

**GRAFT COMPATIBILITY STUDIES FOR RESISTANCE TO
ROOT-KNOT NEMATODE IN TOMATO (*Solanum lycopersicum* L.)**

by

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(J-18-D-357-A)

**Thesis submitted to
Faculty of Agriculture
in partial fulfillment of the requirements
for the degree of**

DOCTOR OF PHILOSOPHY

IN

HORTICULTURE (VEGETABLE SCIENCE)



Division of Vegetable Science

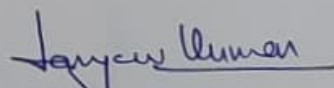
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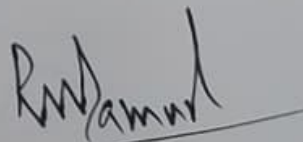
The work has been carried out by **Mr. Sachin S. Chikkeri**, under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma. It is further certified that help and assistance received during the course of thesis investigation have been duly acknowledged.




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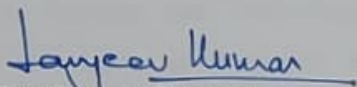
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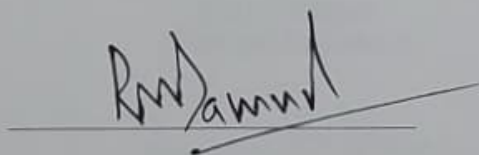
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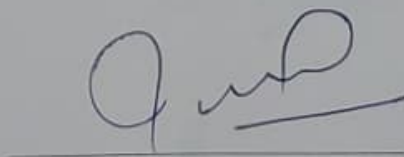
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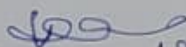
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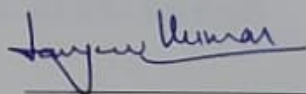
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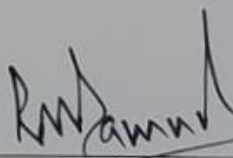

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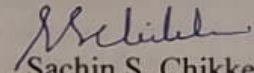
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At the end its needless to say, all omissions and errors are mine.


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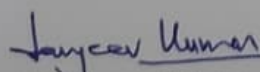
ABSTRACT

Title of thesis	:	Graft Compatibility Studies for Resistance to Root-Knot Nematode in Tomato (<i>Solanum lycopersicum</i> L.)
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The present investigation entitled "**Graft Compatibility Studies for Resistance to Root-Knot Nematode in Tomato (*Solanum lycopersicum* L.)**" was carried out in four experiments conducted under field and laboratory conditions. The study on screening of wild and cultivated *Solanum* genotypes against root-knot nematode was accomplished in collaboration with AICRP Nematodes, SKUAST-Jammu, Chatha in three phases, namely, field survey, laboratory and screen house. Out of eleven wild and cultivated species of *Solanum* screened, wild *Solanum* species namely *Solanum torvum* was found highly resistant to *Meloidogyne incognita* while *Solanum xanthocarpum*, *S. indicum* and *S. khasianum* were found resistant. Punjab Raunak and SJCT-01 showed moderately resistant reaction. The six genotypes (highly resistant, resistant and moderately resistant) were used for graft compatibility studies as rootstocks. Eight genotype (varieties/hybrids) were evaluated for horticultural traits at the Experimental Research Farm-I of Division of Vegetable Science, SKUAST-Jammu, Chatha. On the basis of mean performance, Arka Samrat and Arka Rakshak recorded the highest yield, maximum number of flower cluster per plant, flower per cluster and fruits per cluster as well as number of primary branches per plant and were selected as scions for the graft compatibility studies.

The graft compatibility study was conducted in polyhouse of Experimental Research Farm-II, Division of Vegetable Science, Chatha with two tomato scions viz., Arka Samrat and Arka Rakshak grafted onto six different rootstocks. Graft compatibility studies revealed that highest percentage of grafting success (100%) was recorded in graft combination Arka Samrat on SJCT 01, Arka Samrat on Punjab Raunak and Arka Rakshak on Punjab Raunak with 3.33, 4.00 and 4.33 days taken for healing of graft union respectively. Comparative performance of 12 different graft combinations along with non-grafted checks was evaluated at Experimental Research Farm-I of Division of Vegetable Science. The rootstocks viz., SJCT 01, Punjab Raunak and *Solanum torvum* have significantly influenced plant height for both the scions. The graft combination, Arka Rakshak on SJCT 01 recorded highest yield per plant (3.37 kg), earliest flowering (36.83 days) among graft combinations and maximum number of fruits per cluster (5.56). Arka Samrat grafted on SJCT 01 resulted in highest plant height (143.51 cm) and maximum number of primary branches per plant (9.47). The highest average fruit weight (149.40 g) and equatorial diameter (6.18 cm) was recorded in Arka Samrat on *Solanum torvum* Swartz. The graft combination Arka Samrat on Punjab Raunak Swartz observed maximum number of fruits per plant (46.67). When recorded for the trait yield per plant Arka Samrat on Punjab Raunak (2.22 kg), Arka Samrat on SJCT 01 (1.51 kg), Arka Samrat on *Solanum torvum* Swartz (1.46 kg) and Arka Rakshak on Punjab Raunak (1.33 kg) performed statistically superior to both the checks. Suitable rootstocks identified for tomato were SJCT 01, *Solanum torvum* Swartz and Punjab Raunak. These results showed that grafting could be an advantageous alternative in tomato production under root-knot nematode infected soils and could lay a solid foundation for further research.

Key words: Root-knot nematode, Graft compatibility, Scions and Rootstocks.


Signature of Major Advisor


Signature of the Student

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LIST OF ABBREVIATIONS

var.	:	Variety
cv.	:	Cultivar
mg	:	Milligram(s)
g	:	Gram
%	:	Per cent
<i>et al</i>	:	Et alia (and others)
RKN	:	Root-knot nematode
spp.	:	Species
J2	:	Second-stage juveniles
<i>M.</i>	:	<i>Meloidogyne</i>
<i>S.</i>	:	<i>Solanum</i>
kg	:	Kilogram
cc or cm ³	:	Cubic centimeters
<i>i.e</i>	:	That is
<i>viz.</i>	:	Namely
DAT	:	Days after transplanting
°C	:	Degree celsius
F ₁	:	First filial
m ²	:	Square meter
t	:	Tonne (metric ton)
ha	:	Hectare
cm	:	Centimeter
mm	:	Millimeter
°B	:	Degree brix
h	:	Hour
ml	:	Milliliter
min	:	Minutes
nm	:	Nanometer
@	:	At the rate of
No.	:	Number
CD	:	Critical difference
SE (m)	:	Standard Error of Mean
CV	:	Coefficient of variation

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) with chromosome number $2n=24$ belongs to the family Solanaceae is one of the most important and popular vegetable crops in the world. Tomato has its origin in Peru, Ecuador, Bolivian region of South America and its domestication took place in Mexico. Further, it spread all over the world, in the cold, temperate and warm regions. The most likely ancestor of tomato is the wild cherry tomato, *Solanum lycopersicum* var. *cerasiformae*. Tomato is grown in both open-field and protected conditions, in soil or soil less growing media. Tomato is one of the most versatile vegetables with wide usage in Indian culinary tradition. The demand for tomato comes from the fact that it can either be consumed fresh (salad), cooked or processed (pickles, ketchup, puree, sauces, pastes and powder), which is characterized by its high nutritional value as it contains carbohydrates, vitamins, minerals and organic acids of great nutritional importance (Draie, 2017). Tomato has been universally treated as protective food (Thamburaj and Singh, 2013). It is a reservoir of diverse antioxidants like ascorbic acid (31 mg/ 100 g), vitamin C, carotenoids, flavonoids and phenolic acids. The red ripe fruit of tomato contains 2.5% total sugar content, 350 mg/100 g total amino acid and 20-50 mg/100 g of lycopene.

