	518	523	488	540	514
T ₄	L-0272	1,754	1,801	1,778	1,675	1,694	1,685	525	544	535	521	482	502
T ₅	L-0275	1,741	1,674	1,708	1,712	1,641	1,677	507	547	527	524	522	523
T ₆	L-097	1,929	1,913	1,921	1,869	1,858	1,864	512	493	503	468	482	475
T ₇	Hisar Lal	1,981	1,905	1,943	1,923	1,900	1,912	542	547	545	489	529	509
T ₈	EC-531804	2,015	1,913	1,964	1,894	1,883	1,889	611	643	627	626	587	607
T ₉	EC-119197	2,078	2,078	2,078	1,927	1,941	1,934	601	669	635	634	587	611
T ₁₀	Control (NG)*	1,957	1,946	1,952	343	277	310	527	574	551	79	85	83
	CD(P=0.05)	47	57	38	51	55	52	55	65	40	59	54	39

(NG)*: Non-Grafted

recorded a yield of 551 q/ha which was significantly lower than some of grafted plants but were at par with plants grafted on rootstock Hisar Lal (545 q/ha), PNR-7 (538 q/ha), L-0272 (532 q/ha), L-0275 (527 q/ha), NR-10 (523 q/ha) and NR-5 (521 q/ha). Minimum yield was obtained by plants grafted on rootstock L-097 and recorded a yield of 503 q/ha which was significantly lower among all the treatments.

On concluding, grafting either helped to increase yield by complimenting with overall average fruit weight of fruit or by increasing number of fruits per pant even help in supplementing more number of flowers per cluster (Al-Harbi *et al* 2016). Rootstock and scion have cell to cell interactions when union is formed which helps in promoting overall production of growth hormones in plants hence enhancing yield as well vigor of plants.

While analysing data of infested plots grafted plants demonstrated high resistance against disease and yielded significantly higher than non-grafted plants. Plants grafted on EC-119197 and EC-531804 recorded a yield of 611 q/ha and 607 q/ha which was significantly higher among other treatments followed by L-0275 (523 q/ha), NR-10 (514 q/ha), Hisar Lal (509 q/ha), PNR-7 (507 q/ha), L-0272 (502 q/ha) and NR-5 (492 q/ha). Non-grafted plants recorded minimum yield that is 83 q/ha and was significantly lower than all treatments. Similar results were given by Nina K M and Joze O (2004) in which he demonstrated grafted plants performing more than non-grafted plants under stress conditions. Whereas in non-grafted plants they were highly susceptible to nematodes which formed high numbers of galls on roots of plants hence decreasing overall yield of plants.

4.3.10 Marketable Yield (q/ha)

Marketable yield is an overall beneficial to farmer as well as to the consumers because good size and healthy fruits are attractive and fetch more returns per input units. Therefore for the farmer point of view it was important to increase the income. The data pertaining to the effect of different rootstock on scion for marketable yield was presented in Table 4.3.10.

Punjab Sartaj

Maximum marketable yield was observed in the rootstock EC-119197 (1857 q/ha) which was significantly higher from all other grafted and non-grafted rootstocks under the pooled data of nematode free plots. Lowest marketable fruit yield was observed in the rootstock NR-10 (1534 q/ha). In case of yearly data of 2015-16 and 2016-17, maximum marketable fruit yield was observed in the rootstock EC-119197 (1880 q/ha and 1833 q/ha respectively) which was significantly superior from all other rootstocks.

Among the Nematode infested plots, maximum marketable fruit yield was observed in EC-119197 (1733 q/ha) rootstock which was significantly higher from all other grafted and non-grafted rootstocks and minimum total fruit yield was observed in the rootstock NR-10 (1408 q/ha). Similar trends for marketable fruit yield were observed in both the years (2015-

Table 4.3.10 Effect of different rootstock's on marketable yield (q/ha) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Marketable yield (q/ha) Punjab Sartaj						Marketable yield (q/ha) Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	1660	1680	1670	1635	1594	1615	455	463	459	433	447	440
T ₂	PNR-7	1687	1725	1706	1642	1591	1617	490	495	493	477	466	472
T ₃	NR-10	1552	1515	1534	1410	1405	1408	475	474	475	453	483	468
T ₄	L-0272	1577	1553	1565	1472	1468	1470	479	483	481	424	460	442
T ₅	L-0275	1567	1559	1563	1478	1453	1466	486	489	488	469	493	481
T ₆	L-097	1569	1572	1570	1450	1474	1462	479	475	477	453	424	439
T ₇	Hisar Lal	1664	1641	1653	1549	1598	1574	461	455	458	454	494	474
T ₈	EC-531804	1773	1722	1748	1658	1688	1673	569	561	565	591	552	572
T ₉	EC-119197	1880	1833	1857	1741	1725	1733	572	578	575	599	552	576
T ₁₀	Control (NG)*	1643	1657	1650	211	226	218	539	492	516	49	56	53
	CD(P=0.05)	55	55	34	63	53	38	55	65	40	59	54	39

(NG)*: Non-Grafted

16 and 2016-17).

Punjab Ratta

Grafting helps in improving marketable yield of crop on as scrutinising nematode free plots pooled data revealed that plants grafted on some rootstocks had a noticeable increase in marketable yield. Plants grafted on rootstocks EC-119197 yielded maximum with an average yield 599 q/ha which were significantly higher in both the years of experiment further followed by EC-531804 with yield of 565 q/ha and was at par with each other. Non-grafted plants of Punjab Ratta recorded a yield of 516 q/ha which was significantly lower than EC-119197 and EC-531804. Similar results were highlighted by Khah *et al* (2006).

Further on investigating Nematode infested plots non-grafted plants were highly suppressed by disease and performed poorly which yielded 53 q/ha and were significantly lower than grafted plants. Among grafted plants rootstocks EC-119197 yielded maximum (575 q/ha) followed by EC-531804 which performed significantly better in both the years of experiment. These results were in line with Turkmen *et al* (2010) and Al-Harbi *et al* (2016) which recorded higher marketable yield in grafted plants over non-grafted plants under disease infested conditions. Grafted plants conferred resistance against nematodes and were able to nurture ambient uptake of water and nutrients from rhizosphere which helped in increasing over all physiological activity of plants like enhanced photosynthetic activity, increased hormonal activity more over increase in diameter of xylem and phloem vessels.

4.3.11 Pericarp Thickness

Pericarp thickness is an important parameter for the fruit texture and fruit shape. Pericarp thickness hardens the skin and increase the juiceness behaviour of tomato fruit. The data pertaining to the effect of different rootstock on scion for pericarp thickness was observed in Table 4.3.11.

Punjab Sartaj

Under the pooled data, maximum pericarp thickness was observed in the rootstock EC-119197 (8.49 mm) which was significantly higher from all other grafted and non-grafted rootstocks in the nematode free trial. In case of yearly data of 2015-16 and 2016-17, maximum pericarp thickness was observed in the rootstock EC-119197 (8.30 mm and 8.67 mm respectively) which was significantly superior from all other rootstocks.

In case of pooled data under Nematode infested plots, maximum pericarp thickness was observed in EC-119197 (8.31mm) rootstock which was significantly higher from all other grafted and non-grafted rootstocks. Minimum pericarp thickness was observed in the L-097 rootstock (5.72 mm). Similar trends for pericarp thickness were observed in both the years' e.i. 2015-16 and 2016-17 except for EC-531804 (7.58 mm) which was significantly at par with EC-119197 in year 2016-17. Similar, results were reported by Schwarz and Krumbein in which tomato plants demonstrated higher quality fruit when grown under

Table 4.3.11 Effect of different rootstock's on pericarp thickness of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Pericarp Thickness Punjab Sartaj						Pericarp Thickness Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	7.13	7.01	7.07	7.14	6.96	7.05	7.10	7.07	7.08	7.06	7.01	7.03
T ₂	PNR-7	7.26	7.22	7.24	7.09	7.11	7.10	7.04	7.21	7.13	7.18	7.04	7.11
T ₃	NR-10	6.27	6.35	6.31	6.20	5.91	6.06	6.76	7.05	6.91	6.83	6.99	6.91
T ₄	L-0272	6.78	6.44	6.61	6.60	6.49	6.55	6.35	6.33	6.34	6.29	5.98	6.14
T ₅	L-0275	6.19	6.04	6.12	5.87	5.95	5.91	5.81	5.73	5.77	5.27	5.25	5.26
T ₆	L-097	5.58	5.97	5.77	5.48	5.90	5.72	4.48	4.32	4.40	4.13	4.18	4.15
T ₇	Hisar Lal	6.35	6.40	6.38	6.42	5.98	6.20	5.47	5.36	5.42	5.01	5.22	5.11
T ₈	EC-531804	7.94	7.82	7.88	7.47	7.58	7.53	8.01	7.92	7.96	7.77	7.90	7.83
T ₉	EC-119197	8.30	8.67	8.49	8.47	8.15	8.31	8.62	8.53	8.58	8.46	8.32	8.39
T ₁₀	Control (NG)*	6.97	7.02	7.00	5.97	5.88	5.92	6.87	6.77	6.82	5.50	5.25	5.38
	CD(P=0.05)	0.5	0.3	0.3	0.9	0.9	0.6	0.8	0.4	0.4	0.4	0.7	0.4

(NG)*: Non-Grafted

infested conditions. In grafted plants more quality is obtained due to production of disease free plants because of resistant rootstock which enhance the strength of roots under the soil and improves their ability to uptake more secondary metabolites, so grafted plants have more pericarp thickness as compared to non grafted plants.

Punjab Ratta

Pericarp thickness plays an important role in providing firmness to fruit and has major role in transportation of tomato. While investigating nematode free plots of Punjab Ratta pooled data revealed that rootstocks EC-119197 (8.58 mm) recorded significantly higher pericarp thickness than non-grafted plants (6.82 mm) it was further followed by EC-531804 (7.96 mm) which was also statistically lower than EC-119197 in year pooled data as well as in year 2016-17 (7.92 mm) but recorded a significantly at par value in year 2015-16 (8.01 mm). Plants grafted on rootstock L-097 recorded minimum thickness of 4.30 mm.

On analysing data of Nematode infested plots non-grafted plants were highly susceptible to disease and recorded a poor growth hence decreasing fruit size as well as pericarp thickness of fruit. Non-grafted plants of Punjab Ratta computed a value of 5.38 mm which was significantly lower than plants grafted on rootstocks EC-119197 (8.39 mm) and EC-531804 (7.83 mm) which were significantly at par in year 2016-17 (7.90 mm) but EC-531804 recorded significantly lower value in year 2015-16 (7.77 mm) as well as in pooled data (7.83 mm). Nematode resistant lines were able to impart resistance against nematodes in grafted plants which helped in improving fruit quality both under infested as well as nematode free conditions these result were also substantiated by Kumar *et al* (2016).

4.3.12 TSS ⁰Brix (Total Soluble Solids)

TSS is an indicator of sweetness and determines the amount of solids present in fruit that will dissolve in water. Effect of different rootstock on scion for TSS content was presented in Table 4.3.12.

Punjab Sartaj

Under the nematode free trial, pooled data showed that, maximum TSS content was observed in the rootstock L-097 (6.7 ⁰Brix) which was significantly higher from all other grafted and non-grafted rootstocks. Minimum TSS content was observed in EC-531804 rootstock (4.1 ⁰Brix). In case of yearly data of 2015-16 and 2016-17, maximum TSS content was observed in the rootstock L-097 (7.0 ⁰Brix and 6.5 ⁰Brix respectively) which was significantly superior from all other rootstocks.

Under the Nematode infested plots, maximum TSS content was observed in L-097 (6.2 ⁰Brix) rootstock which was significantly higher from all other grafted and non-grafted rootstocks. Minimum TSS content was observed in the EC-531804 rootstock (3.9 ⁰Brix). While, during 2015-16 and 2016-17, maximum TSS was observed in L-097 rootstock (6.2 ⁰Brix and 6.1 ⁰Brix respectively) which was statistically at par with L-0272 (5.4 ⁰Brix and

Table 4.3.12 Effect of different rootstock's on TSS ⁰Brix (Total Soluble Solids) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	TSS ⁰ Brix Punjab Sartaj						TSS ⁰ Brix Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	4.7	4.7	4.7	4.7	4.7	4.7	4.1	3.8	4.0	3.8	4.2	4.0
T ₂	PNR-7	4.5	4.6	4.5	4.3	4.6	4.5	4.1	4.1	4.1	4.0	3.9	3.9
T ₃	NR-10	5.3	5.1	5.2	5.3	5.0	5.1	3.9	4.0	3.9	3.8	4.0	3.9
T ₄	L-0272	5.5	5.5	5.5	5.4	5.4	5.4	4.4	4.8	4.6	4.5	4.4	4.4
T ₅	L-0275	5.8	5.9	5.9	5.8	5.9	5.9	5.8	5.8	5.8	5.7	5.8	5.8
T ₆	L-097	7.0	6.5	6.7	6.2	6.1	6.2	6.5	6.2	6.4	6.3	6.2	6.3
T ₇	Hisar Lal	5.6	5.7	5.7	5.3	5.2	5.3	6.0	5.8	5.9	5.8	5.8	5.8
T ₈	EC-531804	4.0	4.1	4.1	3.9	3.8	3.9	3.8	4.0	3.9	3.6	3.9	3.7
T ₉	EC-119197	4.3	4.5	4.4	4.2	4.0	4.1	3.8	4.0	3.9	3.8	3.8	3.8
T ₁₀	Control (NG)*	5.5	5.3	5.4	4.6	4.6	4.4	4.8	4.7	4.8	4.2	4.4	4.3
	CD(P=0.05)	0.5	1.1	0.5	0.9	0.9	0.6	0.8	0.7	0.4	0.5	0.7	0.4

(NG)*: Non-Grafted

5.4 °Brix) and L-0275 (5.8 °Brix and 5.9 °Brix) and significantly higher from all other rootstocks. Total soluble solids was increased or decreased in the fruits due to scion and rootstocks interactions (Lopez-Galarza *et al* 2004; Alexopoulos *et al* 2007). Similar results were reported by (Mohammed *et al* 2009) that TSS may be decreased by grafting or may be increased by grafting

Punjab Ratta

Examining nematode free plots of Punjab Ratta it revealed that rootstocks L-097 (6.4 °Brix) recorded maximum TSS and significantly higher than non-grafted plants (4.8 °Brix) as well as other grafted plants. It was followed by Hisar Lal (5.9 °Brix) and L-0275 (5.8 °Brix) but were significantly lower than L-097.

On investigating year-wise data it revealed that plants grafted on rootstock L-097 recorded significantly higher TSS (6.5 °Brix and 6.2 °Brix) in both years (2015-16 and 2016-17 respectively) of experiment but were also at par with plants grafted on rootstock Hisar Lal (6.0 °Brix) and L-0275 (5.8 °Brix) in year 2015-16 and similarly in year 2016-17 it was again at par with Hisar Lal (5.9 °Brix) and L-0275 (5.8 °Brix).