India is the second largest producer of tomato after China. In India it is grown in an area over 0.845 million ha with production of 21.18 million tonnes and productivity of 25.10 tonnes/hectares. The leading tomato producing states in the country are Andhra Pradesh, Madhya Pradesh and Karnataka. In the Union Territory of Jammu and Kashmir, the area under tomato cultivation is 3.29 thousand hectares with an annual production of 79.95 thousand metric tonnes and productivity of 24.34 tonnes/hectares (MoAFW, 2022).

During the tomato growing season, a variety of disorders, insects, pests and diseases can produce difficulties that can harm the crop and lower quality and productivity. Continuous cropping creates a build-up of pathogens (bacteria, fungus and viruses), pests and nematodes in both open fields and protected structures, making crops more susceptible to various illnesses. The extensive applications of chemical to

crops and soil to prevent the spread of diseases, pests and nematodes had a long-term negative impact on human health and environment. So, grafting tomato plants using nematode-resistant rootstock can be a different approach to reduce the overuse of insecticides.

Tomato is commonly affected by several fungi, bacteria, nematodes, and viruses. However, their management is challenging due to the limited number of reliable options (Louws *et al.*, 2001). Soil borne infections have been a bigger threat in tomato cultivation in recent years. Tomato cultivation suffers from soilborne disease like Verticillium wilt (*Verticillium dahliae*), Fusarium wilt (*Fusarium oxysporum* f.sp. *lycopersici*), Collar rot (*Rhizoctonia solani* Kühn) and root-knot nematode (*Meloidogyne* spp.). Pathogens are difficult to control (Colla *et al.*, 2012) and have a wide host range (Inderbitzin, 2013).

Nematodes are a significant stumbling block in achieving global food security. Plant-parasitic nematodes are estimated to inflict \$80 billion in annual damage (Nicol *et al.*, 2011). *Meloidogyne* spp., often known as root-knot nematode (RKN), is the most widely distributed and yield-limiting plant-parasitic nematode in tomato production. RKNs interact with other plant diseases, causing greater damage to world food supplies in addition to direct losses (Sasser, 1980). RKNs cause losses ranging from 25-100 % in yield in tomatoes (Seid *et al.*, 2015). The root system of the affected plants is stunted leading to a poorly growing crop, and such plants are often prone to soil-borne fungal and bacterial diseases. Infected plant material, agricultural implements, rainwater and irrigation water, high winds (which carry diseased soil particles) and contaminated dirt carried on footwear or the feet of animals all contribute to their infestation and transmission. In soil, nematodes can endure as long as the conditions are moist. *Meloidogyne hapla* and *Meloidogyne incognita*, according to Barker *et al.* (1976), can lower tomato yields by 50 % and 85 %, respectively. Although there are many ways to counter the problems due to the biotic and abiotic stresses which include use of chemicals, resistance breeding, wide hybridization and biotechnological approaches etc.

Although there are over 34 species of RKN in tomato, four species are particularly important for tomato production: *Meloidogyne incognita* (SRKN), *Meloidogyne hapla* (peanut root knot nematode; NRKN), *Meloidogyne javanica* (javanese root-knot nematode), *Meloidogyne arenaria* (peanut root knot

nematode) (Noling, 2014). RKN have a wide host range, and therefore limits grower's crop rotation options. According to reports, RKN-infected vegetable yields are reduced by 10 % on average (Collange *et al.*, 2011). Yield losses, on the other hand, might be substantially higher depending on the species, race, population density, crop susceptibility and environmental conditions.

Because of their extensive host range, root knot nematodes are challenging to manage. To suppress root knot nematodes, soil fumigants, contact-systemic nematodes and resistant cultivars are often used. Soil fumigants like methyl bromide were particularly efficient against nematodes, but they were banned in India due to environmental concerns. As a result, there is a pressing need to establish an alternative strategy for dealing with these issues in the field. Of late grafting on suitable rootstocks has proven to enhance resistance to soil borne diseases and root knot nematode resistance (Bersi, 2002; Augustin *et al.*, 2002).

Grafting has become an essential method for growing crops and vegetables. Vegetable grafting has become more common around the world in the case of cucurbits, tomato, eggplant and pepper, with robust and disease-resistant rootstocks being used to provide appropriate yields. Commercial tomato grafting began in the early 1960s and has since evolved into a significant tomato crop farming practice in many regions of the world. The scion is grafted onto the rootstock using a number of different approaches; however, the best approach to use depends on the size, growth stage and compatibility of the two plants involved. The grafted plant's scion is the portion that will give rise to the plant's shoots. All of the plant's leaves, stalks, flowers, and fruits will eventually develop from it. The majority of commercial hybrids and cultivars that are susceptible to some biotic and abiotic elements of environment are usually grafted over specific rootstocks with the potential to withstand adversity. Scions are selected based on yield-related features. Vegetable rootstocks with good compatibility, tolerance to temperature stress, water stress, soil borne pathogens (*Fusarium* spp., *Verticillium* spp.) and nematodes are suitable for grafting. They must encourage scion growth, boost production, while maintaining quality. In tomato, the use of appropriate rootstocks has helped to withstand biotic and abiotic stresses while also increasing production, especially under protected structures (Kumar *et al.*, 2017).

Nematode resistant genotypes or rootstocks have the inherent potential to remain unaffected by nematode attack, which will help to reduce nematode infestations in tomato crops (Corbet *et al.*, 2011). Grafting with resistant rootstocks has been shown to effectively manage Root Knot Nematodes (RKNs) and increase yield in tomato and eggplant grown in naturally infested nematode soils. However, sources of resistance in the available *Solanum* rootstocks for managing the RKN problem in tomato fields must be identified.

Keeping in view, the importance of the disease, socio-economic status of the crop, the losses inflicted to the farming community in terms of volume and value, the present studies were planned with the following objectives:

1. To screen *Solanum* rootstocks for resistance to root-knot nematode.
2. To identify tomato scion varieties/hybrids for horticultural traits and nematode incidence under field conditions.
3. To standardise scion/rootstock compatibility in promising genotypes.
4. To study the performance of successful grafts.

REVIEW OF LITERATURE

The Solanaceae family includes the tomato (*Solanum lycopersicum*). It's a South and Central American native. Tomato accounts for 7% of global vegetable production, is third behind potato and sweet potato (29 and 14 %, respectively). To meet the demand of consumers who are becoming more and more concerned with quality and health, there is a need to boost global productivity and produce quality. The majority of studies on tomatoes conducted in recent years have concentrated on improving production and quality as well as reducing the impact of stress factors.

The review of literature pertaining to the present study entitled “Graft Compatibility Studies for Resistance to Root-Knot Nematode in Tomato (*Solanum lycopersicum* L.)” has been presented and discussed as under:

2.1 Root-knot nematode (*Meloidogyne* spp.)

2.2 Graft compatibility studies.

2.3 Effect of grafting on horticultural traits.

2.1 Root-knot nematode (*Meloidogyne* spp.)

2.1.1 Epidemiology

Berkley first discovered the root-knot nematode on cucumber in UK greenhouses in 1855. Root-Knot Nematode is found all throughout the world and hundreds of plant species are hosts to this pathogen and have a significant impact on global food production. They are more common in the world's warmer and moderately warmer climates, where summer lasts longer than winter. Root-knot nematodes that parasitize plants have a wide host range and distribution (Singh *et al.*, 2012). *Meloidogyne* spp. has a host range of roughly 3000 plant species (Abad *et al.*, 2003).

2.1.2 Biology

Females of Root-knot nematode deposit eggs on plant material or in the soil. Temperature determines egg hatching without the need for plant root stimulation, whereas hatching can stimulate root diffuses (Karssen and Moens, 2006). J2's hatch

as a vermiform second stage from the eggs of the root-knot nematode, which has four larval stages. The first moult of nematodes occurs inside the egg (Rahman, 2003). In the soil, newly hatched juveniles spend a brief free-living stage before entering the rhizosphere of the host plant. The juveniles feed on the plant cells after entering through the root tips. The neighbouring root tissue expands to form a gall in which the developing juvenile is ensconced. Following additional feeding, the juvenile goes through morphological changes and moults three times before maturing into an adult. Root-knot nematodes have a 4-8 week life cycle, depending on temperature and an adult female can produce up to 2000 eggs (Noling, 2012).

2.1.3 Host range

Meloidogyne spp. has wide hosts range and growers who are dealing with a root-knot nematode infestation in their fields have found it challenging to control the parasite by crop rotation (Djian-Caporalino, C., 2012). *Meloidogyne* is a genus with around 80 species worldwide. *M. incognita* (Kofoid and White) Chitwood, *M. javanica* (Treub) Chitwood and *M. arenaria* (Neal) Chitwood are three highly polyphagous apomictic species (Karajeh, 2015). Species like *M. incognita*, *M. javanica* and *M. arenaria* race 1 can infect or survive on alternate hosts in the same or different fields. On the specific crop, there is also a high degree of specialisation of distinct pathogenicity variations (Kokalis-Burelle and Rosskopf, 2012).

2.1.4 Symptomology

Root-knot nematodes are sedentary, polyphagous and semi-endoparasites (Moens *et al.*, 2009). It parasitizes all higher plants as well as a wide range of products, including over 2,000 plant species (Moens *et al.*, 2009). They puncture plants, roam between cells and form galls on roots. *Meloidogyne* spp. has multiple generations and the plants are prevented from absorbing water and nutrients. They spread disease to numerous portions of plants, including taproots and tubers, reducing the economic and qualitative value of vegetable crops (Bird *et al.*, 2003). Above-ground signs of root-knot nematodes include yellowing of plant leaves and stunted growth (Moens *et al.*, 2009). Wilting is caused by an obstruction in the xylem vessels. Root-knot nematodes expose root tissue to other diseases, such as bacteria and fungi, resulting in considerable losses (Agrios, 2005). Nematodes have caused severe yield

losses in warmer to moderately warmer regions of the planet parallel to a less warm zone.

2.1.5 Economic Impact

Many pests and illnesses are wreaking havoc on tomato production, both in terms of quality and quantity. One of them is plant parasitic nematodes. They are a significant impediment to achieving global food security. Plant-parasitic nematodes are estimated to inflict \$ 80 billion in annual damage (Nicol *et al.*, 2011). *Meloidogyne* spp. damage is one of the biggest barriers to the development of appropriate food supplies in many impoverished countries (Sasser, 1980). It is generally observed that four major species, *i.e.*, *Meloidogyne incognita*, *M. javanica*, *M. hapla* and *M. arenaria*, as well as a few emerging species such as *M. chitwoodi* and *M. enterolobii*, cause the vast majority of crop damage (Moens *et al.*, 2009).

Tomato roots can be severely damaged by root-knot nematodes. Tropical root-knot nematodes have more prevalent symptoms than temperate root-knot nematodes. Tomato cultivars are susceptible to distinct *Meloidogyne* species to varying degrees. So far, damage and yield loss investigations have revealed a significant variance in susceptibility among tomato varieties. Furthermore, various populations of the same *Meloidogyne* species have varying degrees of pathogenicity on a particular tomato cultivar. A tomato cultivar that is completely sensitive to one population of the same species may be relatively resistant to another. Several studies have been conducted around the world to assess the damage potential of several *Meloidogyne* spp. on various tomato cultivars in pots, microplots and field experiments.

Duncan and Noling (1998) created the methodology for calculating crop losses and damage functions. In the tropics, Sasser (1979) estimated yearly crop losses of 29%. RKN caused 50-60 % losses in tomato and eggplant (Lamberti, 1979). *M. incognita* caused a 46.2 per cent loss in tomato (Bhatti and Jain, 1977). Average crop output losses in places where RKN are not controlled are estimated to be in the neighbourhood of 25%, with damage in particular fields ranging as high as 60% (Sasser, 1982). For every solanaceous crop, Koenning *et al.* (1999) predicted yield losses of 4-8 per cent on average. Nematodes are responsible for 70-90 per cent yield losses in tomato and brinjal (Alam and Jairajpuri, 1990). Tomato crop losses up to 95

per cent have been documented in warmer, drier places with sandier soils (Bourne *et al.*, 2004).

2.1.6 Survey and distribution of root-knot nematode

Esfahani (2009) performed a survey in 8 areas in and around Aligarh (India) to investigate the prevalence of root-knot nematodes on tomato. The results revealed that the tomato crops in all 8 localities were infested. The tomato-infecting species *Meloidogyne incognita* and *M. javanica* were discovered in the sampling sites. Either solitary or mixed populations of the species were identified. *M. javanica* was the more prevalent of the two.

Kiewnick *et al.* (2008) noted significant stunting and extensive root galling on tomato rootstock Maxifort resistant to *Meloidogyne incognita*, *M. javanica* and *M. arenaria*, as well as on the cucumber cultivar Loustik in two commercial greenhouses in northern Switzerland. Numerous root-knot nematodes were found when the roots of affected plants were examined. *M. enterolobii* was the species that infected plants and it was the first time that *M. enterolobii* had been reported in Switzerland.

Uysal *et al.* (2017) examined 160 samples taken in vegetable-growing regions of Turkey's Lakes Region to determine the distribution and characterization of root-knot nematode species (*Meloidogyne* spp.). 83 out of 160 samples tested (51.8%) were found to have root-knot nematodes. The identified species were *M. incognita*, *M. hapla*, *M. javanica* and *M. arenaria* and their populations were present in amounts of 36.7%, 32.3%, 36.5% and 1.5%, respectively.

Bhati and Baheti (2020) analysed 158 samples from roots and soil in 40 polyhouses, in a two-year survey to ascertain the prevalence and population status of the root-knot nematode in polyhouses in various regions of Rajasthan. Results showed that *Meloidogyne incognita*, a root-knot nematode, was present in all samples of soil and roots. A 100% occurrence of root-knot nematodes above the economic threshold level (ETL) was also noted in the poly-houses that were inspected.

Bem *et al.* (2014) commissioned a survey in various Makurdi neighbourhoods in Benue State of Nigeria from October 2010 to January 2011 to determine the prevalence of root-knot disease in tomato crop. Based on signs like wilting, leaf yellowing and stunted development, 160 samples in total were randomly taken from

sample sites. The two agents that caused the infection were found to be *Meloidogyne incognita* and *M. javanica*.

2.1.7 Screening for resistance to root-knot nematode.

Root-knot nematodes (*Meloidogyne* spp.) represented as agricultural pest that affects a variety of economically important crops, including potatoes and tomatoes. They establish a complex parasitic interaction with tomato plant roots, causing structural and physiological changes in the host in addition to severe yield loss. Resistance to RKNs in solanaceous plants has been identified and linked to the presence of the Mi gene. As tomato is considered a susceptible crop in the tropics and subtropics, RKNs have a significant impact on tomato production (De Lannoy, 2001; Charchar, 2003). Farmers are currently using soil solarization, crop rotation, nematode-free seedlings and nematicides to control nematodes (Hemeng, 1981; Gowen, 2016). Because of the carcinogenic nature of widely used fumigants like ethylene dibromide and its ability to contaminate groundwater (Chitwood, 2016; Nordmeyer, 1992) tolerant/resistant rootstocks have been adopted and used worldwide as a substitute for nematode control because they are safe for both farmers and the environment (Khanzada *et al.*, 2012). Nematode resistant plants or rootstocks have the inherent potential to remain unaffected by nematode attack, which will help to reduce nematode outbreaks in tomato fields (Conceicao *et al.*, 2003; Corbett *et al.*, 2011). Grafting using resistant rootstocks has been shown to efficiently manage RKNs and boost production in tomato and eggplant grown in naturally nematode-infested soils (Ioannou, 2001).

Okorley *et al.* (2018) in a study on screening of *Solanum* plants as potential rootstocks for the management of root-knot nematodes (*Meloidogyne incognita*) reported that *Solanum macrocarpon*, *S. aethiopicum* and Mongal F₁ were showing tolerant responses with reduced root galling and low to high reproductive factors in pot and field experimentation.