In Nematode infested plots pooled data revealed that plants grafted on rootstocks L-097 recorded highest TSS (6.3 °Brix) which was significantly higher from non-grafted as well as other grafted plants. In year wise data it revealed that L-097 (6.3 °Brix) was also at par with Hisar Lal (5.8 °Brix) and L-0275 (5.7 °Brix) in year 2015-16 similar result were obtained in year 2016-17. Non-grafted plants recorded a reduced level of TSS with the value of 4.3 °Brix which was significantly lower than L-097. Grafting alters TSS value as per interactions between scions when grafted on different rootstocks which may alter levels of hormonal production in plants. So, it may carry both negative and positive effect on quality of fruit. Parallel results have been reported by many authors like Lopez-Galarza *et al* (2004) and Alexopoulos *et al* (2007).

4.3.13 Lycopene content (mg/ 100g)

Lycopene content is responsible for the color pigmentation in tomato. More the lycopene pigment, more will be the color and more beneficial for processing as well as for raw material. The data pertaining to the effect of different rootstocks on scion for lycopene content was presented in Table 4.3.13.

Punjab Sartaj and Punjab Ratta scion did not show any significant difference with various rootstocks for lycopene content under both the years (2015-16 and 2016-17) and both the trials (nematode free trial and Nematode infested trials). Similar results were observed by Liana *et al* (2009) and Turhan *et al* (2011) in tomato.

Punjab Ratta

Lycopene content greatly depends upon genetic structure of scion but sometimes it gets alter due to interactions of rootstocks with scion. Similarly while observing data of Table

Table 4.3.13 Effect of different rootstock's on lycopene content (mg/ 100g) of Punjab Sartaj and Punjab Ratta in nematode free and nematode infested plots

Sr. no	Rootstocks	Lycopene content Punjab Sartaj						Lycopene content Punjab Ratta					
		Nematode free			Nematode infested			Nematode free			Nematode infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	4.80	4.89	4.85	4.88	4.72	4.82	8.04	8.09	8.07	7.99	8.06	8.03
T ₂	PNR-7	4.98	4.87	4.94	4.65	4.83	4.75	8.01	8.09	8.05	8.02	8.06	8.04
T ₃	NR-10	5.28	5.37	5.34	5.20	5.39	5.30	8.54	8.49	8.52	8.41	8.49	8.45
T ₄	L-0272	5.20	5.15	5.29	5.13	5.27	5.22	8.61	8.54	8.58	8.34	8.44	8.39
T ₅	L-0275	5.20	5.21	5.21	5.03	5.12	5.09	8.66	8.64	8.65	8.54	8.59	8.57
T ₆	L-097	5.38	5.42	5.42	5.30	5.40	5.35	8.49	8.58	8.55	8.44	8.54	8.49
T ₇	Hisar Lal	5.13	5.17	5.17	4.80	4.90	4.86	7.88	7.79	7.82	7.84	7.74	7.79
T ₈	EC-531804	5.50	5.55	5.53	5.43	5.52	5.49	6.54	6.49	6.52	6.41	6.39	6.40
T ₉	EC-119197	5.18	5.27	5.22	4.95	4.98	4.94	6.74	6.69	6.72	6.66	6.59	6.63
T ₁₀	Control (NG)*	5.20	5.27	5.24	4.98	5.10	5.10	7.91	7.84	7.88	7.82	7.69	7.76
	CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

(NG)*: Non-Grafted

4.3.13 nematode free plots no significant difference was obtained in grafted and non-grafted plants. Turhan *et al* (2011) also reported that lycopene content did not differ significantly between the grafted and non-grafted plants and in contrast, Mohammed *et al* (2009) found a decrease for lycopene content in grafted tomato plants as compared to non-grafted plants. Many authors reported that fruit qualitative characters are not altered by grafting (Khah *et al* 2006).

On investigating Nematode infested plots grafted plants and non-grafted plants did not yield any significant data although plants grafted on rootstock L-0275 recorded maximum lycopene content (8.57 mg/100) but was significantly at par with Non-grafted plants of Punjab Ratta as well as other treatments of grafted plants. Liana Maria Alda *et al* (2009) observed similar results showing on difference of lycopene in grafted plants and non-grafted plants.

4.4 Comparative analysis of different grafting methods

Different methods were used for grafting which have a significant effect on the grafted plants. All grafted plants were compared and the data was analyzed to compute best performing method as well as rootstock and scion combination that can be used for grafting under Punjab conditions.

4.4.1 Effect of different grafting methods on rootstocks success percentage

Although methods used for grafting were already commercialized but methods have different success rate as well as different effect with respect to different rootstocks and scion used. From the data presented in Table 4.4.1 it can be concluded that tube grafting method had maximum success percentage. Moreover when plants of Punjab Sartaj were grafted with tube graft method on rootstock EC-119197 recorded a 95 percent success. In case of tongue

Table 4.4.1 Effect of different methods and rootstocks on graft success percentage (%)

Sr. no.	Rootstocks	Experiment No 1		Experiment No 2		Experiment No 3	
		Pb. Sartaj	Pb. Ratta	Pb. Sartaj	Pb. Ratta	Pb. Sartaj	Pb. Ratta
T ₁	NR-5	75	78	90	89	80	82
T ₂	PNR-7	78	80	93	91	81	83
T ₃	NR-10	82	85	94	92	78	80
T ₄	L-0272	72	79	85	84	81	82
T ₅	L-0275	79	80	86	85	80	83
T ₆	L-097	82	83	87	88	84	88
T ₇	Hisar Lal	83	81	93	92	83	82
T ₈	EC-531804	85	87	92	94	82	84
T ₉	EC-119197	86	88	95	93	85	83
T ₁₀	<i>Solanum torvum</i>	0	0	0	0	0	0

*Pb: Punjab

grafting success rate was around 86 percent and when done with cleft graft method it decreased to 85 %. So, there was clear effect of different grafting method on different rootstocks for their success of continued existence.

Similarly for Punjab Ratta maximum success rate was achieved by plants grafted on rootstock EC-531804 and recorded a success rate of 94 percent when grafted with tube graft method while recorded minimum success of 84 percent when grafted with cleft graft method.

4.4.2 Effect of different grafting techniques on various rootstock and scion combinations for earliness of tomato

Punjab Sartaj

On scrutinizing Table 4.4.2 it revealed that there was significant effect of methods of grafting on grafted plants. On analyzing grafted plants for days to flowering, plants grafted with tube graft method took minimum number of days to flower (85.6 days) which was significantly lower than other methods. Whereas plants grafted with tongue graft method took maximum number of days to flower (89.2 days) and was at par with plants grafted with cleft graft method and took 87.8 days to flower. Further while investigating for different rootstocks, plants grafted on rootstock PNR-7 recorded minimum number of days to flower and recorded a value of 84.86 days which was significantly lower than some of the grafted plants and was at par with plants grafted on rootstock L-097 (85.15), NR-10 (86.15), L-0275 (86.36), L-0272 (87.13) and Hisar Lal (87.81). Plants grafted on rootstock NR-5, EC-119197 and EC-531804 took 91.68, 92.11 and 93.16 days respectively which was significantly higher among some of the grafted plants.

Where as when plants analyzed for days to picking there was no significant difference among methods by which plants were grafted but there was significant effect of different rootstocks. Plants grafted on rootstock L-097 took minimum days to picking and recorded a value of 110.8 days which was significantly lower than some of the grafted plants but was at par with plants grafted on rootstock L-0275 (112.8), PNR-7 (113.4), NR-10 (113.5), Hisar Lal (116.3), L-0272 (116.9) and NR-5 (117.7). Whereas plants grafted on rootstock EC-119197 and EC-531804 took 127.9 and 133.8 days to picking which was significantly higher among some of the grafted plants.

Punjab Ratta

Similarly while examining data for Punjab Ratta grafted plants it revealed that there was no significant effect on days to flowering by either method practiced for grafting and nor there was any significant effect of different rootstocks used for grafting. So it can be clearly stated that there was no effect of method as well as of rootstock on days to flowering.

On other hand when data was considered for days to picking there was significant of method on grafted plants. Plants grafted with Tube graft method recorded significantly lower number of days (120.0) to picking where as plants grafted with Tongue Graft took 126.6 days

to picking which was significantly higher than both the methods. On further analyzing data a significant effect of different rootstocks on grafted plants was recorded in which plants grafted on rootstocks L-097 recorded significantly lower number of days to picking (118.1) among some of the grafted plants and was somehow at par with plants grafted on L-0275 (121.7), L-0272 (121.7), Hisar Lal (123.7), PNR-7 (124.1), NR-10 (124.4) and NR-5 (125.4) whereas plants grafted on rootstock EC-119197 and EC-531804 recorded 126.9 and 129.7 days which was significantly higher among some of the grafted plants.

Table 4.4.2 Comparative performance for earliness of tomato under different grafting methods

Sr. no	Grafting Methods (G)	Punjab Sartaj		Punjab Ratta	
		Days to flowering	Days to picking	Days to flowering	Days to picking
G ₁	Tongue Graft	89.2	116.1	105.5	126.6
G ₂	Tube Graft	85.6	112.8	101.3	120.0
G ₃	Cleft Graft	87.8	115.7	104.8	124.7
	CD(P=0.05)	1.2	NS	NS	1.3
	Rootstocks (R)				
R ₁	NR-5	91.68	117.7	103.4	125.4
R ₂	PNR-7	84.86	113.4	102.5	124.1
R ₃	NR-10	86.15	113.5	103.3	124.4
R ₄	L-0272	87.13	116.9	102.0	121.7
R ₅	L-0275	86.36	112.8	101.3	121.7
R ₆	L-097	85.15	110.8	102.1	118.1
R ₇	Hisar Lal	87.81	116.3	103.1	123.7
R ₈	EC-531804	93.16	133.8	104.3	129.7
R ₉	EC-119197	92.11	127.9	105.2	126.9
	CD(P=0.05)	6.5	7.0	NS	8.51
	CD (G × R)	NS	NS	NS	NS

4.4.3 Effect of different grafting techniques on various rootstock and scion combinations for yield related traits of tomato

For computing yield attributes of tomato three yield characters were analyzed in which Number of fruits, Average fruit weight and Marketable yield were examined and effect of different methods and rootstocks were calculated on grafted plants of Punjab Sartaj and Punjab Ratta.

Punjab Sartaj

On scrutinizing Table 4.4.4 grafted plants of Punjab Sartaj revealed that there was no significant effect of methods used for grafting when calculated for Number of fruits and Average fruit weight but different methods had a significant effect on Marketable yield of grafted plants and maximum yield was recorded when plants were grafted with Tube graft method and recorded a significant higher yield of 1669.9 q/ha followed by Cleft graft method which recorded a yield of 1651.5 q/ha which was also significantly higher than plants grafted with Tongue graft method which recorded lowest yield with value of 1636.0 q/ha.

While analyzing data for effect of different rootstock there was significant effect of rootstocks on grafted plants. Maximum number of fruits was obtained when plants were grafted on L-097 which recorded 73.3 numbers of fruit and was significantly higher among some of the grafted plants and was at par with L-0275 and L-0272. Minimum fruit count was recorded on NR-5 (58.3) and was significantly lower than rest of the grafted plants. Whereas maximum average fruit weight was recorded from plants when grafted on rootstock EC-119197 which recorded maximum fruit average fruit weight of 96.1 g which was further followed by EC-531804 (88.3 g) and NR-5 (85.8 g). These graft combination recorded significantly higher fruit weight than some of the grafted plants like L-0275 (65.6 g), NR-10 (67 g), L-0272 (67.9 g) and L-097 (68.3 g). While maximum marketable yield was obtained by plants grafted on rootstock EC-119197 which recorded a yield of 1846.1 q/ha and was significantly higher among all the grafted plants further followed by plants grafted on EC-531804 (1747.2 q/ha). Minimum marketable yield was obtained when plants were grafted on rootstock NR-5 (1535.9 q/ha) and was significantly lower among some of the grafted plants but was at par with plants grafted on L-0275 and L0272.

Table 4.4.3 Comparative performance for yield attributing characters of tomato with different grafting methods

Sr. no	Methods	Punjab Sartaj			Punjab Ratta		
		No. Fruits	Avg. wt. (g)	#M*Yield (q/ha)	No. Fruits	Avg. wt. (g)	M*Yield (q/ha)
G ₁	Tongue Graft	64.6	78.9	1636.0	35.7	76.8	492.2
G ₂	Tube Graft	64.3	79.2	1669.9	41.4	76.9	517.7
G ₃	Cleft Graft	63.6	78.4	1651.5	34.9	77.6	499.9
	CD(P=0.05) (P=0.05)	NS	NS	14.6	5.5	NS	16.4
	Rootstocks						
R ₁	NR-5	58.3	85.8	1663.0	33.3	82.1	480.6
R ₂	PNR-7	60.8	83.2	1695.7	35.8	78.6	489.4
R ₃	NR-10	61.7	67.0	1535.9	37.8	73.9	489.2
R ₄	L-0272	71.1	67.9	1558.5	39.6	70.5	477.0
R ₅	L-0275	72.4	65.6	1559.9	42.7	69.5	495.3
R ₆	L-097	73.3	68.3	1579.9	44.5	66.8	471.2
R ₇	Hisar Lal	64.1	83.1	1676.8	34.1	80.9	475.5
R ₈	EC-531804	59.7	88.3	1747.2	36.0	85.5	568.4
R ₉	EC-119197	59.8	96.1	1846.1	36.8	88.3	583.7
	CD(P=0.05)	8.3	11.6	26.7	7.3	10.9	29.9
	CD (G × R)	NS	NS	46.28	NS	NS	NS

M*yield: Marketable Yield

Punjab Ratta

Similarly when data was examined for grafted plants of Punjab Ratta it revealed that there was a significant effect of different methods practiced. Plants which were grafted with help of tube graft method recorded maximum number of fruits (41.4) and were significantly superior to both of the methods which recorded 35.7 and 34.9 number of fruits but were at par among them. Whereas there was no significant effect of methods recorded when data was analyzed for average fruit of plants but recorded a significant effect when calibrated for marketable yield of plants. Plants grafted with tube graft method recorded significantly higher marketable yield (517.7 q/ha) as compared to other two methods which recorded a yield of 499.9 q/ha (Cleft Graft) and 492.2 q/ha (tongue graft) and were significantly at par among themselves.