Patra and Nayak (2019) identified that out of 25 varieties screened, only two varieties were resistant with least gall number (4-6 galls/plant), one variety was moderately resistant (25 galls/plant), nine varieties were susceptible (32-66 galls/plant) and eleven were highly susceptible (105-132 galls/pant).

Nihal *et al.* (2019) while evaluating 51 genotypes of tomato revealed that no genotype was highly resistant, genotypes (EC-620394, EC-620427, EC-617047) were resistant having 1.1 to 2.0 root gall index, 10 genotypes exhibited moderately resistant reaction having root gall index between 2.1 to 3.0, 20 were found susceptible and 18 lines were found to be highly susceptible.

Dhivya *et al.* (2014) conducted an experiment to identify resistant rootstocks in *Solanum* spp. for grafting of tomato against *Meloidogyne incognita*, a root knot nematode. After 60 days of inoculation, seven wild *Solanum* rootstocks, one *Physalis* wild rootstock and two tomato F₁ hybrids were evaluated for various factors. *Solanum torvum* and *Physalis peruviana* exhibited a resistant reaction followed by *Solanum sisymbriifolium*. Among tomato F₁ hybrids, TNAU tomato hybrid CO-3 showed moderately resistant reaction while tomato hybrid US-618 and *Solanum violaceum* were highly susceptible to *M. incognita*.

Jaiteh *et al.* (2012) conducted a study to evaluate tomato genotypes reaction to root-knot nematodes, recording different responses in gall growth and nematode reproduction. Tomato seedlings were inoculated at five different levels: 100, 500, 1000, 1500 and 2000 root-knot nematode eggs per 1.6 litres of soil per pot. *Meloidogyne* spp. resistance was tested against 33 genotypes in total. For host resistance to *Meloidogyne* spp., the genotypes were screened in pots and in the field. The largest number of eggs, juveniles and fresh root weight were found at 1500 egg per plant inoculation level. Tomato Mongal T-11 and Tomato Beef Master were found to be extremely resistant to *Meloidogyne* spp. and had the lowest reproductive factors of 0.71 and 0.53 respectively.

Cortada *et al.* (2008) subjected 10 commercial tomato rootstocks to high initial population densities (2050-900 second-stage juveniles per 250 cm³ soils) of the nematode over the course of their investigation. The findings showed that Beaufort and Maxifort were susceptible, whereas seven rootstocks had high degrees of resistance and one (He-Man) demonstrated an intermediate level of resistance.

Kawaguchi *et al.* (2008) reported that despite the high soil infestation (4290 nematodes kg⁻¹ soil), 100% of survival was observed for plants grafted onto eggplant rootstocks, whereas for plants grafted onto tomato rootstocks survival ranged from 25 to 100 %.

2.2 Graft compatibility studies

A suitable rootstock is one that is resistant to biotic and abiotic stresses, enhances scion growth, yield and fruit quality and is compatible with a scion under question (Savvas *et al.*, 2009). Suitability for growing seasons, climate and growing conditions should also be the criterion for selection of rootstocks (Bumgarner and Kleinhenz, 2013).

Kumar *et al.* (2016b) at CSK HPKV, Palampur employed three grafting techniques *viz.*, cleft, tongue and tube while grafting the commercial bell pepper hybrid Indra on five chilli and three brinjal rootstocks under protected conditions. The best rootstock for bell pepper was the chilli *i.e.*, PI-201232. Compared to cleft and tube grafting, tongue grafting had the highest grafting success rate.

Bausher (2013) conducted two experiments to examine the relationship between graft angle and plant survival in greenhouses at the USDA-ARS Horticultural Research Laboratory facility. In the first experiment tomato seedlings of FL-47 and Rutgers were utilised as scions on Roma rootstock and the results revealed that, increase in graft angle resulted in higher survival rate of grafted plants from 79% (20°), 81% (45°) and 92% (70°). In the second experiment When the 70° graft angle was applied, survival rates in commercial rootstocks such as Aloha, Anchor-T, BB, Big Power, Body, Camel, Cheong Gang, Imperial 643, Multifort, Maxifort, Vigostar 12, BHN 833, H-7997, FL-91 and Sebring were greater than 97 %.

Johnson *et al.* (2014) conducted a research at the Department of Horticulture, Washington State University. The eggplant cv. Epic was grafted on the rootstocks Beaufort (*S. lycopersicum* × *S. habrochaites*) and *S. aethiopicum* which showed a graft success rate of about 86% and the stem diameters of the rootstock and scion were roughly equivalent throughout the growing season.

Ramesh *et al.* (2016) in a study on graft compatibility conducted from 2013 to 2015 at the ICAR-Central Coastal Agricultural Research Institute, Goa used *S. torvum* as root stock (tolerant to bacterial wilt) and indigenous eggplant cultivars Agassaim, Taleigao and lines from segregating population as scions. They reported graft success rates of 77.24 per cent in segregated populations, 79.57 per cent in Taleigao, 78.57 per cent in Agassaim cultivars of eggplant and 78.46 per cent overall. They further

reported that root stock and scion diameters of 3 mm, high humidity and limited light during the first few days critical for the graft union.

Kumar *et al.* (2017b) conducted a study at College of Horticulture and Forestry (CAU) Pasighat during 2014-15, it was found that graft combinations of *Solanum torvum* + Pusa Hybrid-6 had a graft survival rate of 81.85 per cent at 10 days after grafting and 67.35 per cent at 30 days after grafting, while *Solanum xanthocarpum* grafted with Pusa Shyamala had the lowest survival rate of 30 per cent.

Sharma *et al.* (2018) investigated the performance of grafted tomatoes in terms of growth, yield and quality under polyhouse conditions at CSKHPKV, Palampur. Sixteen different solanaceous rootstocks were grafted with scion cultivar GS-600. Thirteen rootstocks were found to be compatible with GS-600, while three rootstocks, PI-201232, AVPP0205 and Local Pumpkin were non compatible.

Sharma *et al.* (2019) performed research for two cropping seasons (2016-17 and 2017-18) at CSKHPKV, Palampur to examine the compatibility reaction and to estimate grafting success rate (per cent) across several solanaceous rootstocks grafted on scion GS-600. The results revealed that different rootstocks had higher grafting success rate ranging from 92 - 97 per cent and the highest grafting success rate was observed in plants grafted on rootstock Hawaii-7998 for both the years and in the pooled analysis.

Arefin *et al.* (2019) at Sher-e-Bangla Agricultural University, Dhaka, Bangladesh, examined compatibility of grafting two different tomato varieties, BARI tomato-2 and BARI tomato-11, on three different potato rootstocks, Diamant, Cardinal and Asterix, based on vegetative growth and fruit and tuber output of pomato plants. The results showed that the tomato variety BARI tomato 11 and the potato variants Cardinal and Asterix outperformed the other graft combinations in terms of growth and yield characteristics.

Singh *et al.* (2019a) conducted experiments under both field and protected structure during 2018-2019 at LPU, Punjab to asses grafting success (%) between different tomato cultivars *viz.*, Punjab Varkha Bahar-4, Sona NTH-2829 and Heemshikhar used as scions and Brinjal cv. Navkiran as rootstock. It was revealed that Sona NTH 2829 + Navkiran (96.33 %), followed by Heemshikhar + Navkiran (95.00 %) had the highest success rate of all graft combination.

Priyanka *et al.* (2019) undertook a study at TNAU, Coimbatore from November 2015 to April 2016 to assess the health and compatibility of commercial cv. PKM 1 tomato grafts on solanaceous rootstocks. *Solanum lycopersicum* (LE 523, LE 828 and LE 102), *Solanum aculeatissimum*, *Solanum torvum* and *Solanum sisymbriifolium* were employed as rootstocks for the graft. *Solanum torvum* + PKM 1 tomato grafts had a highest graft success rate of 95%, whereas LE 102 + PKM 1 tomato grafts had the lowest success (9.34%).

Islam *et al.* (2019) carried out tomato grafting experiment in November 2017 at UBKV, West Bengal. They employed 30-day-old tomato seedlings of Avinash 2 variety and 20-day-old potato seedlings of Kufri Jyoti variety as scion and rootstock, respectively. They were successfully cleft-grafted with a survival rate of 62%.

Kawaguchi *et al.* (2008) performed a graft compatibility experiment on varieties of solanaceous crops like tomato (*Solanum lycopersicum* L.), eggplant (*Solanum melongena* L.) and pepper (*Capsicum annuum* L.). When compared to the compatible homo-specific graft combinations of tomato/tomato, eggplant/eggplant and pepper/pepper, it was determined that the tomato/pepper (scion/rootstock) and pepper/tomato grafts were severely incompatible and the tomato/eggplant and eggplant/tomato grafts were deemed moderately incompatible.

Sherly (2011) grafted four brinjal accessions *viz.*, COBH 2, HD 1, HD 2 and HD 3 as scion with five wild *Solanum* rootstocks *viz.*, *S. torvum*, *S. xanthocarpum*, *S. elaeagnifolium*, *S. incanum* and *S. viarum*, in TNAU, Coimbatore. In comparison to other *Solanum* species, she observed that the *Solanum torvum* rootstock and brinjal accessions combination had the highest grafting success and the highest survival rate of grafted plants.

2.3 Performance of graft combinations on horticultural traits in tomato

2.3.1 Plant height (cm)

Khah *et al.* (2006) in an experiment done in a glasshouse and in the open-field at Magnesia, Greece on effect of grafting on growth and yield of tomato found that 30, 60 and 90 days after transplanting, tomato cv. Big Red (scion) grafted onto rootstock Primavera produced the maximum plant height of 48.44 cm, 91.88 cm and 106.38 cm, respectively. In the greenhouse, the lowest plant height (38.00 cm) was observed in self-grafted cv. Big Red at 30 DAT, while the highest plant height (80.31

cm and 94.19 cm) was recorded at 60 DAT and 90 DAT, respectively. Furthermore, in open field, cv. Big Red grafted onto rootstock Heman produced the maximum plant height of 53.75 cm, 67.7 cm and 75.13 cm, whereas rootstock Primavera produced the lowest plant height of 46.44 cm, 62.50 cm and 69.13 cm at 34, 89 and 130 DAT, respectively.

Bie *et al.* (2010) carried out research in the spring of 2006 at Huazhong Agricultural University in Wuhan, China. The commercial squash hybrids Xiuli, Nanzhen No. 3, Nanzhen No. 4, Quannengtiejia, Degaotiezhu, Huangli, Baili, Liuli No. 1 and Liuli No. 2 were utilised as rootstocks and the melon cultivar Yilishabai was used as the scion. According to the study, melon grafted onto Xiuli, Nanzhen No. 3, Nanzhen No. 4 and Quannengtiejia rootstocks had the maximum plant height, stem diameter and leaf number per vine when compared to the un-grafted control plants.

Bekhradi *et al.* (2011) in the University of Tehran in 2006 grafted Charleston Gray variety of watermelon onto three different cucurbit rootstocks: *Cucurbita pepo*, *Lagenaria siceraria* and Ferro (*Cucurbita maxima* x *Cucurbita moschata*). Watermelon cv. Charleston Gray when grafted onto Ferro resulted in the longest main stem length (4.98 m), while the control resulted in the lowest main stem length (3.40 m).

Sherly (2011) in studies on grafting of brinjal accessions (*Solanum melongena* L.) with wild *Solanum* rootstocks at TNAU, Coimbatore found that grafting COBH 2 brinjal on *S. torvum* resulted in a plant height of 178.50 cm, which was higher than non-grafted plants (154.21 cm).

Yarsi (2010) conducted an experiment in a commercial glasshouse of Silifke province of Mersin, Turkey. The plants were grafted using the cleft grafting technique using Beaufort rootstock and the Cobra F₁ hybrid as the scion. Grafting tomato cultivars onto Beaufort rootstocks reportedly had an impact on plant development. At 45 and 90 DAT *i.e.*, 51.97 cm and 86.13 cm, respectively, the non-grafted plants were taller than the grafted plants *i.e.*, 47.27 cm and 79.26 cm, respectively.

Mohamed *et al.* (2012) grafted watermelon hybrid Aswan with five rootstocks (Tetsukabuto F₁, Strongtosa F₁ and Shintoza F₁ Nun 6001 F₁, Ferro F₁) in the two subsequent spring-summer seasons of 2010 and 2011 at Suez Canal University, Ismailia, Egypt. Watermelon hybrid Aswan grafted on rootstock Nun 6001 F₁ was

reported to have the maximum plant height 265.67 cm and 241.8 cm, whereas plants in control (Aswan F₁ non-grafted) had the lowest plant height 135.17 cm and 195.0 cm in 2010 and 2011 respectively.

Petropoulos *et al.* (2014) investigated the effects of grafting of watermelon hybrids Vanessa and Obla onto rootstock TZ 148 (*Cucurbita maxima* × *Cucurbita moschata*) and Dias F₁ (*Lagenaria* sp.) in the year 2009 and 2010 in the region of Filiatra, Greece. The watermelon F₁ Obla grafted onto TZ 148 (*Cucurbita maxima* × *Cucurbita moschata*) produced the largest plant height (150.7 cm), but self-rooted Obla F₁ produced the lowest plant height (108.5 cm).

El-Sayed *et al.* (2014) carried out experiments at the University of Cairo in Egypt throughout the summer and winter of 2013 to investigate the impact of grafting using various rootstocks. According to report when cucumber cv. Hady grafted onto the rootstock Ferro recorded higher values for plant height 69.33 cm, 69.67 cm and 196.50 cm in summer planting whereas, 51.00, 118.30 and 163.0 cm in winter at 30, 60 and 90 days after planting respectively.

Al-Harbi *et al.* (2017) used the commercial tomato cultivar Faridah, which was grafted on Unifort rootstock and grown under deficit watering in a glasshouse, in 2011-2012 and 2012-2013 at College of Agriculture Experimental Station, Riyadh, Saudi Arabia. They found that the grafted tomato displayed a significant increase in plant height, stem diameter and shoot fresh weight compared to the non-grafted tomato.

Kumar *et al.* (2016b) at CSK HPKV, Palampur employed three grafting techniques the cleft, tongue and tube while grafting the commercial bell pepper hybrid Indra on five chilli and three brinjal rootstocks under protected conditions. They reported the highest plant height for a Bell pepper (160.44 cm) when grafted on a chilli rootstock (PI-201232) and the lowest plant height of 110.35 cm when grafted on brinjal rootstock (VI-047335), which was quite low in comparison to chilli rootstocks.

Sabatino *et al.* (2019) conducted an experiment in two spring–summer growing period (2014 and 2015) at Montanaso Lombardo, Italy by grafting eggplant hybrid Scarlatti F₁ on four rootstocks, including two accessions of *S. aethiopicum* gr. gilo, interspecific hybrid (*S. melongena* × *S. aethiopicum* gr. gilo) and *S. torvum*. The

highest plant heights were found on *S. aethiopicum* gr. gilo (accession 1), while the lowest values were found on *S. aethiopicum* gr. gilo (accession 2).

Sabatino *et al.* (2013) tested four Sicilian eggplant ecotypes (B1, B2, B3 and B4) that were raised in open fields in Sicily, Italy in 2011 for their suitability for grafting with rootstock *S. torvum* Swartz. At 35 days, the eggplant ecotype B1 grafted on *Solanum torvum* Swartz had the highest plant height (62.80 cm) whereas the lowest plant height (56.60 cm) was found in the non-grafted B3 ecotype. At 60 days, the highest plant height (110.4 cm) was recorded in the B2 grafted on *S. torvum* Swartz and the lowest plant height had been found in the non-grafted B2.