Further on calculating effect of rootstocks on grafted plants. Plants grafted on rootstocks L-097 recorded maximum number of fruits that is 44.5 which was significantly higher among some the rootstocks and was at par with plants grafted on L-0275 (42.7), L-0272 (39.6) and NR-10 (37.8). Minimum number of fruits was recorded on plants which were grafted on rootstock NR-5 (33.3) followed by PNR-7 (35.8) and Hisar Lal (34.1) whereas fruit count of 36.8 and 36 was recorded on EC-119197 and EC-531804 respectively. While advancing to average fruit weight there was significant effect of rootstock on grafted plants and plants grafted on rootstock EC-119197 recorded highest fruit weight that is 88.3 g which was significantly higher than some of the rootstock followed by EC-531804 (85.5 g) and NR-5 (82.1 g). Minimum fruit weight was recorded with plants grafted on L-097 (66.8 g) and recorded significantly lower than some of the grafted plants. While analyzing data for marketable yield plants grafted on rootstock EC-119197 recorded maximum yield that is 583.7 q/ha and was significantly higher among other grafted plant except for plants grafted on rootstock EC-531804 which recorded a yield of 568.4 q/ha. Minimum yield was observed with plants grafted on rootstock L-097 (471.2 q/ha) further followed by Hisar Lal (475.5 q/ha) and L-0272 (477.0 q/ha).

On analyzing the interaction Table 4.4.3.1 it was concluded that method of grafting have a influence on performance of specific rootstock and scion combination. So, there was a clear significant effect on marketbale yield of grafted plants when plants were grafted with different methods. Rootstock EC-119197 recorded maximum marketable yield (1882.0 q/ha) when grafted with tube graft method (G2) and was significantly higher as compared to other methods. NR-10 recorded minimum yield when grafted with tounge graft method (1525.6 q/ha).

Table 4.4.3.1 Comparing marketable yield of different rootstocks against different methods of grafting

	Tongue Graft (G1)	Tube Graft (G2)	Cleft Graft (G3)	(R)
Rootstock	Mean	Mean	Mean	Mean (R)
NR-5	1616.9	1701.9	1670.2	1663.0
PNR-7	1640.7	1740.5	1705.9	1695.7
NR-10	1525.6	1548.3	1533.8	1535.9
L-0272	1529.9	1580.5	1565.1	1558.5
L-0275	1552.5	1564.5	1562.8	1559.9
L-097	1570.3	1575.9	1593.5	1579.9
Hisar lal	1652.7	1674.0	1703.8	1676.8
EC-531804	1724.4	1770.6	1747.7	1747.2
EC-119197	1799.5	1882.0	1856.7	1846.1
Mean (G)	1636.1	1669.9	1651.5	
CD (G) (P=0.05)	Method of grafting			14.63
CD (G×R) (P=0.05)	Method × Rootstock			46.28
CD (R) (P=0.05)	Rootstock			26.64

4.4.4 Effect of different grafting techniques on various rootstock and scion combinations for quality traits of tomato

For examining data for quality of fruit, characters like TSS (total soluble solids) and pericarp thickness (mm) were analyzed and compared for effect of different methods as well as for effect of different rootstock.

Punjab Sartaj

On observing Table 4.4.4 it can conclude that there was no significant effect of different grafting methods on quality characters of fruits while on other hand a significant effect was observed when analyzed for effect of different rootstocks used. Plants grafted on rootstock L-097 recorded a maximum TSS of 6.18 °Brix which was significantly higher among all the grafted plants further followed by L-0275 (5.81 °Brix). Minimum TSS was recorded with plants grafted on rootstock EC-531804 that is 4.08 °Brix and was significantly lower among some of the grafted plants. Further while investigating for effect of rootstock on pericarp thickness plants grafted on rootstock EC-119197 recorded a maximum thickness of 8.23 mm and was significantly higher among all the grafted treatments further followed by EC-531804 with a pericarp thickness of 7.55 mm. Minimum pericarp thickness was recorded by L-097 with a value of 4.83 mm and was significantly lower among all the grafted plants.

Table 4.4.4 Comparative performance for quality characters of tomato under different grafting methods

Sr. no	Methods	Punjab Sartaj		Punjab Ratta	
		TSS °Brix	Pericarp Thickness (mm)	TSS °Brix	Pericarp Thickness (mm)
G ₁	Tongue Graft	5.12	6.70	4.67	6.46
G ₂	Tube Graft	5.15	6.69	4.62	6.42
G ₃	Cleft Graft	5.13	6.72	4.71	6.49
	CD(P=0.05) (P=0.05)	NS	NS	NS	NS
	Rootstocks				
R ₁	NR-5	4.71	7.02	3.83	6.82
R ₂	PNR-7	4.60	7.09	4.12	7.08
R ₃	NR-10	5.14	6.29	3.69	6.59
R ₄	L-0272	5.41	6.53	4.18	6.22
R ₅	L-0275	5.81	6.05	5.93	5.42
R ₆	L-097	6.18	4.83	6.31	4.40
R ₇	Hisar Lal	5.66	6.39	5.83	5.45
R ₈	EC-531804	4.08	7.55	3.95	8.07
R ₉	EC-119197	4.30	8.23	3.92	8.43
	CD(P=0.05)	0.32	0.51	0.29	0.28
	CD (G × R)	NS	NS	NS	NS

Punjab Ratta

While scrutinizing data of Table 4.4.4 it revealed that grafted plants of Punjab Ratta did not show any significant difference on quality parameters of fruit when grafted by either method but while analyzing the effect of rootstock there was a significant difference. Plants grafted on rootstock L-097 recorded highest TSS (6.31 °Brix) and was significantly higher among all the grafted plants followed by L-0275 (5.93 °Brix) and Hisar Lal (5.83 °Brix). Minimum TSS was recorded on plants grafted on rootstocks NR-5 with TSS of 3.83 °Brix followed by EC-531804 and EC-119197 which recorded 3.92 and 3.95 which was significantly lower than some of the grafted treatments. Similarly a significant effect was recorded for pericarp thickness in which plants grafted on rootstock EC-119197 recorded maximum pericarp thickness (8.43 mm) and was significantly higher among all the grafted plants further followed by EC-531804 (8.07 mm). Minimum pericarp thickness was obtained in plants grafted on L-097 which recorded a value of 4.40 mm and was significantly lower than some of the grafted treatments.

CHAPTER-V

SUMMARY

Tomato (*Solanum lycopersicum* L., syn. *Lycopersicon esculentum*, 2n=24) is one of the most versatile crops of Solanaceous family which is grown all around the world. Tomato is one of the most important 'protective foods' because of its high nutritive value and shares a major parts of our daily dishes so it is also known as 'poor man's orange' (Singh *et al* 2004). Tomatoes are used in soups, salad, pickle, ketchup, puree, sauces etc. Tomato is one of the major crops in processing industries and in India it is second largest crop grown subsequent to potato with a total area of 786 thousand hectare and with a total production of 195.41 thousand MT with a productivity of 28.1 MT/ha (Anonymous 2019). In Punjab it is grown on an area of 10.17 thousand hectare with an average yield of 24.88 MT/ha with a total production of 25.26 MT (Anonymous 2019).

Tomato is a warm season crop and requires a relatively long growing season with plenty of sunshine and moderate temperature of 20 to 28⁰C which also becomes a feasible temperature of many pest and pathogens. Hence, production of tomato is limited in many parts of India. Out of these pathogens soil borne pathogens are one of the problems in tomato. So, in order to achieve economically high yield of tomato, most of the production system uses synthetic chemicals and pesticides which are ultimately induced in the food chain and affecting human health. In India, intensive cultivation is practiced for high returns, but later leads to development of severe soil health problems. Hence an alternative approach is needed which is quick, practically applicable and eco-friendly to nature. In this situation grafting can be a feasible alternative which can control both biotic and abiotic stresses and besides that it has many other beneficial effects like; to enhance nutrient uptake (Ruiz *et al* 1997) to improve the yield when plants are cultivated in infected soils (Kacjan-Marsic and Osvald 2004) to increase the synthesis of endogenous hormones (Proebsting *et al* 1992) to improve water use efficiency (Cohen and Naor 2002) to increase flower set and seed production (Lardizabal and Thompson 1990) to enhance vegetable tolerance to drought, salinity and flooding (Estan *et al* 2005). Rootstock used for grafting are generally acquainted with vigorous root system which enhances nutrient and mineral uptake of plant which further enhances yield and quality character of plants. In Punjab conditions root knot nematode is emerging as a major disease especially under intensive and protected cultivation which can be controlled by many approaches like chemically and other methods like crop rotation but these are not efficient methods for controlling nematode. Moreover severity of there diseases increase under polyhouse conditions as same piece of land is used for cultivation. India has potential germplasm of vegetables which can be exploited for grafting as well as for selection of ideal rootstock. But, a little information is available regarding grafting for disease free produce

along with its economic feasibility under Indian conditions. Therefore, the present study entitled “Imparting root knot nematode resistance through grafting in tomato (*Solanum lycopersicum* L.)” has been conducted with the following objectives:

- To study the compatibility of root stocks and scion in tomato
- To standardize method of grafting against root knot nematode in tomato
- To evaluate identified root stock-scion combination for growth, yield and quality

The research experiment on ‘Imparting root knot nematode resistance through grafting in tomato (*Solanum lycopersicum* L.) was conducted at the Vegetable Research Farm and Bio chemistry lab, Department of Vegetable Sciences, Punjab Agricultural University, Ludhiana in year 2015-16 and 2016-17. The work plan was divided into three experiments based on different grafting methods which further divided into two different sites i.e. infested with root knot nematode and non-infested soil. Ten rootstocks with combination of two different scions (Punjab Sartaj and Punjab Ratta) were used as experiment material.

Experiments were designed according to three different grafting methods. In experiment no. 1 plants were grafted with tongue graft method similarly in experiment no. 2 and experiment no. 3 tube graft and cleft graft were used respectively. Observations were recorded for different horticulture traits as well as for quality traits similar observations were recorded under protected cultivation for both nematodes free as well as for Nematode infested plots where susceptible scion Punjab Sartaj and Punjab Ratta were grafted on ten different rootstocks. On summarizing the performance of grafted plants it revealed that:

- Grafted plants of Punjab Sartaj recorded maximum plant height when grafted on rootstocks EC-119197 in all three methods used both for nematode free as well as Nematode infested plots. Similarly while inspecting plants for earliness in tomato it was concluded that when plants of Punjab Sartaj were grafted with either method there was significant effect of tube graft method on days to flowering. Among rootstock, PNR-7, L-097, L-0275, L-0272 and NR-10 recorded minimum days to flowering which were at par with non-grafted control plants in nematode free plots and maximum number of days to flowering was recorded in non-grafted plants of Nematode infested plots, due high susceptibility to root knot nematode.
- While for days to picking there was no significant effect of different methods used for grafting. Among rootstocks, plants grafted on L-097, L-0275, PNR-7 and NR-10 recorded significantly less number of days to picking and was at par with non-grafted plants of Punjab Ratta in nematode free plots. While evaluating in Nematode infested plots non-grafted plants took maximum number of days to picking due to disease infestation but grafted plants took less number of days to picking and obtained a similar result as in nematode free plots.
- Increased uptake of nutrients and water also helps in prolonging harvest duration where

as grafted plants recorded a positive effect when examined for infested plots. Non-grafted plants recorded minimum duration of harvest where as grafted plants recorded significantly higher number of days for harvest.

- Further analyzing data for grafted plants of Punjab Sartaj has significant effect on fruit shape and size, when plants were grafted on different rootstocks in nematode free plot. Maximum fruit width was obtained when plants were grafted on rootstock EC-119197 in which both length and width of fruit was significantly higher than non-grafted plants.
- Although no significant effect of grafting methods was reported while computing for average fruit weight as well as on number of fruits. Plants of Punjab Sartaj when grafted on rootstock L-097 recorded maximum number of fruits followed by L-0275 and L-0272. Whereas maximum average fruit weight was obtained on plants grafted with EC-119197 which was significantly higher among all the grafted as well as non-grafted plants followed by EC-531804 and NR-5. Non-grafted plants had a drastic effect of disease in infested plots resulting in reduced number of fruits as well as average fruit weight while alike lines of grafted plants that is EC-119197 recorded higher fruit width and L-097 recorded higher fruit number in infested plots.
- Further while over looking grafted plants of Punjab Sartaj, plants grafted with tube graft method also recorded maximum marketable yield as compared to other methods. Among comparing different rootstocks in nematode free plots, total and marketable yield of Punjab Sartaj effected significantly as compared to non-grafted plants. Further, it was recorded that plants grafted on rootstock EC-119197 has maximum total as well as marketable yield both in infested and non infested plots followed by EC-531804. Whereas plants grafted on rootstocks NR-10 recorded minimum yield it was purely due to effect of rootstocks. Sometimes cell to cell interactions of scion and rootstocks communication may alter growth of plants which may trigger or halt production of growth promoters which plays important role in physiological processes of growth. Long distance signalling of growth hormones in leaves from roots may also shape the physiological growth of plants. Root system of rootstocks may enhance uptake of water from roots and newly formed union may also help in controlling flow of water to aerial parts of plants. Hence may show both increased and decreased growth of plant.(Shift) Similarly grafted plants of Punjab Ratta also recorded maximum yield when grafted on rootstocks EC-119197 followed by EC-531804 both in infested as well as non infested plots of root knot nematode
- Grafting methods do have a positive effect on yield character of tomato but for quality characters grafting methods did not had any significant effect on TSS, pericarp thickness and lycopene content of grafted tomatoes. On analyzing effect of different rootstocks there was a significant effect on grafted plants but there was no difference in lycopene

content of grafted and non-grafted plants of tomato. Whereas plants grafted on rootstocks L-097 recorded maximum TSS ⁰Brix where as maximum pericarp thickness was obtained when Punjab Sartaj was grafted on rootstocks EC-119197 in nematode free as well Nematode infested plants.

- Similarly, while investigating the effect of grafting on Punjab Ratta, it was observed that plants grafted on rootstock EC-531804 recorded maximum plant height for both nematode free and infested plots. Grafted plants demonstrated significantly more vigor in height as compared to non-grafted plants.
- On other hand grafted plants of Punjab Ratta did not has any significant effect on days to flowering either did not have any effect of different grafting methods in nematode free plots but rootstock recorded a significant effect in Nematode infested plots. Where plants grafted on rootstock L-0275 recorded minimum number of days followed by L-0272, PNR-7, NR-10 and NR-5 in while non-grafted plants took maximum number of days to flowering.
- While computing for days to picking, a significant effect of different methods on grafted plants of Punjab Ratta was observed, in which tube graft was comparatively better than other methods. Grafted plants also helped in achieving early picking when scion of Punjab Ratta was grafted on rootstock L-097 in nematode free as well as Nematode infested plots. Whereas in infested plots, non-grafted plants took maximum number of days as compared to grafted plants.
- Similarly while observing data for grafted plants of Punjab Ratta, grafting methods had a significant effect on fruits number per plant and tube graft method recorded maximum number. While for average fruit weight no significant effect of different methods was observed. Further scrutinized for different rootstock, maximum numbers of fruits were recorded in L-097 which was significant higher from non grafted plants, while highest fruit weight was observed on rootstocks EC-119197 which was also significantly higher from non grafted plants both in nematode free as well as in Nematode infested plots.
- While analyzing for quality characters of Punjab Ratta, there was no significant effect of grafting methods on TSS, pericarp thickness and lycopene content. While rootstock posses a significant effect on TSS and pericarp thickness of fruits. Further it was noticed that grafted plants on rootstocks L-097 recorded maximum TSS ⁰Brix where as maximum pericarp thickness was recorded on EC-119197.