Kumar *et al.* (2016 a) attempted grafting two brinjal cultivars *i.e.*, Surati Ravaiya (pink and purple cultivar) onto the rootstock of *Solanum torvum* employing cleft grafting in the Kharif seasons of 2014 and 2015 at NAU, Navsari, Gujarat. Grafting significantly increased plant height in Surati Ravaiya pink cultivar (85.71 cm) whereas, minimum plant height (74.69 cm) was recorded in control self-rooted Surati Ravaiya Purple.

Kumar *et al.* (2017 a) used the commercial hybrid tomato Avtar as a scion and seven different tomato and brinjal rootstocks-namely, Hawaii 7996, Hawaii 7998, Palam Pink, Palam Pride, VI034845, VI45276 and VI047335 in a polyhouse at CSKHPKV Palampur in 2012-2013 and observed that the rootstocks used in the study had a significant influence on plant height. The tallest plants (205.66 mm) were produced by plants grafted on the brinjal rootstock VI034845, which were 10.37% taller than un-grafted plants.

Sharma *et al.* (2018) assessed sixteen distinct tomato rootstocks that were grafted with the scion cultivar GS-600 over two consecutive years, *viz.*, 2016–17 and 2017–18, in polyhouse conditions at CSKHPKV, Palampur. Plants grafted on the rootstock Back Attack grew to a maximum height of 278.80 cm, followed by Arka Nidhi (227.33 cm), LS89 (221.95 cm), Hawaii-7998 (214.27 cm) and Palam Pride (212.83 cm).

Soare *et al.* (2018) investigated the impact of tomato grafting on various morphological, yield related and quality aspects at University of Craiova, Romania during 2013–2014. The scion grafted onto the Beaufort rootstock was Lorely F₁ and

the results revealed that Beaufort + Lorely F₁ with one stem was taller (211.50 cm) than Beaufort + Lorely F₁ with two stems (142.8 cm).

Kumar *et al.* (2018) at CSKHPKV, Palampur used eight rootstock including tomato and brinjal genotypes as well as three tomato varieties as scions, namely GS-600, Rakshita and Naveen 2000+ in an experiment conducted in polyhouse. The results showed that the graft combination 2123 A-1 + Rakshita achieved the highest plant height (318.66 cm), followed by GS 600 + Hawaii-7996 and Arka Nidhi + Rakshita, both of which registered plant height of 313.33 cm.

Arefin *et al.* (2019) studied grafting compatibility of two tomato scions on three different potato rootstocks in an experiment performed in Dhaka, Bangladesh and concluded that graft combination BARI Tomato-11 (25-day old seedling) when used as scion and Cardinal as rootstock, recorded a significantly greater plant height of 115.13 cm as compared to other grafting combinations.

2.3.2 Number of primary branches per plant and number of fruits per cluster

Arefin *et al.* (2019) studied grafting compatibility of two tomato scions on three different potato rootstocks in an experiment performed at Sher-e-Bangla Agricultural University, Dhaka, Bangladesh and found that when BARI- Tomato-11 (25-day old seedling) was used as scion and Cardinal was used as rootstock, they produced significantly more primary branches (6.66/plant) and they also produced the highest number of fruits per cluster (17) than other grafting combinations.

2.3.3 Number of fruits per plant

Yetisir and Sari (2003) at University of Cukurova, Turkey employed Crimson Tide, a cultivar of watermelon as scion and 10 different open pollinated and hybrid cultivars of cucurbits as rootstocks in a grafting experiment carried out during 1999 and 2000. Crimson Tide when grafted on bottle gourd hybrid Skopje, produced maximum fruits (2.4 fruits/plant), while rootstocks of the *Cucurbita* type (*Cucurbita moschata*, *Cucurbita maxima*, P360 and Strong Tosa) produced least fruits (1.0 fruits/plant).

Maršić and Osvald (2004) investigated the effect of different grafting techniques on grafting success and fruit yield of two tomato cultivars (Monroe and Belle) where PG 3 and Beaufort were chosen as the rootstock cultivars. Cleft grafting and tube grafting were used as grafting methods. The results revealed that cv. Monroe

produced 20.10 fruits per plant in cleft grafting and 16.10 fruits per plant in tube grafting. Cleft grafting yielded 20.10 fruits per plant, while tube grafting yielded 13.70 fruits per plant in cv. Belle.

Davis and Perkins-Veazie (2005) at USDA-ARS, Oklahoma investigated effects of rootstocks like 1330 (hybrid squash), 1332 and 451 (*Cucurbita argyrosperma*) on plant vigour and fruit quality in watermelon (SF800 and SS5244). Cultivar SF800, when grafted to rootstocks 451 and 1330, produced 10 fruits and 16 fruits, respectively, but this was less than the control (18 fruits per vine) and cultivar SS5244, when grafted to rootstocks 451 and 1332, produced 27 fruits and 19 fruits, respectively, while the control recorded 25 fruits per vine.

Alexopoulos *et al.* (2007) studied fruit yield and quality of watermelon in relation to grafting involving four rootstocks (Early Max, Long gourd, F-14 gourd and Max-2 hybrid) and one scion (Crimson Sweet) and reported that the mean number of fruits per plant were similar for both the grafted and non-grafted plants irrespective of rootstock. It was concluded that fruit yield was significantly higher in the grafted plants than in the non-grafted control.

Abdelmageed and Gruda (2009) at Humboldt University of Berlin, Germany utilised brinjal cultivar Black Beauty as rootstock and tomato cultivars Summerset (heat tolerant) and UC 82-B (heat sensitive) as scion. When Summerset grafted on eggplant rootstock (Black Beauty) produced the most fruits (12.80) at a temperature of 26/20 °C while self-rooted UC 82-B produced the least fruits (10.20).

Sherly (2011) in studies on grafting of brinjal accessions (*Solanum melongena* L.) with wild *Solanum* rootstocks at TNAU, Coimbatore observed that COBH 2 grafted on *S. torvum* rootstock produced the maximum fruits per plant when compared to other graft combinations.

Khankahdani *et al.* (2012) used various rootstocks *viz.*, Shintoza, Pumpkin and Bottle gourd as well as grafting methods such as splicing, tongue-approach and hole insertion grafting to examine their effects on compatibility and output in watermelon cultivar Crimson Sweet. The maximum fruit number (2.60 fruits) was observed in watermelon grafted onto bottle gourd rootstocks by splice grafting compared to tongue-approach technique (1.8 fruits) and least in seedy watermelon (1.0 fruit).

Petropoulos *et al.* (2014) investigated the impact of grafting watermelon (*Citrullus lanatus*) hybrids Vanessa F₁ and Obla F₁ onto TZ 148 and Dias F₁ (*Lagenaria* spp.) rootstocks for plant growth and fruit production in the territory of Filiatra, Greece, during two years (2009–2010). When Obla F₁ grafted onto TZ 148 (*Cucurbita maxima* × *Cucurbita moschata*) rootstock, which produced the highest number of fruits per hectare (13972) while, the lowest fruit number was recorded (7867) in self rooted Obla F₁.

Sabatino *et al.* (2013) evaluated four Sicilian eggplant ecotypes (B1, B2, B3 and B4) that were cultivated in open fields in Sicily, Italy in 2011 for their suitability for grafting with rootstock *Solanum torvum* Swartz. Ecotype B4 grafted on *Solanum torvum* Swartz produced the highest number (16.34) of fruits per plant, while non-grafted B3 ecotype produced the lowest number (4.79).

Kumar *et al.* (2017a) investigated the outcomes of an experiment including seven rootstocks and a tomato hybrid Avtar (scion), which had a substantial impact on plant growth, yield and fruit quality. The results showed that Avatar seedlings grafted on brinjal rootstock VI034845 outperformed all other rootstocks studied, generating the maximum fruits per plant (35.66).