Conclusion

Although, rootstocks and scion combination should be selected carefully for specific and geographic condition as there may be different effect of different rootstocks on different scion combinations. Similarly it can be applied for disease pathogens also which may be site specific as per geographic conditions and indigenous resistance can be used. So from present

investigation it can be concluded tube grafting was a best method observed for grafting as it has highest success rate and was responsible for earliness as well as high marketable yield in tomato plants. It recorded minimum days to flowering besides other two methods used. On evaluation of rootstocks plants grafted on EC-119197 superior for total and marketable yield, fruit weight, harvest duration and pericarp thickness while L-097 was favorable for TSS both in Nematode infested and nematode free plots. Whereas, for earliness in tomato under infested soil, rootstock PNR-7 was observed better among all the rootstocks. Overall rootstock EC-119197 can be used as a resistant rootstock against root knot nematode in addition it can fetch higher yield and better fruit quality.

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LIST OF PUBLISHED/ACCEPTED/SUBMITTED RESEARCH ARTICLES

S.No	Title	Journal	NAAS rating	Status
1	Systemizing methods of grafting against root knot nematode in tomato	Plant, Soil and Environment	7.34	Submitted
2	Re-accounting nematode resistance in tomato through tube grafting	Journal of Plant Nutrition	6.75	Submitted



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Dear Mr Sumeet Singh, PhD Scholar,

Thank you for your interest to publish your manuscript in Plant, Soil and Environment. Your manuscript **Systemizing methods of grafting against root knot nematode in tomato** written by Singh Sumeet (sumeet0051@gmail.com), Singh Kulbir (kulbirpawar@pau.edu), Jindal Salesh Kumar (saleshjindal@pau.edu), Dhatt Ajmer Singh (ajmerdhatt@pau.edu) and Kaur Nirmaljeet (nirmalkaur@pau.edu) has been registered as 6/2020-PSE. You will be duly informed about the assessment procedure. The "system author" (the one who has submitted the manuscript) can view the status of the manuscript at any time by checking the Author's account after logging into the system.

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Systemizing methods of grafting against root knot nematode in tomato

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Abstract

The present investigation was conducted at vegetable research farm, Department of Vegetable Science and Biochemistry lab, Punjab Agricultural University, Ludhiana during Autumn season of 2015-2016 and 2016-17. Although, rootstocks and scion combination should be selected carefully for specific and geographic condition as there may be different effect of different rootstocks on different scion combinations. Similarly it can be applied for disease pathogens also which may be site specific as per geographic conditions and indigenous resistance can be used. The work plan was divided into three experiments based on different grafting methods (Tongue grafting, tube grafting and cleft grafting) which further divided into two different sites i.e. infested with root knot nematode and non-infested soil. Ten rootstocks with combination of two different scions (Punjab Sartaj and Punjab Ratta) were used as experiment material. For infested plots pure culture of nematodes were raised by taking galled roots of tomato plants from infested plots than galls were teased and freshly hatched second stage juveniles were raised and used for inoculums. It may be concluded from the present investigation that tube grafting was a best method observed for grafting as it has highest success rate and was responsible for earliness as well as high marketable yield in tomato plants. Overall tube grafting methods and EC-119197 can be used as a resistant rootstock against root knot nematode in **North Indian conditions**.

Keywords: Nematode, Pathogen, Rootstock, Scion and Grafting

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important *Solanaceous* vegetable crops. Tomato is considered as protective food because of its special nutritive value. It shares major part of the daily dishes prepared in Indian kitchen being rich in vitamins, minerals and other phyto-nutraceuticals like lycopene which acts as antioxidants (Singh *et al* 2014). Tomatoes are used for soup, salad, pickles, ketchup, puree, sauces and in many other ways. Tomato has very few competitors in the value addition chain of processing so, it has wide industrial use. It is second largest vegetable crop grown in India after potato with total area of 786.0 thousand hectare and production of 195.41 thousand MT with a productivity of 28.1 MT/ha (Anonymous 2019a). In Punjab it is grown on an area of 10.17 thousand hectare with an average yield of 24.88 MT/ha with a total production of 25.26 MT (Anonymous 2019b). In India, tomato growers are mostly small and marginal farmers who are generally associated with intensive cultivation which gives high returns in early years, but later leads to the development of severe soil health problems. Although crop rotation can be practiced to control the soil borne pathogens but area

under vegetable production system is restricted and the host can persist in the soil for many years. So it becomes very difficult to prepare a pathogen free land (Garber *et al* 1973). This situation is further aggravated in protected cultivation of vegetables under net and poly-houses where same piece of land is used for same set of vegetables every year. This practice of monoculture and intensive cultivation has increased the intensity of soil born pathogen and affecting vegetable production system (Anonymous 2015). In this situation there is need to find such techniques which can be easily adopted by farmers and moreover acceptable to consumers. Grafting can be one of them as it is quick, practical in its application and eco-friendly and focusing for bumper produce. Vegetable grafting has been proved and useful in sustaining production and reducing the soil borne host pathogen. Grafting is mostly related to biotic and abiotic stress tolerance (Suchoff *et al* 2015). Root knot nematode is very harmful to the crop which leads to severe loss to the farmers financially and does not have a proper remedy for controlling this disease. Grafting can be the best alternative method to solve these problems both in the field and net/poly house cultivation. Therefore, the present study has been planned.

Material and method

The research experiment on Imparting root knot nematode resistance through grafting in tomato (*Solanum lycopersicum* L.) was conducted at the Vegetable Research Farm and Bio chemistry lab, Department of Vegetable Sciences, Punjab Agricultural University, Ludhiana in year 2015-16 and 2016-17. The work plan was divided into three experiments based on different grafting methods which further divided into two different sites i.e. infested with root knot nematode and non-infested soil. Ten rootstocks with combination of two different scions (Punjab Sartaj and Punjab Ratta) were used as experiment material. Experiments were designed according to three different grafting methods. In Experiment no. 1 plants were grafted with tongue graft method similarly in experiment no. 2 and experiment no. 3 tube graft and cleft graft were used respectively. Observations were recorded for different horticulture traits as well as for quality traits similar observations were recorded under protected cultivation for both nematodes free as well as for nematode infested plots where susceptible scion Punjab Sartaj and Punjab Ratta were grafted on ten different rootstocks. The data was analyzed by using SAS software.

Results and discussion

Different methods were used for grafting which have a significant effect on the grafted plants. All grafted plants were compared and the data was analyzed to compute best performing method as well as rootstock and scion combination that can be used for grafting under Punjab conditions.

Effect of different grafting methods on rootstocks success percentage

Although methods used for grafting were already commercialized but methods have different success rate as well as different effect with respect to different rootstocks and scion used. From the data presented in Table 1 it can be concluded that tube grafting method had maximum success percentage. Moreover when plants of Punjab Sartaj were grafted with tube graft method on rootstock EC-119197

recorded a 95% success. In case of Tongue grafting success rate was around 86 % and when done with cleft graft method it decreased to 85 %. So, there was clear effect of different grafting method on different rootstocks for their success of continued existence. Similarly for Punjab Ratta maximum success rate was achieved by plants grafted on rootstock EC-531804 and recorded a success rate of 94 % when grafted with tube graft method while recorded minimum success of 84% when grafted with cleft graft method. Tube graft method requires more precision for performing similar results were given by Myung Lee (2010) in which it was concluded that maximum surface for union of scion and rootstock was exposed when plants were grafted with tube graft method.

Effect of different grafting techniques on various rootstock and scion combinations for earliness of tomato

Punjab Sartaj

On scrutinizing Table 2 it revealed that there was significant effect of methods of grafting on grafted plants. On analyzing grafted plants for days to flowering, plants grafted with Tube Graft method took minimum number of days to flower (85.6 days) which was significantly lower than other methods. Whereas plants grafted with Tongue Graft method took maximum number of days to flower (89.2 days) and was at par with plants grafted with Cleft Graft method and took 87.2 days to flower. Further while investigating for different rootstocks, plants grafted on rootstock PNR-7 recorded minimum number of days to flower and recorded a value of 84.86 days which was significantly lower than some of the grafted plants and was at par with plants grafted on rootstock L-097 (85.15), NR-10 (86.15), L-0275 (86.36), L-0272 (87.13) and Hisra Lal (87.81). Plants grafted on rootstock NR-5, EC-119197 and EC-531804 took 91.68, 92.11 and 93.16 days respectively which was significantly higher among some of the grafted plants. Where as when plants analyzed for days to picking there was no significant difference among methods by which plants were grafted but there was significant effect of different rootstocks. Plants grafted on rootstock L-097 took minimum days to picking and recorded a value of 110.8 days which was significantly lower than some of the grafted plants but was at par with plants grafted on rootstock L-0275 (112.8), PNR-7 (113.4), NR-10 (113.5), Hisar Lal (116.3), L-0272 (116.9) and NR-5 (117.7). Whereas plants grafted on rootstock EC-119197 and EC-531804 took 127.9 and 133.8 days to picking which was significantly higher among some of the grafted plants. Increase in number of days in grafted plants was purely due to the interactions between scion and rootstocks which altered days to production of growth hormones in grafted plants which changes the behavior of cell to cell interaction in graft junction hence altering days to picking in grafted plants. Similar data was recorded by Gilardi *et al* (2013) in which grafted tomato plants were able to produce more number of fruits per cluster and took less number of days to picking.

Punjab Ratta

Similarly while examining data for Punjab Ratta grafted plants it revealed that there was no significant effect on days to flowering by either method practiced for grafting and nor there was any significant effect of different rootstocks used for grafting. So it can be clearly stated that there was no effect of method as well as of rootstock on days to flowering. On other hand when data was considered for days to picking there was significant of method on grafted plants. Plants grafted with Tube graft method recorded significantly lower number of days (120.0) to picking where as plants grafted with Tongue Graft took 126.6 days to picking which was significantly higher than both the methods. On further analyzing data a significant effect of different rootstocks on grafted plants was recorded in which plants grafted on rootstocks L-097 recorded significantly lower number of days to picking (118.1) among some of the grafted plants and was somehow at par with plants grafted on L-0275 (121.7), L-0272 (121.7), Hisar Lal (123.7), PNR-7 (124.1), NR-10 (124.4) and NR-5 (125.4) whereas plants grafted on rootstock EC-119197 and EC-531804 recorded 126.9 and 129.7 days which was significantly higher among some of the grafted plants.

Effect of different grafting techniques on various rootstock and scion combinations for yield related traits of tomato

For computing yield attributes of tomato three yield characters were analyzed in which Number of fruits, Average fruit weight and Marketable yield were examined and effect of different methods and rootstocks were calculated on grafted plants of Punjab Sartaj and Punjab Ratta.

Punjab Sartaj

On scrutinizing Table 3 grafted plants of Punjab Sartaj revealed that there was no significant effect of methods used for grafting when calculated for Number of fruits and Average fruit weight but different methods had a significant effect on Marketable yield of grafted plants and maximum yield was recorded when plants were grafted with Tube graft method and recorded a significant higher yield of 1669.9 q/ha followed by Cleft graft method which recorded a yield of 1651.5 q/ha which was also significantly higher than plants grafted with Tongue graft method which recorded lowest yield with value of 1636.0 q/ha. While analyzing data for effect of different rootstock there was significant effect of rootstocks on grafted plants. Maximum number of fruits was obtained when plants were grafted on L-097 which recorded 73.3 numbers of fruit and was significantly higher among some of the grafted plants and was at par with L-0275 and L-0272. Minimum fruit count was recorded on NR-5 (58.3) and was significantly lower than rest of the grafted plants. Whereas maximum average fruit weight was recorded from plants when grafted on rootstock EC-119197 which recorded maximum fruit average fruit weight of 96.1 g which was further followed by EC-531804 (88.3 g) and NR-5 (85.8 g). These graft combination recorded significantly higher fruit weight than some of the grafted plants like L-0275 (65.6 g), NR-10 (67 g), L-0272 (67.9 g) and L-097 (68.3 g). While maximum marketable yield was obtained by plants grafted

on rootstock EC-119197 which recorded a yield of 1846.1 q/ha and was significantly higher among all the grafted plants further followed by plants grafted on EC-531804 (1747.2 q/ha). Minimum marketable yield was obtained when plants were grafted on rootstock NR-5 (1535.9 q/ha) and was significantly lower among some of the grafted plants but was at par with plants grafted on L-0275 and L0272.

Punjab Ratta

Similarly when data was examined for grafted plants of Punjab Ratta it revealed that there was a significant effect of different methods practiced. Plants which were grafted with help of Tube Graft method recorded maximum number of fruits (41.4) and were significantly superior to both of the methods which recorded 35.7 and 34.9 number of fruits but were at par among them. Whereas there was no significant effect of methods recorded when data was analyzed for average fruit of plants but recorded a significant effect when calibrated for marketable yield of plants. Plants grafted with Tube Graft method recorded significantly higher marketable yield (517.7 q/ha) as compared to other two methods which recorded a yield of 499.9 q/ha (Cleft Graft) and 492.2 q/ha (Tongue Graft) and were significantly at par among themselves. Further on calculating effect of rootstocks on grafted plants. Plants grafted on rootstocks L-097 recorded maximum number of fruits that is 44.5 which was significantly higher among some the rootstocks and was at par with plants grafted on L-0275 (42.7), L-0272 (39.6) and NR-10 (37.8). Minimum number of fruits was recorded on plants which were grafted on rootstock NR-5 (33.3) followed by PNR-7 (35.8) and Hisar Lal (34.1) whereas fruit count of 36.8 and 36 was recorded on EC-119197 and EC-531804 respectively. While advancing to average fruit weight there was significant effect of rootstock on grafted plants and plants grafted on rootstock EC-119197 recorded highest fruit weight that is 88.3 g which was significantly higher than some of the rootstock followed by EC-531804 (85.5 g) and NR-5 (82.1 g). Minimum fruit weight was recorded with plants grafted on L-097 (66.8 g) and recorded significantly lower than some of the grated plants. While analyzing data for marketable yield plants grafted on rootstock EC-119197 recorded maximum yield that is 583.7 q/ha and was significantly higher among other grafted plant except for plants grafted on rootstock EC-531804 which recorded a yield of 568.4 q/ha. Minimum yield was observed with plants grafted on rootstock L-097 (471.2 q/ha) further followed by Hisar Lal (475.5 q/ha) and L-0272 (477.0 q/ha). Sometimes cell to cell interactions of scion and rootstocks communication may alter growth of plants which may trigger or halt production of growth promoters which plays important role in physiological processes of growth Turkmen *et al* (2010) and. Long distance signalling of growth hormones in leaves from roots may also shape the physiological growth of plants. Root system of rootstocks may enhance uptake of water from roots and newly formed union may also help in controlling flow of water to aerial parts of plants. Hence may show both increased and decreased growth of plant. Al-Harbi *et al* (2016)

Effect of different grafting techniques on various rootstock and scion combinations for quality traits of tomato

For examining data for quality of fruit, characters like TSS (total soluble solids) and Pericarp Thickness (mm) were analyzed and compared for effect of different methods as well as for effect of different rootstock.