Soare *et al.* (2018) investigated the effects of tomato plant grafting on morphological, production and nutritional parameters at University of Craiova, Romania. The scion grafted onto the Beaufort rootstock was the Lorely F₁ cultivar and the results revealed that Beaufort + Lorely F₁ with two stems produced more fruits per plant (43.5) than Beaufort + Lorely F₁ with one stem (33.2).

Sharma *et al.* (2018) conducted research to examine the performance of grafted tomatoes in terms of growth, output and quality. Plants grafted on rootstock Green Gourd (23.67) produced the most fruits per plant, followed by *Solanum torvum* (21.67), Arka Keshav (21.17) and VI47335 (21.17).

Kumar *et al.* (2018) conducted an experiment which consisted of eight rootstocks *viz.* Pumpkin Jalag, 2123 A-1 (Tomato), Palam Pink (Tomato) Hawaii 7998 (Tomato), Palam Pride (Tomato), Hawaii 7996 (Tomato), Arka Keshav (Brinjal) and Arka Nidhi (Brinjal) and three tomato varieties as scions *viz.* Rakshita, GS-600 and Naveen 2000+. The results showed that the treatment (GS 600 + Hawaii-7996) produced the maximum fruits per plant (38.00).

Singh *et al.* (2019a) investigated the effect of grafting different tomato scions on brinjal rootstocks and revealed that the highest number of fruits per plant (140.66) were found in Sona NTH 2829 + Navkiran, followed by (129.40) in Heemshikhar + Navkiran and the lowest number of fruits per plant (91.93) in Punjab Varkha Bahar-4 + Navkiran.

Arefin *et al.* (2019) investigated the grafting compatibility of two tomato scions on three different potato rootstocks at Sher-e-Bangla Agricultural University, Dhaka, Bangladesh and found that the graft combination BARI- Tomato-11 (25-day old seedling) with Cardinal as rootstock produced the maximum fruits per plant (272) among the other grafting combinations.

Islam *et al.* (2019) conducted a study at UBKV, West Bengal in which 30 days old tomato seedlings were cleft grafted in a 20 days old potato seedling and the data reported an average of 35 fruits per plant.

2.3.4 Average fruit weight

Bletsos *et al.* (2003) at ARC Macedonia and Thrace, Greece grafted brinjal cultivar Tsakoniki on *Solanum sisymbriifolium* and *Solanum torvum* which produced mean fruit weights of 137.70 g and 226.50 g in 1998 and 1999, respectively.

Yetisir and Sari (2003) reported that when cultivar Crimson Tide was grafted onto rootstock Skopje (*Lagenaria* hybrid) it recorded the highest fruit weight (8.80 kg) whereas, the lowest fruit weight (2.03 kg) was recorded on root stock *Cucurbita moschata* (CMO).

Colla *et al.* (2006) carried out study during growing season of spring-summer at Central Italy under greenhouse. They reported highest mean fruit weight (1.89 kg) when watermelon cultivar Tex grafted onto rootstock Ercole (*Cucurbita maxima*) at salinity 2.0 dS/m² whereas, the lowest fruit weight (1.13 kg) was recorded in control at salinity 5.2 dS/m².

Abdelmageed and Gruda (2009) at Humboldt University, Berlin, Germany under two controlled temperature regimes (37/27 °C and 26/20 °C) utilised brinjal cultivar Black Beauty and tomato cultivar Summerset (heat tolerant) as rootstock and the tomato cultivar UC 82-B (heat sensitive) as scion. The study found that the highest fruit weight was recorded at temperature of 37/27 and 26/20 °C in Summerset self rooted plants was 13.13 g and 284.00 g, respectively, in tomato.

Çürüket *et al.* (2009) evaluated the impact of grafting Pala and Faselis brinjal cultivars onto *Solanum torvum* Swartz for morphological, production and quality parameters in Turkey's Mediterranean region. Mean fruit weight improved by 20% when Faselis was grafted on *Solanum torvum*.

Huitroñ-Ramírez *et al.* (2009) examined triploid watermelon Tri-X 313 grafted on two interspecific hybrid rootstocks, RS 841 and Shintosa Camelforce, over the course of two years in Mexican State of Colima. When compared to non-grafted plants, an average fruit weight increase ranging from 13% to 28% was observed in grafted plants.

Turhan *et al.* (2011) undertook a study during summers of 2009 and 2010 in Uludag University, Turkey using Beril, Swanson and Yeni Talya cultivars of tomato as scions and Arnold and Beaufort cultivars as rootstocks with the approach of cleft grafting. The maximum fruit weight was obtained by the graft combinations Yeni Talya/Beaufort (202.09 g), Swanson/Beaufort (189.05 g) and Beril/Beaufort (181.89 g) compared to non-grafted plants.

Yarsi (2010) carried out a study in commercial glasshouse of Silifke, Turkey's province of Mersin. The Beaufort rootstock and the Cobra (F₁ hybrid) scion plants were grafted using cleft grafting. Grafting tomato cultivars onto Beaufort rootstocks had an impact on the average fruit weight; grafted plants had a much higher fruit weight (149.70 g) when compared to non-grafted plants (129.80 g).

Khankahdani *et al.* (2012) used various rootstocks e. g., Shintoza, Pumpkin and Bottle gourd as well as grafting methods such as splicing, tongue - approach and hole insertion grafting to examine their effects on compatibility and output in watermelon cultivar Crimson Sweet. The results revealed that the average fruit weight was higher in watermelon grafted plants than un-grafted plants. Maximum fruit weight (7.00 kg) was observed in watermelon grafted onto bottle gourd rootstock by tongue approach grafting technique and the minimum was observed in seedy watermelons (4.20 kg).

Voutsela *et al.* (2012) conducted experiments both indoors (heated glasshouse) and outdoors at the Thessaly University (Velesino, Greece) where tomato cultivar Despina was grafted onto five different rootstocks (P1, P2, P3, P4 and P5). In both

indoor and outdoor tomato cultivation, grafting enhanced mean fruit weight, while P2, P5, and P6 graft pairings had greater mean fruit weight.

Moncada *et al.* (2013) assessed the production and quality of brinjal cultivars (Birgah, Black Bell, Black Moon and Longo) grafted onto *Solanum torvum* at University of Palermo, Italy. The results depicted that, the average weight of fruits was significantly higher in all the grafted plants (274.20 g), particularly, for large cultivars. Longo (lengthened shape fruit) produced average fruit weight of 184.10 g, whilst Birgah (large sized fruit) had the greatest average fruit weight (321.80 g).

Johnson *et al.* (2014) conducted a research at the Washington State University's Department of Horticulture with the brinjal variety Epic grafted on the rootstocks Beaufort (*S. lycopersicum* × *S. habrochaites*) and *S. aethiopicum*. The highest fruit weight (0.50 kg) was observed for Epic when it was grafted onto Beaufort, whereas the lowest fruit weight was noted for self-grafted plants.

Petropoulos *et al.* (2014) investigated the impact of grafting watermelon hybrids Vanessa F₁ and Obla F₁ onto TZ 148, *Lagenaria* spp. and Dias F₁ rootstocks on the plant growth and fruit production at the territory of Filiatra, Greece, during two years (2009-2010) and recorded highest fruit weight (6.40 kg) when cultivar Obla F₁ grafted onto TZ 148 (*Cucurbita maxima* × *Cucurbita moschata*), whereas, the lowest fruit weight was (6.30 kg) in self rooted Obla F₁.

El-Sayed *et al.* (2014) tested the influence of grafting on cucumber cultivar Hady using several rootstocks at the University of Cairo in Egypt during the summer and winter of 2013. When cucumber cultivar Hady was grafted onto the rootstock Ferro, average fruit weight (70.67, 69.67 and 69 g) was reported in summer planting, but average fruit weight (68.67, 69.67 and 69 g) was recorded in winter planting at 30, 60 and 90 days, respectively.

Kumar *et al.* (2016b) investigated the effects of chilli and brinjal rootstocks on commercial capsicum hybrid Indra for growth, yield and quality at CSKHPKV Palampur under protected environment during 2014. Among the rootstocks tested, PI-201232 (chilli rootstock) provided the highest average fruit weight of 99.73 g, followed by AVPP0205 (95.73 g).