Punjab Sartaj

On observing Table 4 it can conclude that there was no significant effect of different grafting methods on quality characters of fruits while on other hand a significant effect was observed when analyzed for effect of different rootstocks used. Plants grafted on rootstock L-097 recorded a maximum TSS of 6.18 °Brix which was significantly higher among all the grafted plants further followed by L-0275 (5.81 °Brix). Minimum TSS was recorded with plants grafted on rootstock EC-531804 that is 4.08 °Brix and was significantly lower among some of the grafted plants. Further while investigating for effect of rootstock on pericarp thickness plants grafted on rootstock EC-119197 recorded a maximum thickness of 8.23 mm and was significantly higher among all the grafted treatments further followed by EC-531804 with a pericarp thickness of 7.55 mm. Minimum pericarp thickness was recorded by L-097 with a value of 4.83 mm and was significantly lower among all the grafted plants.

Punjab Ratta

While scrutinizing data of table 4 it revealed that grafted plants of Punjab Ratta did not show any significant difference on quality parameters of fruit when grafted by either method but while analyzing the effect of rootstock there was a significant difference. Plants grafted on rootstock L-097 recorded highest TSS (6.31 °Brix) and was significantly higher among all the grafted plants followed by L-0275 (5.93 °Brix) and Hisar Lal (5.83 °Brix). Minimum TSS was recorded on plants grafted on rootstocks NR-5 with TSS of 3.83 °Brix followed by EC-531804 and EC-119197 which recorded 3.92 and 3.95 which was significantly lower than some of the grafted treatments. Similarly a significant effect was recorded for pericarp thickness in which plants grafted on rootstock EC-119197 recorded maximum pericarp thickness (8.43 mm) and was significantly higher among all the grafted plants further followed by EC-531804 (8.07 mm). Minimum pericarp thickness was obtained in plants grafted on L-097 which recorded a value of 4.40 mm and was significantly lower than some of the grafted treatments. It can be concluded that grafted plants helped in improving fruit quality both under stressed as well as healthy conditions these result were also substantiated by Kumar *et al* (2015).

Conclusion

It may be concluded from the present investigation that tube grafting was a best method observed for grafting as it has highest success rate and was responsible for earliness as well as high marketable yield in tomato plants. On evaluation of rootstocks plants grafted on EC-119197 superior for total and

marketable yield, fruit weight and pericarp thickness. Overall tube grafting methods and EC-119197 can be used as a resistant rootstock against root knot nematode.

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Table1: Effect of different methods and rootstocks on Graft success percentage (%)

Sr. no.	Rootstocks	Experiment No 1		Experiment No 2		Experiment No 3	
		Pb. Sartaj	Pb. Ratta	Pb. Sartaj	Pb. Ratta	Pb. Sartaj	Pb. Ratta
T ₁	NR-5	75	78	90	89	80	82
T ₂	PNR-7	78	80	93	91	81	83
T ₃	NR-10	82	85	94	92	78	80
T ₄	L-0272	72	79	85	84	81	82
T ₅	L-0275	79	80	86	85	80	83
T ₆	L-097	82	83	87	88	84	88
T ₇	Hisar Lal	83	81	93	92	83	82
T ₈	EC-531804	85	87	92	94	82	84
T ₉	EC-119197	86	88	95	93	85	83
T ₁₀	<i>Solanum torvum</i>	0	0	0	0	0	0

Table 2: Comparative performance for earliness of tomato under different grafting methods

Sr. no	Methods	Punjab Sartaj		Punjab Ratta	
		Days to flowering	Days to picking	Days to flowering	Days to picking
G ₁	Tongue Graft	89.2	116.1	105.5	126.6
G ₂	Tube Graft	85.6	112.8	101.3	120.0
G ₃	Cleft Graft	87.8	115.7	104.8	124.7
	CD(P=0.05) (P=0.05)	1.2	NS	NS	1.3
	Rootstocks				
R ₁	NR-5	91.68	117.7	103.4	125.4
R ₂	PNR-7	84.86	113.4	102.5	124.1
R ₃	NR-10	86.15	113.5	103.3	124.4
R ₄	L-0272	87.13	116.9	102.0	121.7
R ₅	L-0275	86.36	112.8	101.3	121.7
R ₆	L-097	85.15	110.8	102.1	118.1
R ₇	Hisar Lal	87.81	116.3	103.1	123.7
R ₈	EC-531804	93.16	133.8	104.3	129.7
R ₉	EC-119197	92.11	127.9	105.2	126.9
	CD(P=0.05) (P=0.05)	6.5	7.02	NS	8.51

Table 3: Comparative performance for yield attributing characters of tomato with different grafting methods

Sr. no	Methods	Punjab Sartaj			Punjab Ratta		
		No. Fruits	Avg. wt. (g)	#M*Yield (q/ha)	No. Fruits	Avg. wt. (g)	M*Yield (q/ha)
G ₁	Tongue Graft	64.6	78.9	1636.0	35.7	76.8	492.2
G ₂	Tube Graft	64.3	79.2	1669.9	41.4	76.9	517.7
G ₃	Cleft Graft	63.6	78.4	1651.5	34.9	77.6	499.9
	CD(P=0.05) (P=0.05)	NS	NS	14.6	5.5	NS	16.4
	Rootstocks						
R ₁	NR-5	58.3	85.8	1663.0	33.3	82.1	480.6
R ₂	PNR-7	60.8	83.2	1695.7	35.8	78.6	489.4
R ₃	NR-10	61.7	67.0	1535.9	37.8	73.9	489.2
R ₄	L-0272	71.1	67.9	1558.5	39.6	70.5	477.0
R ₅	L-0275	72.4	65.6	1559.9	42.7	69.5	495.3
R ₆	L-097	73.3	68.3	1579.9	44.5	66.8	471.2
R ₇	Hisar Lal	64.1	83.1	1676.8	34.1	80.9	475.5
R ₈	EC-531804	59.7	88.3	1747.2	36.0	85.5	568.4
R ₉	EC-119197	59.8	96.1	1846.1	36.8	88.3	583.7
	CD(P=0.05) (P=0.05)	8.3	11.6	26.7	7.3	10.9	29.9

G X R interaction M*yield (Punjab Sartaj), CD(P=0.05) (P=0.05)= 46.28

M*yield: Marketable Yield

Table 4: Comparative performance for quality characters of tomato under different grafting methods

Sr. no	Methods	Punjab Sartaj		Punjab Ratta	
		TSS (%)	Pericarp Thickness (mm)	TSS (%)	Pericarp Thickness (mm)
G ₁	Tongue Graft	5.12	6.70	4.67	6.46
G ₂	Tube Graft	5.15	6.69	4.62	6.42
G ₃	Cleft Graft	5.13	6.72	4.71	6.49
	CD(P=0.05) (P=0.05)	NS	NS	NS	NS
	Rootstocks				
R ₁	NR-5	4.71	7.02	3.83	6.82
R ₂	PNR-7	4.60	7.09	4.12	7.08
R ₃	NR-10	5.14	6.29	3.69	6.59
R ₄	L-0272	5.41	6.53	4.18	6.22
R ₅	L-0275	5.81	6.05	5.93	5.42
R ₆	L-097	6.18	4.83	6.31	4.40
R ₇	Hisar Lal	5.66	6.39	5.83	5.45
R ₈	EC-531804	4.08	7.55	3.95	8.07
R ₉	EC-119197	4.30	8.23	3.92	8.43
	CD(P=0.05) (P=0.05)	0.32	0.51	0.29	0.28

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Re-accounting nematode resistance in tomato through tube grafting

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Abstract

The present investigation was conducted at vegetable research farm, Department of Vegetable Science, Punjab Agricultural University, Ludhiana during Autumn season of 2015-2016 and 2016-17. The work plan was divided into two different sites i.e. infested with root knot nematode and non-infested soil. Ten rootstocks with combination of two different scions (Punjab Sartaj and Punjab Ratta) were used as experiment material. For infested plots pure culture of nematodes were raised by taking galled roots of tomato plants from infested plots than galls were teased and freshly hatched second stage juveniles were raised and used for inoculums. It was observed that fruit characters like fruit weight, fruit length, fruit width, marketable yield as well as total yield increased in tube grafted plants over non-grafted plants both in nematode free as well as nematode infested plots. On evaluation of rootstocks plants grafted on EC-119197 recorded higher total and marketable yield and higher fruit weight both in nematode infested and nematode free plots. Overall rootstock EC-119197 can be used as a resistant rootstock against root knot nematode in addition it can fetch higher yield.

Keywords: Tomato, nematode, grafting and fruit yield

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most versatile crops of Solanaceous family which is grown all around the world. Tomato is one of the most important 'protective foods' because of its high nutritive value and shares a major parts of our daily dishes so it is also known as 'poor man's orange' (Singh *et al* 2014). Tomato is a warm season crop and requires a relatively long growing season with plenty of sunshine and moderate temperature of 20 to 28°C which also becomes a feasible temperature of many pest and pathogens. Hence, production of tomato is limited in many parts of India. Out of these pathogens soil borne diseases are at one of the problems in tomato. In India, root knot nematode is emerging as a major disease especially under intensive and protected cultivation which can be controlled by many approaches like chemically and other methods like crop rotation but these are not efficient methods for controlling nematode. Hence an alternative approach is needed which is quick, practically applicable and eco-friendly to nature. In this situation grafting can be a feasible alternative which can control both biotic and abiotic stresses (Kacjan-Marsic and Osvald 2004). India has potential germplasm of vegetables which can be exploited for grafting as well as for selection of ideal rootstock. But, a little information is available regarding grafting for disease free produce along with its economic feasibility under Indian conditions. Therefore, the present study planned.

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Material and Methods

The research experiment was conducted at the Vegetable Research Farm and Bio chemistry lab, Department of Vegetable Sciences, Punjab Agricultural University, Ludhiana in year 2015-16 and 2016-17. The work plan was divided into two different sites i.e. infested with root knot nematode and non-infested soil. Ten rootstocks with combination of two different scions (Punjab Sartaj and Punjab Ratta) were used as experiment material. Experiments were designed according to tube graft technique. The plants were sown in three replications. Observations were recorded for different horticulture and yield traits. The data were collected and analyzed by using SAS software.

Results and Discussion

Tube graft method was used for grafting (10 different rootstocks and 2 scions namely Pnjab Sartaj and Punjab Ratta were used for this study).

Days to first picking

Days to first picking are responsible for earliness in tomato. Lesser the number of day's earlier yield can be fetched from the plants. Effect of different nematode resistant rootstock on two nematode susceptible scions named Punjab Sartaj and Punjab Ratta for days to first picking was analyzed and presented in Table 1.

Punjab Sartaj

From the data it was observed that in case of nematode free plots, minimum number of days for first picking was noticed in the rootstock PNR-7 (105.7 days) followed by L-097 (106.2 days), L-0275 (108.7 days), Hisar Lal (111.8 days) and NR-10 (112.8 days) which was significantly lower from rest of the rootstocks. Further the study reported that during the year 2015-16 and 2016-17, rootstock PNR-7 took minimum number of days for first picking (105.1 and 106.3 respectively) which was statistically at par with all other grafted rootstocks except EC-531804 (132.6 and 133.5 days), EC-119197 (126.2 and 123.5 days) and non grafted plants (116.0 and 119.2 days respectively). On the other hand, pooled data under the nematode infested plot revealed that minimum number of days for first picking was noticed in the rootstock PNR-7 (107.5 days) which was significantly lower from all other grafted and non grafted rootstocks except L-097 (109.1 days), L-0275 (110.5 days), Hisar Lal (112.8 days) and NR-10 (113.9 days) rootstocks. During the 2015-16 and 2016-17, rootstock PNR-7 took minimum number of days for first picking (106.8 and 108.2 days respectively) which was statistically at par with all other grafted rootstocks except EC-531804 (136.4 and 132.6 days), EC-119197 (12.4 and 127.8 days) and non grafted plants (140.5 and 142.6 days). Similar results were reported by Khah *et al* (2006) that grafted plant took lesser number of days for picking than non-grafted plants due to susceptibility of non-grafted plants to nematodes, which hindered growth of plants while resistant rootstock of grafted plants helped to confer resistance against disease.

Punjab Ratta

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In case of nematode free plots pooled data revealed that there was no significant effect on days to first picking of grafted as well as non-grafted plants of Punjab Ratta. Minimum days to first picking was noticed in plants grafted on rootstock L-097 (116.1) while non-grafted plants of Punjab Ratta took 120.5 days for picking but recorded a statistically at par data with each other. Similar data was observed in both the years of trial which recorded a non-significant data. On other hand while investigating nematode infested plots of Punjab Ratta pooled data revealed that all grafted plants recorded a significant lower number of days for picking as compared to non-grafted plants (148.8). Plants grafted on rootstocks L-097 (117.4) took minimum days for picking followed by L-0272 (118.4), L-0275 (118.9), PNR-7 (120.9), Hisar Lal (121.4), NR-5 (123.1), NR-10 (123.4) and EC-119197 (122.3) which was statistically at par with each other. Similar results were obtained in both experimental trials that is in year 2015-16 and 2016-17 where plants grafted on rootstock L-097 recorded minimum number of days to picking (116.7 and 118 respectively). Similar, results were obtained by Khah *et al* (2006), which stated that early yield was obtained in infested plots where grafted plants increased overall vigor of plants due to enhanced physiological activity of grafted plants as increased uptake of water and minerals enhanced yield of plants compared to non-grafted plants.

Fruit width (cm)

Fruit width is an important parameter that determines the health of the fruits. Fruit width also influences the shape index of tomato. Data related to effect of different rootstock on scion for fruit width was presented in Table 2.

Punjab Sartaj

Different rootstocks may influence fruit characters of scion while ongoing investigation recorded a significant effect of rootstocks on fruit width of scion. Maximum fruit width was obtained by rootstock EC-119197 (6.2 cm) which was significantly higher from PNR-7 (4.9 cm), NR-10 (4.6 cm), L-0275 (4.3 cm), L-0272 (4.2 cm), L-097 (4.1 cm) and non-grafted plant (5.3 cm) and statistically at par with rest of all grafted rootstocks. Similar trend for fruit width was observed in both years of experiment that confirms the influence of different rootstocks on scion. While observing data of infested plots pooled data, maximum fruit width was observed in EC-119197 rootstock (6.1 cm) which was statistically at par with NR-5 (5.5 cm), Hisar Lal (5.5 cm), EC-531804 (5.6 cm) and significantly higher from all other rootstocks. In case of yearly data, same genotype EC-119197 showed highest fruit width (6.1 cm and 6.1 cm respectively) which was statistically at par with NR-5 (5.3 and 5.8 cm), Hisar Lal (5.7 and 5.4 cm) and EC-531804 (5.4 and 5.7 cm) rootstocks. Grafted plants possessed more fruit width than non-grafted plants due to infestation of disease, which hindered growth of non-grafted plants. Different rootstocks possessed different fruit sizes on scion, although key characters of scion fruit possesses total characters of fruit but sometimes there may be minor effect of rootstocks on shape as well as on quality characters of fruits (Rivard and Louws 2010).

Punjab Ratta

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While investigating nematode free plots of Punjab Ratta pooled data revealed that fruit width of grafted plants was influenced by rootstocks and had significant results. Plants grafted on rootstocks EC-119197 recorded maximum fruit width (6.2 cm) and was significantly higher from all the treatments. It was further followed by EC-531804 (6.0) which was at par with EC-119197. While rootstocks NR-5 (5.6 cm), PNR-7 (5.1 cm), L-0272 (5.0 cm), Hisar Lal (4.9 cm) and NR-10 (4.8 cm) were at par with the non-grafted plants of Punjab Ratta (5.1 cm). Similar results were followed in both the years of experiment except for rootstock EC-119197 (6.1 and 6.3 cm) which were also statistically at par with NR-5 in year 2015-16 (5.7 cm) and 2016-17 (5.6 cm) in addition to EC-531804 (6.0 and 5.9 cm). Although fruit characters of scion are highly dependent on genetic for scion but it may have a little effect of rootstocks which is purely due to the interactions between scion and rootstocks, which altered the transport of growth hormones through the union hence fruit characters may vary accordingly. On the other hand while investigating nematode infested plots, pooled data revealed that plants grafted on rootstock EC-119197 (6.1 cm) recorded maximum fruit width followed by EC-531804 (5.7 cm) which was statistically at par with each other. Non-grafted plants of Punjab Ratta (4.4 and 4.7 cm) recorded significantly lower fruit width from EC-119197 (6.0 and 6.1 cm) and EC-531804 (5.7 and 5.8 cm). Reduced fruit width in grafted plants was due to effect of nematode infestation which hinders plants growth hence decreasing overall vigor of plants as well as fruit width. Rivard and Louws (2010) acknowledged that grafted plants of tomato show high tolerance to nematodes when grafted on nematode resistant lines and were able to perform better over non-grafted plants.

Fruit length (cm)

Fruit length has influence the fruit shape index. More the fruit length more will be the fruit yield. Fruit length determines the size index and fruit pulp ratio of tomato. Data regarding the effect of different rootstocks on scions for fruit length was analyzed and summarized in Table 3.

Punjab Sartaj

Pooled data of nematode infested free plots showed that maximum fruit length was observed under EC-119197 rootstock (6.3 cm) which was statistically at par with Hisar Lal and EC-531804 (5.8 cm) rootstocks and significantly higher from all other rootstocks. In case of yearly data of 2015-16 and 2016-17, similar trend for fruit length was observed where plants grafted on EC-119197 recorded significantly higher fruit length than non-grafted plants. While observing the data for nematode infested plots, EC-119197 (6.3 cm) recorded a significant higher fruit length among other grafted and non-grafted rootstocks. Minimum fruit length was observed in the rootstock L-0272 (3.8 cm). In case of yearly data, maximum fruit width was observed in the rootstock EC-119197 (6.2 cm and 6.4 cm) during 2015-16 and 2016-17 years respectively which was statistically at par with Hisar Lal (5.6 and 5.7 cm) and EC-531804 (5.4 and 5.8 cm) rootstocks and significantly higher from all other rootstocks. Non-grafted plants recorded a reduction in fruit length due to harsh effect of infested disease but grafted plants easily escaped the effect of nematodes. Reduction of fruit length observed in grafted plants is was due to interaction

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3 between scion and rootstocks. Pygoni *et al* (2005) reported that different combination of graft behave
4 differently and observed both higher and lower fruit lengths of plants than non-grafted control plants due
5 to improved secondary metabolites and xylem flow movements between the stems for the grafted plants.
6 Results were in line with Rivard and Louws (2010).
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9 **Punjab Ratta**

10 On observing data for fruit length of Punjab Ratta pooled data of nematode free plots revealed
11 that plants grafted on rootstocks EC-119197 (6.2 cm) recorded maximum fruit length and was statistically
12 higher than non-grafted plants (5.6 cm). Further it was followed by EC-531804 (6.0 cm), NR-5 (5.9 cm),
13 Hisar Lal (5.9 cm), PNR-7 (5.8 cm), and NR-10 (5.8 cm) rootstocks which were at par with EC-119197.
14 Higher fruit length in grafted plants was due to effect of rootstocks and scion interactions which had
15 significant effect in fruit length of plants. Similar results were obtained in both the years of experiment
16 and were in line with the findings of Rivard *et al* (2010). Identical testimony was obtained in nematode
17 infested plots as obtained in nematode free plots except for non-grafted plants as they recorded a reduced
18 fruit length of 4.7 cm and 4.4 cm in year 2015-16 and 2016-17 further 4.6 cm in pooled data which was
19 significantly lesser than EC-119197, EC-531804 and NR-5 which recorded a length of 6.2 cm. 5.9 cm and
20 5.8 cm. Non-grafted plants recorded lesser fruit length due to stress caused by nematodes which caused
21 galling in roots of plants and hindered absorption capability of roots which decreased overall vigor of
22 fruits in plant. These results were in line with Rivard and Louws (2010) which stated that higher fruit
23 length was observed in grafted plants as compared to non-grafted plants.
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26 **Average fruit weight (g)**

27 Average fruit weight has direct and positive association with fruit yield. Fruit weight expresses
28 the total health status of plant. The data pertaining to the effect of different rootstocks on scions for
29 average fruit weight was noticed in Table 4.
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32 **Punjab Sartaj**

33 The pooled data of nematode free trial showed that, maximum average fruit weight was observed
34 in the rootstock EC-119197 (97.2 g) which was significantly higher from all other grafted and non-grafted
35 rootstocks (82.9 g). Further it was followed by rootstock EC-531804 (88.4 g) and NR-5 (87.5 g) which
36 was significantly lower than EC-119197. Minimum average fruit weight was observed in the rootstock L-
37 0275 (65.7 g). In case of yearly data of 2015-16 and 2016-17, maximum average fruit weight was
38 observed in the rootstock EC-119197 (96.6 g and 97.9 g respectively) which was significantly superior
39 from all other rootstocks but was statistically at par with EC-531804 (88.3 g) in year 2015-16. In case of
40 nematode infested plots, maximum average fruit weight was observed in EC-119197 (95.2g) rootstock
41 which was significantly higher from all other grafted and non-grafted rootstocks and minimum average
42 fruit weight was observed in the rootstock L-0275 (63.8g). Similar trends for average fruit weight was
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3 observed in both the years (2015-16 and 2016-17). These results show a similar pattern as recorded by
4 Wahb-Allah (2014) and Kumar *et al* (2015) in grafted tomatoes.

6 **Punjab Ratta**

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8 In case of nematode free plots pooled data revealed that plant of Punjab Ratta had significant
9 effect on average fruit weight when grafted with different combinations of rootstock. Plants grafted on
10 rootstock EC-119197 recorded higher fruit weight (88.1 g) and was significantly higher than non-grafted
11 plants of Punjab Ratta (75.9 g). Further it was followed by plants grafted on rootstock EC-531804 (87.0
12 g), NR-5 (81.2 g) and Hisar Lal (81.0 g) which were statistically at par with EC-119197. Similar data was
13 recorded in both the years of experiment which recorded a value of 88.2 g in year 2015-16 and 88.0 g in
14 year 2016-17 respectively. Enhanced fruit weight recorded in grafted plant was due to robust rootstock
15 used which responds more likely to nutrients and were able to promote growth in aerial parts of the plant
16 increasing stomatal conductance and photosynthetic activity in plant hence improving dry matter content
17 of plant. Further while going through data for infested plots non-grafted plants recorded decline in
18 average fruit weight of plants and recorded a value of 34.3 g, which was significantly lower from grafted
19 plants. It was due to the impact of nematodes, which damaged roots of plant disturbing uptake of plants
20 hence reducing overall yield of non-grafted plants. Grafted plants recorded a similar trend of result as in
21 nematode free plots where rootstocks EC-119197 significantly recorded a higher fruit weight (87.4 g)
22 followed by EC-531804 (82.9 g) which were at par among themselves. These results were in line with
23 results of Pogonyi *et al* (2005) who reported that when Lemance (F1) when grafted onto Beaufort
24 rootstock, increased over all yield of plants and which mainly was due to higher average fruit weight of
25 plants hence increasing fruit size and overall yield of plants.

26 **Number of fruits**

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28 Number of fruits per plant has direct association with fruit yield. More the number of fruits per
29 plant more will be the yield. The data pertaining to the effect of different rootstock on scion for number of
30 fruits per plant was discussed in Table 5.

31 **Punjab Sartaj**

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33 Fruit yield was enhancement when plants are grafted on different rootstocks. Data revealed that
34 under the nematode free plots, maximum number of fruits per plant was observed in the grafted rootstock
35 L-097 (72.8) which was statistically at par with NR-10 (66.7), L-0272 (71.6) and L-0275 (72.7) and
36 significantly higher from all other rootstocks. On analysis of yearly data of 2015-16 and 2016-17, similar
37 trend for number of fruits per plant was observed. In nematode infested plots, maximum number of fruits
38 per plant was observed in grafted rootstock L-097 (71.8) which was statistically at par with NR-10 (64.8),
39 L-0272 (70.4) and L-0275 (70.8) and significantly higher from all other grafted and non grafted
40 rootstocks. In case of year 2015-16, maximum number of fruits per plant was observed in the grafted
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3 rootstock L-097 (72.2) which was significantly higher from all other grafted and non-grafted plants
4 except NR-10 (65.3), L-0275 (70.3) and L-0272 (71.2). Whereas during 2016-17, highest number of fruits
5 per plant was observed in L-097 and L-0275 (71.3) which was statistically at par with NR-10 (63.2), L-
6 0272 (69.5) and significantly higher from all other grafted and non grafted rootstocks. Similar, results
7 were reported by Khah *et al* (2006) that number of fruits per plant was more in grafted plants because of
8 disease free rootstock.
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10 11 12 **Punjab Ratta**

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14 While scrutinizing data for nematode free plots it revealed that there was no significant effect of
15 rootstocks on number of fruits per plant. While maximum number of fruits were observed on rootstock L-
16 097 (43.7) which was statistically at par with all the treatments. On other hand while analyzing pooled
17 data for nematode infested plots it revealed that there was significant effect of rootstocks. Plants grafted
18 on rootstocks L-097 recorded maximum number of fruit (43.3) which was significantly higher from non-
19 grafted plants (11.8). L-097 was also at par with plants grafted on rootstock L-0272 (38.5), L-0275 (38.4)
20 and NR-10 (37.1). In year 2015-16 and 2016-17 Similar data was recorded where L-097 recorded 42.3
21 and 44.2 numbers of fruits respectively which significantly higher than non-grafted plants in both the
22 years of trial. Reduced number of fruits in non-grafted plants was due to susceptibility of non-grafted
23 plants to nematodes which deterred growth of plant due to suppression of nutrient uptake of plant causing
24 stunted growth hence decreasing overall height of plant decreasing number of branches hence reducing
25 over fruit number on plants. Similar results were given by Lowus *et al* (2010) in which higher yield of
26 grafted plants was observed mainly due to increase in overall fruit number of plants which was due to
27 increase in flower clusters of tomato plant.
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29 30 31 **Total yield (q/ha)**

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33 Total yield of the plant describes the potentially of the crop plant. Success or failure of any
34 variety or genotype depends on the total and marketable yield of that variety in the adopted area. The data
35 pertaining to the effect of different rootstock on scion for total yield was presented in table 6.
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37 38 39 **Punjab Sartaj**

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41 The pooled data of nematode free trial showed that, maximum total yield was observed in the
42 rootstock EC-119197 (2159 q/ha) which was significantly higher from all other grafted and non-grafted
43 rootstocks (2015 q/ha). It was further followed by plants grafted on rootstock EC-531804 (2047 q/ha),
44 PNR-7 (2032 q/ha) and NR-5 (2017 q/ha) which recorded significantly lower yield than EC-119197 but
45 were statistically at par with non-grafted plants of Punjab Sartaj. Minimum total fruit yield was observed
46 in the rootstock NR-10 (1775 q/ha). In case of yearly data of 2015-16 and 2016-17, maximum total fruit
47 yield was observed in the rootstock EC-119197 (2167 q/ha and 2151 q/ha respectively) which was
48 significantly superior from all other rootstocks. In case of nematode infested plots, maximum total fruit
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3 yield was observed in EC-119197 (2114 q/ha) rootstock which was significantly higher from all other
4 grafted and non-grafted rootstocks and minimum total fruit yield was observed in the rootstock NR-10
5 (1767 q/ha). Similar trends for total fruit yield were observed in both the years (2015-16 and 2016-17).
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7 Similar results were observed by Di Gioia *et al* (2010). Results were in contrast with (Nina and Joze
8 2004) that there was a negative effect of grafting with lower yield. Plants grafted on to vigorous
9 rootstocks have an ability to respond more towards nutrient and water uptake hence making them more
10 vigorous and hence help in improving yield of plant either by complimenting with overall average fruit
11 weight of fruit or by increasing number of fruits per pant even help in supplementing more number of
12 flowers per cluster (Al-Harbi *et al* 2016).
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17 **Punjab Ratta**

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19 On investigating nematode free plots pooled data revealed that plants grafted on rootstocks EC-
20 119197 recorded maximum yield (642 q/ha) which was significantly higher from all other grafted
21 rootstocks as well as non-grafted plants of Punjab Ratta (557 q/ha) followed by EC-531804 (619 q/ha).
22 Minimum yield was recorded by plants grafted on rootstock L-097 which recorded a yield of 530 q/ha
23 and was also at par with non-grafted plants. Sometimes a negative effect of grafting may also be seen
24 with lower yield similar results were obtained by Nina K M and Joze O (2004) which was due to effect of
25 different rootstock as only vigorous root morphology only does not indicate higher growth of grafted
26 plants but cell to cell interaction on union and genotype of scion/rootstock also have a major role in
27 enhancing growth in grafted plants (Carmen *et al* 2010). Grafting has a positive effect mainly due to
28 presence of vigorous root system of rootstocks which enhances water and mineral nutrient uptake of
29 plants hence improving vigour and fruit yield of plants and even helps to confer disease in plant.
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36 While interpreting data of infested plots pooled data revealed that grafted plants yielded
37 significantly higher than non-grafted plants. Plants grafted on rootstock EC-119197 and EC-531804
38 recorded a yield of 632 q/ha and 601 q/ha which significantly higher among all the grafted and non-
39 grafted plants. There was decrease in yield of non-grafted plants and recorded a value of 66 q/ha which
40 was due to infestation of nematodes in roots which formed galls damaging root system of plants. Similar
41 results were recorded in both the years of experiment in which grafted plants EC-119197 and EC-531804
42 yielded significantly higher than non-grafted plants. These results were also confirmed by Turhan *et al*
43 (2011) in which he demonstrated that grafted plants performing better and yielding more than non-grafted
44 plants under stress conditions.
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50 **Marketable Yield (q/ha)**

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52 Marketable yield determines the success or failure of any crop plant. Marketable yield is the end
53 product which was delivered to consumers from farmer field. Therefore for the farmer point of view it
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3 was important to increase the income. The data pertaining to the effect of different rootstock on scion for
4 marketable yield was presented in Table 7.
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6 **Punjab Sartaj**

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8 The pooled data of nematode free trial showed that, maximum marketable yield was observed in
9 the rootstock EC-119197 (1882 q/ha) which was significantly higher from all other grafted and non-
10 grafted rootstocks. It was further followed by plants grafted on rootstock EC-531804 (1771 q/ha) and
11 PNR-7 (1744 q/ha) but were statistically lower than plants grafted on rootstock EC-119197. Minimum
12 marketable fruit yield was observed in the rootstock NR-10 (1548 q/ha). In case of yearly data of 2015-16
13 and 2016-17, maximum marketable fruit yield was observed in the rootstock EC-119197 (1911 q/ha and
14 1853 q/ha respectively) which was significantly superior from all other rootstocks. In case of nematode
15 infested plots, maximum marketable fruit yield was observed in EC-119197 (1805 q/ha) rootstock which
16 was significantly higher from all other grafted and non-grafted rootstocks and minimum total fruit yield
17 was observed in the rootstock NR-10 (1496 q/ha). Similar trends for marketable fruit yield were observed
18 in both the years (2015-16 and 2016-17).
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20 **Punjab Ratta**

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22 On going through case of nematode free plots pooled data revealed that plants grafted on
23 rootstocks EC-119197 yielded maximum with a yield 606 q/ha which were significantly higher in both
24 the years further followed by EC-531804 with yield of 575 q/ha which was at par with EC-119197. Non-
25 grafted plants of Punjab Ratta recorded a yield of 502 q/ha and was also at par with plants grafted on
26 rootstock PNR-7 (515 q/ha) and L-0275 (514 q/ha). Similar results were highlighted by Khah *et al* (2006)
27 which reported enhanced yield of grafted plants than non-grafted plants.

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29 On investigating nematode infested plots non-grafted plants were highly suppressed by disease
30 and recorded a yield of 49 q/ha which was significantly lower than grafted plants. Similar trend of result
31 was followed by grafted plants as in nematode free plots where rootstocks EC-119197 yielded maximum
32 (589 q/ha) followed by EC-531804 (556 q/ha) and were at par among themselves. In both years of
33 experiment results were alike. These results were in also in line with Al-Harbi *et al* (2016) which reported
34 higher yield of grafted tomato over non-grafted tomato plants.
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37 In general plants with superior and resistance root system have higher resistance to soil borne
38 disease. Grafted plants were acquainted with nematode resistant roots showing higher resistance to
39 nematode which hindered gall formation in roots moreover improved water and nutrient uptake of plants
40 effectively, providing more vigour as well as more number fruits per plant and supplementing average
41 fruit weight which helped in increasing marketable yield of plants both in nematode infested and
42 nematode free plots. Similar, findings were reported by Di Gioia *et al* (2010) and Al-Harbi *et al* (2016).
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Conclusion

Although, rootstocks and scion combination should be selected carefully for specific and geographic condition as there may be different effect of different rootstocks on different scion combinations. Similarly it can be applied for disease pathogens also which may be site specific as per geographic conditions and indigenous resistance can be used. It may be concluded that tube grafting was a best method observed for grafting as it has highest marketable yield in tomato plants. On evaluation of rootstocks plants grafted on EC-119197 superior for total and marketable yield and fruit weight.

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Table 1: Effect of different rootstock's on days to picking of Punjab Sartaj and Punjab Ratta in Nematode free and Nematode infested plots.

Sr no	Rootstocks	Days to Picking Punjab Sartaj						Days to Picking Punjab Ratta					
		Nematode free			Nematode Infested			Nematode free			Nematode Infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	112.2	114.6	113.4	115.7	116.8	116.2	120.6	121.7	121.2	123.6	122.5	123.1
T ₂	PNR-7	105.1	106.3	105.7	106.8	108.2	107.5	122.2	119.3	120.8	122.3	119.5	120.9
T ₃	NR-10	113.6	112.0	112.8	114.4	113.4	113.8	120.2	122.5	121.4	125.7	121.0	123.4
T ₄	L-0272	114.1	113.0	113.3	112.9	115.0	114.9	116.2	117.7	117.0	119.3	117.4	118.4
T ₅	L-0275	106.3	111.0	108.7	109.7	111.3	110.5	117.9	119.4	118.7	119.3	118.5	118.9
T ₆	L-097	105.3	107.0	106.2	108.9	109.2	109.1	115.1	117.0	116.1	116.7	118.0	117.4
T ₇	Hisar Lal	110.7	112.9	111.8	112.1	113.4	112.8	116.9	119.7	118.3	122.4	120.3	121.4
T ₈	EC-531804	132.6	133.5	133.1	136.4	132.6	134.5	124.7	124.5	124.6	128.8	125.1	127.0
T ₉	EC-119197	126.2	123.5	124.9	124.4	127.8	126.1	123.2	119.6	121.4	123.2	121.3	122.3
T ₁₀	Control (NG)*	116.0	119.2	117.1	140.5	142.6	141.6	118.0	123.0	120.5	147.2	150.3	148.8
	CD(P=0.05)	10.7	11.9	7.3	7.5	8.5	6.8	NS	NS	NS	11.2	11.4	7.0

(NG)*: Non-Grafted

Table 2: Effect of different rootstock's on Fruit width (cm) of Punjab Sartaj and Punjab Ratta in Nematode free and Nematode infested plots.

Sr no	Rootstocks	Fruit width (cm) Punjab Sartaj						Fruit width (cm) Punjab Ratta					
		Nematode free			Nematode Infested			Nematode free			Nematode Infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	5.6	5.8	5.7	5.3	5.8	5.5	5.7	5.6	5.6	5.4	5.6	5.5

T ₂	PNR-7	4.9	4.8	4.9	4.7	4.6	4.6	5.2	4.9	5.1	4.9	5.0	5.0
T ₃	NR-10	4.7	4.5	4.6	4.7	4.4	4.6	4.8	4.8	4.8	4.6	4.4	4.5
T ₄	L-0272	4.1	4.3	4.2	4.1	4.2	4.2	4.9	5.1	5.0	4.6	4.8	4.7
T ₅	L-0275	4.4	4.2	4.3	3.9	4.3	4.1	3.9	4.1	4.0	3.9	3.8	3.9
T ₆	L-097	4.2	4.1	4.1	4.1	3.9	4.0	4.2	4.1	4.1	3.9	3.8	3.8
T ₇	Hisar Lal	5.8	5.4	5.6	5.7	5.4	5.5	4.7	5.0	4.9	4.4	4.8	4.6
T ₈	EC-531804	5.8	6.1	5.9	5.4	5.7	5.6	6.0	5.9	6.0	5.7	5.8	5.7
T ₉	EC-119197	6.1	6.3	6.2	6.1	6.1	6.1	6.1	6.3	6.2	6.0	6.1	6.1
T ₁₀	Control (NG)*	5.3	5.3	5.3	4.2	4.5	4.5	5.0	5.3	5.1	4.4	4.7	4.6
	CD(P=0.05)	0.7	0.9	0.6	0.9	0.9	0.6	0.6	0.9	0.5	0.9	1.0	0.6

NG*: Non-Grafted

Table 3: Effect of different rootstock's on Fruit length (cm) of Punjab Sartaj and Punjab Ratta in Nematode free and Nematode infested plots

Sr . no	Rootstocks	Fruit length (cm) Punjab Sartaj						Fruit length (cm) Punjab Ratta					
		Nematode free			Nematode Infested			Nematode free			Nematode Infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	5.1	5.0	5.0	5.0	4.8	4.9	5.8	6.1	5.9	5.8	5.7	5.8
T ₂	PNR-7	5.3	5.6	5.5	5.1	5.4	5.3	5.4	5.5	6.0	5.9	5.7	5.8
T ₃	NR-10	4.4	4.6	4.7	4.2	4.4	4.3	5.8	5.8	5.8	5.7	5.9	5.7
T ₄	L-0272	3.8	4.1	3.9	3.8	3.8	3.8	5.4	5.3	5.3	5.3	5.2	5.3
T ₅	L-0275	3.8	4.1	4.0	3.9	3.8	3.8	4.9	5.1	5.0	4.8	4.9	4.9
T ₆	L-097	3.7	4.0	4.0	3.8	4.0	3.9	4.8	4.9	4.8	4.4	4.8	4.6
T ₇	Hisar Lal	5.7	5.9	5.8	5.6	5.7	5.6	5.8	6.0	5.9	5.7	5.9	5.7
T ₈	EC-531804	5.7	5.9	5.8	5.4	5.8	5.6	6.0	6.1	6.0	5.8	6.0	5.9
T ₉	EC-119197	6.2	6.5	6.3	6.2	6.4	6.3	6.5	6.2	6.3	6.1	6.3	6.2
T ₁₀	Control (NG)*	5.1	5.3	5.2	4.6	4.2	4.4	5.8	5.5	5.6	4.7	4.4	4.6
	CD(P=0.05)	0.6	0.7	0.5	0.9	0.9	0.5	0.8	0.9	0.5	1.0	0.9	0.6

(NG)*: Non-Grafted

Table 4: Effect of different rootstock's on Average fruit weight (g) of Punjab Sartaj and Punjab Ratta in Nematode free and Nematode infested plots

Sr. no	Rootstocks	Average fruit weight (g) Punjab Sartaj						Average fruit weight (g) Punjab Ratta					
		Nematode free			Nematode Infested			Nematode free			Nematode Infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	86.7	88.4	87.5	85.6	87.5	86.5	82.1	80.3	81.2	81.2	80.1	80.7
T ₂	PNR-7	83.3	84.5	83.4	82.3	83.2	82.1	78.5	77.3	77.9	75.3	77.5	76.9
T ₃	NR-10	66.3	67.3	66.7	66.5	65.1	65.8	73.2	72.2	72.7	72.1	71.2	71.7
T ₄	L-0272	67.9	66.5	67.2	65.2	66.3	65.8	70.4	69.3	69.9	69.3	68.5	68.9
T ₅	L-0275	66.1	65.3	65.7	63.2	64.3	63.8	70.3	68.5	69.4	66.3	65.0	65.7
T ₆	L-097	67.3	68.5	67.4	66.4	67.3	66.4	67.2	66.5	67.1	64.2	63.4	63.0
T ₇	Hisar Lal	82.2	83.8	82.8	82.2	82.3	81.9	80.1	81.9	81.0	79.7	80.1	79.9
T ₈	EC-531804	88.3	88.2	88.4	85.4	88.7	87.5	85.5	87.0	86.3	84.5	82.2	82.9
T ₉	EC-119197	96.6	97.9	97.2	94.1	96.3	95.2	88.2	88.0	88.1	87.3	87.5	87.4
T ₁₀	Control (NG)*	83.6	84.3	82.9	34.6	33.7	34.1	76.5	75.3	75.9	35.2	33.3	34.3
	CD(P=0.05)	7.1	8.4	5.8	8.1	9.5	6.3	10.0	10.3	7.2	8.9	9.1	5.5

(NG)*: Non-Grafted

Table 5: Effect of different rootstock's on Number of fruits on Punjab Sartaj and Punjab Ratta in Nematode free and Nematode infested plots

Sr. no	Rootstocks	Number of fruits Punjab Sartaj						Number of fruits Punjab Ratta					
		Nematode free			Nematode Infested			Nematode free			Nematode Infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	59.3	57.9	58.6	58.5	56.2	57.4	31.2	32.2	31.7	30.2	31.9	31.1
T ₂	PNR-7	60.1	59.2	59.7	61.5	60.1	60.8	34.3	33.3	33.8	32.2	33.1	32.7
T ₃	NR-10	68.2	65.2	66.7	65.3	63.2	64.8	38.5	37.2	37.9	36.8	37.3	37.1
T ₄	L-0272	71.1	72.0	71.6	71.2	69.5	70.4	38.5	39.4	39.0	38.0	39.0	38.5
T ₅	L-0275	73.2	72.2	72.7	70.3	71.3	70.8	41.2	40.2	40.7	39.3	37.4	38.4
T ₆	L-097	72.3	73.2	72.8	72.2	71.3	71.8	43.2	44.2	43.7	42.3	44.2	43.3

T ₇	Hisar Lal	63.1	64.5	63.8	62.2	60.5	61.4	33.3	31.2	32.3	32.4	31.2	31.8
T ₈	EC-531804	59.3	60.1	59.7	59.3	58.7	59.0	34.2	35.4	34.8	33.2	34.3	33.8
T ₉	EC-119197	61.2	60.5	60.9	58.5	59.6	59.1	31.2	32.2	31.7	31.3	32.2	31.8
T ₁₀	Control (NG)*	61.5	60.2	60.9	24.2	25.5	24.9	35.3	37.3	36.3	12.0	12.1	11.8
	CD(P=0.05)	8.8	9.1	6.6	9.5	10.6	7.2	NS	NS	NS	8.6	9.3	6.1

(NG)*: Non-Grafted

Table 6: Effect of different rootstock's on Total yield (q/ha) of Punjab Sartaj and Punjab Ratta in Nematode free and Nematode infested plots.

Sr. no	Rootstocks	Total yield (q/ha) Punjab Sartaj						Total yield (q/ha) Punjab Ratta					
		Nematode free			Nematode Infested			Nematode free			Nematode Infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	1,999	2,035	2,017	1,976	1,970	1,973	530	547	539	515	531	523
T ₂	PNR-7	2,019	2,045	2,032	1,987	1,977	1,982	546	556	551	524	537	531
T ₃	NR-10	1,797	1,753	1,775	1,797	1,736	1,767	548	541	545	538	534	536
T ₄	L-0272	1,850	1,894	1,872	1,817	1,804	1,811	538	555	547	531	513	522
T ₅	L-0275	1,784	1,812	1,798	1,884	1,806	1,845	535	533	534	504	533	519
T ₆	L-097	1,954	1,953	1,954	1,886	1,982	1,934	525	535	530	499	467	483
T ₇	Hisar Lal	1,995	1,975	1,985	1,988	1,969	1,978	540	535	538	534	508	521
T ₈	EC-531804	2,070	2,023	2,047	2,020	2,041	2,031	623	615	619	600	602	601
T ₉	EC-119197	2,167	2,151	2,159	2,079	2,149	2,114	640	644	642	636	628	632
T ₁₀	Control (NG)*	2,008	2,022	2,015	343	292	318	546	567	557	62	70	66
	CD(P=0.05)	39	53	33	57	46	48	48	44	40	52	42	36

(NG)*: Non-Grafted

Table 7: Effect of different rootstock's on Marketable yield (q/ha) of Punjab Sartaj and Punjab Ratta in Nematode free and Nematode infested plots

Sr. no	Rootstocks	Marketable yield (q/ha) Punjab Sartaj						Marketable yield (q/ha) Punjab Ratta					
		Nematode free			Nematode Infested			Nematode free			Nematode Infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled

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T ₁	NR-5	1710	1690	1702	1702	1652	1677	510	505	508	478	445	462
T ₂	PNR-7	1748	1741	1744	1635	1710	1672	513	517	515	475	476	476
T ₃	NR-10	1557	1540	1548	1499	1487	1496	500	501	500	498	452	475
T ₄	L-0272	1599	1562	1581	1552	1538	1545	478	474	476	447	471	459
T ₅	L-0275	1594	1535	1565	1540	1510	1525	513	515	514	490	477	484
T ₆	L-097	1589	1562	1576	1505	1499	1502	480	475	477	444	465	455
T ₇	Hisar Lal	1677	1671	1674	1628	1635	1632	503	510	507	450	458	454
T ₈	EC-531804	1792	1749	1771	1689	1712	1701	574	575	575	549	563	556
T ₉	EC-119197	1911	1853	1882	1783	1806	1805	608	603	606	600	578	589
T ₁₀	Control (NG)*	1642	1682	1662	216	284	250	505	498	502	48	51	49
	CD(P=0.05)	48	57	37	59	51	33	52	56	40	59	61	36

(NG)*: Non-Grafted

Table 1: Effect of different rootstock's on days to picking of Punjab Sartaj and Punjab Ratta in Nematode free and Nematode infested plots.

Sr no	Rootstocks	Days to Picking Punjab Sartaj						Days to Picking Punjab Ratta					
		Nematode free			Nematode Infested			Nematode free			Nematode Infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	112.2	114.6	113.4	115.7	116.8	116.2	120.6	121.7	121.2	123.6	122.5	123.1
T ₂	PNR-7	105.1	106.3	105.7	106.8	108.2	107.5	122.2	119.3	120.8	122.3	119.5	120.9
T ₃	NR-10	113.6	112.0	112.8	114.4	113.4	113.8	120.2	122.5	121.4	125.7	121.0	123.4
T ₄	L-0272	114.1	113.0	113.3	112.9	115.0	114.9	116.2	117.7	117.0	119.3	117.4	118.4
T ₅	L-0275	106.3	111.0	108.7	109.7	111.3	110.5	117.9	119.4	118.7	119.3	118.5	118.9
T ₆	L-097	105.3	107.0	106.2	108.9	109.2	109.1	115.1	117.0	116.1	116.7	118.0	117.4
T ₇	Hisar Lal	110.7	112.9	111.8	112.1	113.4	112.8	116.9	119.7	118.3	122.4	120.3	121.4
T ₈	EC-531804	132.6	133.5	133.1	136.4	132.6	134.5	124.7	124.5	124.6	128.8	125.1	127.0
T ₉	EC-119197	126.2	123.5	124.9	124.4	127.8	126.1	123.2	119.6	121.4	123.2	121.3	122.3
T ₁₀	Control (NG)*	116.0	119.2	117.1	140.5	142.6	141.6	118.0	123.0	120.5	147.2	150.3	148.8
	CD(P=0.05)	10.7	11.9	7.3	7.5	8.5	6.8	NS	NS	NS	11.2	11.4	7.0

(NG)*: Non-Grafted

Table 2: Effect of different rootstock's on Fruit width (cm) of Punjab Sartaj and Punjab Ratta in Nematode free and Nematode infested plots.

Sr no	Rootstocks	Fruit width (cm) Punjab Sartaj						Fruit width (cm) Punjab Ratta					
		Nematode free			Nematode Infested			Nematode free			Nematode Infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	5.6	5.8	5.7	5.3	5.8	5.5	5.7	5.6	5.6	5.4	5.6	5.5
T ₂	PNR-7	4.9	4.8	4.9	4.7	4.6	4.6	5.2	4.9	5.1	4.9	5.0	5.0
T ₃	NR-10	4.7	4.5	4.6	4.7	4.4	4.6	4.8	4.8	4.8	4.6	4.4	4.5
T ₄	L-0272	4.1	4.3	4.2	4.1	4.2	4.2	4.9	5.1	5.0	4.6	4.8	4.7
T ₅	L-0275	4.4	4.2	4.3	3.9	4.3	4.1	3.9	4.1	4.0	3.9	3.8	3.9
T ₆	L-097	4.2	4.1	4.1	4.1	3.9	4.0	4.2	4.1	4.1	3.9	3.8	3.8

T ₇	Hisar Lal	5.8	5.4	5.6	5.7	5.4	5.5	4.7	5.0	4.9	4.4	4.8	4.6
T ₈	EC-531804	5.8	6.1	5.9	5.4	5.7	5.6	6.0	5.9	6.0	5.7	5.8	5.7
T ₉	EC-119197	6.1	6.3	6.2	6.1	6.1	6.1	6.1	6.3	6.2	6.0	6.1	6.1
T ₁₀	Control (NG)*	5.3	5.3	5.3	4.2	4.5	4.5	5.0	5.3	5.1	4.4	4.7	4.6
	CD(P=0.05)	0.7	0.9	0.6	0.9	0.9	0.6	0.6	0.9	0.5	0.9	1.0	0.6

NG*: Non-Grafted

Table 3: Effect of different rootstock's on Fruit length (cm) of Punjab Sartaj and Punjab Ratta in Nematode free and Nematode infested plots

Sr . no	Rootstocks	Fruit length (cm) Punjab Sartaj						Fruit length (cm) Punjab Ratta					
		Nematode free			Nematode Infested			Nematode free			Nematode Infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	5.1	5.0	5.0	5.0	4.8	4.9	5.8	6.1	5.9	5.8	5.7	5.8
T ₂	PNR-7	5.3	5.6	5.5	5.1	5.4	5.3	5.4	5.5	6.0	5.9	5.7	5.8
T ₃	NR-10	4.4	4.6	4.7	4.2	4.4	4.3	5.8	5.8	5.8	5.7	5.9	5.7
T ₄	L-0272	3.8	4.1	3.9	3.8	3.8	3.8	5.4	5.3	5.3	5.3	5.2	5.3
T ₅	L-0275	3.8	4.1	4.0	3.9	3.8	3.8	4.9	5.1	5.0	4.8	4.9	4.9
T ₆	L-097	3.7	4.0	4.0	3.8	4.0	3.9	4.8	4.9	4.8	4.4	4.8	4.6
T ₇	Hisar Lal	5.7	5.9	5.8	5.6	5.7	5.6	5.8	6.0	5.9	5.7	5.9	5.7
T ₈	EC-531804	5.7	5.9	5.8	5.4	5.8	5.6	6.0	6.1	6.0	5.8	6.0	5.9
T ₉	EC-119197	6.2	6.5	6.3	6.2	6.4	6.3	6.5	6.2	6.3	6.1	6.3	6.2
T ₁₀	Control (NG)*	5.1	5.3	5.2	4.6	4.2	4.4	5.8	5.5	5.6	4.7	4.4	4.6
	CD(P=0.05)	0.6	0.7	0.5	0.9	0.9	0.5	0.8	0.9	0.5	1.0	0.9	0.6

(NG)*: Non-Grafted

Table 4: Effect of different rootstock's on Average fruit weight (g) of Punjab Sartaj and Punjab Ratta in Nematode free and Nematode infested plots

Sr . no	Rootstocks	Average fruit weight (g) Punjab Sartaj						Average fruit weight (g) Punjab Ratta					
		Nematode free			Nematode Infested			Nematode free			Nematode Infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled

T ₁	NR-5	86.7	88.4	87.5	85.6	87.5	86.5	82.1	80.3	81.2	81.2	80.1	80.7
T ₂	PNR-7	83.3	84.5	83.4	82.3	83.2	82.1	78.5	77.3	77.9	75.3	77.5	76.9
T ₃	NR-10	66.3	67.3	66.7	66.5	65.1	65.8	73.2	72.2	72.7	72.1	71.2	71.7
T ₄	L-0272	67.9	66.5	67.2	65.2	66.3	65.8	70.4	69.3	69.9	69.3	68.5	68.9
T ₅	L-0275	66.1	65.3	65.7	63.2	64.3	63.8	70.3	68.5	69.4	66.3	65.0	65.7
T ₆	L-097	67.3	68.5	67.4	66.4	67.3	66.4	67.2	66.5	67.1	64.2	63.4	63.0
T ₇	Hisar Lal	82.2	83.8	82.8	82.2	82.3	81.9	80.1	81.9	81.0	79.7	80.1	79.9
T ₈	EC-531804	88.3	88.2	88.4	85.4	88.7	87.5	85.5	87.0	86.3	84.5	82.2	82.9
T ₉	EC-119197	96.6	97.9	97.2	94.1	96.3	95.2	88.2	88.0	88.1	87.3	87.5	87.4
T ₁₀	Control (NG)*	83.6	84.3	82.9	34.6	33.7	34.1	76.5	75.3	75.9	35.2	33.3	34.3
	CD(P=0.05)	7.1	8.4	5.8	8.1	9.5	6.3	10.0	10.3	7.2	8.9	9.1	5.5

(NG)*: Non-Grafted

Table 5: Effect of different rootstock's on Number of fruits on Punjab Sartaj and Punjab Ratta in Nematode free and Nematode infested plots

Sr. no	Rootstocks	Number of fruits Punjab Sartaj						Number of fruits Punjab Ratta					
		Nematode free			Nematode Infested			Nematode free			Nematode Infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	59.3	57.9	58.6	58.5	56.2	57.4	31.2	32.2	31.7	30.2	31.9	31.1
T ₂	PNR-7	60.1	59.2	59.7	61.5	60.1	60.8	34.3	33.3	33.8	32.2	33.1	32.7
T ₃	NR-10	68.2	65.2	66.7	65.3	63.2	64.8	38.5	37.2	37.9	36.8	37.3	37.1
T ₄	L-0272	71.1	72.0	71.6	71.2	69.5	70.4	38.5	39.4	39.0	38.0	39.0	38.5
T ₅	L-0275	73.2	72.2	72.7	70.3	71.3	70.8	41.2	40.2	40.7	39.3	37.4	38.4
T ₆	L-097	72.3	73.2	72.8	72.2	71.3	71.8	43.2	44.2	43.7	42.3	44.2	43.3
T ₇	Hisar Lal	63.1	64.5	63.8	62.2	60.5	61.4	33.3	31.2	32.3	32.4	31.2	31.8
T ₈	EC-531804	59.3	60.1	59.7	59.3	58.7	59.0	34.2	35.4	34.8	33.2	34.3	33.8
T ₉	EC-119197	61.2	60.5	60.9	58.5	59.6	59.1	31.2	32.2	31.7	31.3	32.2	31.8
T ₁₀	Control (NG)*	61.5	60.2	60.9	24.2	25.5	24.9	35.3	37.3	36.3	12.0	12.1	11.8

	CD(P=0.05)	8.8	9.1	6.6	9.5	10.6	7.2	NS	NS	NS	8.6	9.3	6.1
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(NG)*: Non-Grafted

Table 6: Effect of different rootstock's on Total yield (q/ha) of Punjab Sartaj and Punjab Ratta in Nematode free and Nematode infested plots.

Sr. no	Rootstocks	Total yield (q/ha) Punjab Sartaj						Total yield (q/ha) Punjab Ratta					
		Nematode free			Nematode Infested			Nematode free			Nematode Infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	1,999	2,035	2,017	1,976	1,970	1,973	530	547	539	515	531	523
T ₂	PNR-7	2,019	2,045	2,032	1,987	1,977	1,982	546	556	551	524	537	531
T ₃	NR-10	1,797	1,753	1,775	1,797	1,736	1,767	548	541	545	538	534	536
T ₄	L-0272	1,850	1,894	1,872	1,817	1,804	1,811	538	555	547	531	513	522
T ₅	L-0275	1,784	1,812	1,798	1,884	1,806	1,845	535	533	534	504	533	519
T ₆	L-097	1,954	1,953	1,954	1,886	1,982	1,934	525	535	530	499	467	483
T ₇	Hisar Lal	1,995	1,975	1,985	1,988	1,969	1,978	540	535	538	534	508	521
T ₈	EC-531804	2,070	2,023	2,047	2,020	2,041	2,031	623	615	619	600	602	601
T ₉	EC-119197	2,167	2,151	2,159	2,079	2,149	2,114	640	644	642	636	628	632
T ₁₀	Control (NG)*	2,008	2,022	2,015	343	292	318	546	567	557	62	70	66
	CD(P=0.05)	39	53	33	57	46	48	48	44	40	52	42	36

(NG)*: Non-Grafted

Table 7: Effect of different rootstock's on Marketable yield (q/ha) of Punjab Sartaj and Punjab Ratta in Nematode free and Nematode infested plots

Sr. no	Rootstocks	Marketable yield (q/ha) Punjab Sartaj						Marketable yield (q/ha) Punjab Ratta					
		Nematode free			Nematode Infested			Nematode free			Nematode Infested		
		2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
T ₁	NR-5	1710	1690	1702	1702	1652	1677	510	505	508	478	445	462
T ₂	PNR-7	1748	1741	1744	1635	1710	1672	513	517	515	475	476	476
T ₃	NR-10	1557	1540	1548	1499	1487	1496	500	501	500	498	452	475
T ₄	L-0272	1599	1562	1581	1552	1538	1545	478	474	476	447	471	459

T ₅	L-0275	1594	1535	1565	1540	1510	1525	513	515	514	490	477	484
T ₆	L-097	1589	1562	1576	1505	1499	1502	480	475	477	444	465	455
T ₇	Hisar Lal	1677	1671	1674	1628	1635	1632	503	510	507	450	458	454
T ₈	EC-531804	1792	1749	1771	1689	1712	1701	574	575	575	549	563	556
T ₉	EC-119197	1911	1853	1882	1783	1806	1805	608	603	606	600	578	589
T ₁₀	Control (NG)*	1642	1682	1662	216	284	250	505	498	502	48	51	49
	CD(P=0.05)	48	57	37	59	51	33	52	56	40	59	61	36

(NG)*: Non-G

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