Kumar *et al.* (2016a) attempted grafting two cultivars *i.e.*, Surati Ravaiya (pink) and Surati Ravaiya (purple) onto the rootstock of *Solanum torvum* employing

cleft grafting in the Kharif seasons of 2014 and 2015 at NAU, Navsari, Gujarat. The maximum fruit weight (73.43 g) was recorded in grafted Surati Ravaiya Pink followed by self-rooted Surati Ravaiya Pink (73.06 g), however the minimum fruit weight (69.02 g) was recorded in self rooted Surati Ravaiya Purple (control).

Soare *et al.* (2018) at University of Craiova, Romania during 2013–2014 studied the impact of tomato plant grafting on morphological, production and nutritional parameters. The scion grafted onto the Beaufort rootstock was the Lorely F₁ cultivar and the results revealed that Beaufort + Lorely F₁ with two stems had a larger average fruit weight of 210.5 g than Beaufort + Lorely F₁ with one stem (204.7 g).

Singh *et al.* (2019a) conducted experiments under both field and protected structure during 2018–2019 at LPU, Punjab to assess grafting success (%) between different tomato cultivars Punjab Varkha Bahar-4, Sona NTH-2829 and Heemshikhar used as scions and Brinjal cv. Navkiran used as rootstock. Study revealed that the average tomato fruit weight was the highest (57.30 g) in the Sona NTH 2829 + Navkiran, followed by (49.24 g) in the Heemshikhar + Navkiran.

Arefin *et al.* (2019) investigated the compatibility of two tomato scions on three different potato rootstocks in an experiment in Dhaka, Bangladesh, where BARI- Tomato-11 (a 25-day-old seedling) used as scion and Cardinal as rootstock recorded the highest average fruit weight of 7.66 g out of all the grafting combinations.

Islam *et al.* (2019) carried out tomato grafting experiment at UBKV, West Bengal. They employed 30-day-old tomato seedlings of the Avinash 2 (scion) variety and 20-day-old potato seedlings of the Kufri Jyoti (rootstock), and the average fruit weight recorded was 78 g.

2.3.5 Yield per plant

Traka-Mavrona *et al.* (2000) carried out a study in greenhouse at ARC Macedonia (Greece) and reported that melons grafted onto squash rootstock have significant differences in the marketable yield. The maximum yield of 2.69 kg/vine was obtained in grafted plants and 2.02 kg/vine in control.

Nisini *et al.* (2002) undertook a study to determine the effect of commercial melon and various *Cucurbitaceae* spp. Rootstocks (*Benincasa hispida*, *Cucumis*

metuliferus, *Cucumis ficifolia*, *Cucurbita maxima*, *Cucurbita moschata* and *Lagenaria siceraria*) on Supermarket and Proteo scion cultivars of muskmelon. Scions Supermarket and Proteo recorded higher yields (3.10 kg/ m² and 3.80 kg/ m²) when both grafted on rootstock P360 compared to other rootstocks and significant differences in the marketable yield between control and grafted plants of muskmelon was also noted.

Alan *et al.* (2007) at Ege University Turkey executed a comparative analysis of the performance of grafted and non-grafted plants of watermelon cultivar Crispy. The yield characteristics of grafted and non-grafted watermelon plants revealed that grafting had an impact on fruit yield, with the yield of grafted plants being roughly 18.95 kg/vine as opposed to non-grafted plants (8.98 kg/vine).

Rouphael *et al.* (2008a) tested the yield and tolerance to copper toxicity in Akito cucumber cultivar, either ungrafted or grafted with the Shintoza (commercial rootstock) in glasshouse. According to a study, cucumber grafted onto a commercial cucurbita rootstock (Shintoza) under conditions of copper toxicity produced more fruit (8.40 kg/vine) than non-grafted plants did at a concentration of copper (0.3 M).

Kumar *et al.* (2016b) investigated the effect of chilli and brinjal rootstocks on commercial capsicum hybrid Indra for growth, yield and quality at CSKHPKV Palampur under protected environment during 2014. They found that the chilli rootstock PI-201232 produced the highest fruit yield per plant (2.47 kg), followed by VI-037556 (1.97 kg) and AVPP0205 (1.91 kg).

Kumar *et al.* (2017b) conducted a study at College of Horticulture and Forestry (CAU) Pasighat in the growing season of 2014-15 involving four wild *Solanum* spp. rootstocks and two cultivated brinjal genotypes Pusa Shyamala and Pusa Hybrid-6. Tomato grafted on brinjal rootstock VI034845 outperformed all other combinations, yielding 2.14 kg per plant, which was significantly greater than all other rootstocks.

Kumar *et al.* (2017a) used seven different rootstocks and the horticulturally superior scion Avtar as scion in an experiment to see how they affected plant growth, yield and fruit quality in a polyhouse at CSKHPKV Palampur over the years. The rootstock VI034845 outperformed all other treatments in terms of yield per plant (2.14 kg), followed by rootstock VI047335 per plant (2.00 kg).

Soare *et al.* (2018) carried out an investigation to study the effect of tomato plant grafting on morphological, production and nutritional qualities. The scion grafted onto the Beaufort rootstock was the Lorely F₁ cultivar. The results revealed that Beaufort + Lorely F₁ with two stems had a higher yield per plant of 9.2 kg than Beaufort + Lorely F₁ with one stem (6.8 kg).

Sharma *et al.* (2018) investigated the performance of grafted tomatoes in terms of growth, yield and quality under polyhouse at conditions CSKHPKV, Palampur. Sixteen different tomato rootstocks were grafted with scion cultivar GS-600 and plants grafted on the rootstock Green Gourd produced the highest yield per plant (2.16 kg), followed by Palam Pride (1.92 kg), Arka Keshav (1.80 kg) and VI45376 (1.80 kg) (1.78 kg).

Arefin *et al.* (2019) in a grafting compatibility experiment involving two tomato scions and three different potato rootstocks concluded that among other grafting combinations, BARI- Tomato-11 (25-day old seedlings) when used as scion and Cardinal as rootstock, recorded the maximum yield per plant (2.25 kg) followed by 1.90 kg/plant produced by BARI Tomato-11 (35-day old seedlings) used as scion and Cardinal as rootstock.

Sabatino *et al.* (2016) conducted a study at the experimental fields of the Department of Agricultural and Forest Sciences of Palermo, Sicily (Italy) where four eggplant landraces grown in Sicily, namely Bianca (L1), Sciacca (L2), Marsala (3) and Sicilia (4), were grafted on to *Solanum torvum* rootstock. The number of marketable fruits, marketable production and total fruit production were all significantly enhanced by grafting, with L1 being the most prolific (averaging 9.4 kg m⁻²) and L4 being the least productive (5.0 kg m⁻²).

Khah *et al.* (2006) conducted an experiment in a glasshouse and in the open-field at Magnesia, Greece and reported that Tomato cv. Big Red grafted onto Heman gave highest fruit weight of 7568.16 g and 2096.25 g while, lowest fruit weight was recorded in 4995.16 g and 1771.88 g in greenhouse and open fields, respectively.

Khankahdani *et al.* (2012) investigated the effects of several rootstocks Shintoza, Pumpkin and Bottle gourd, as well as grafting methods such as splicing, tongue-approach, and hole insertion grafting, on compatibility and output in the watermelon cultivar Crimson Sweet. Watermelon grafted onto bottle gourd rootstock

by splice grafting produced the highest yield of 13.60 kg/vine compared to tongue grafting technique (12.17 kg/vine) and the lowest yield (4.37 kg/vine) in non-grafted seedy watermelons, indicating that bottle gourd rootstock had higher yield potential in watermelon grafting.

Sabatino *et al.* (2016) evaluated four Sicilian eggplant ecotypes (B1, B2, B3 and B4) that were cultivated in open fields in Sicily, Italy in 2011 for their suitability for grafting with rootstock *S. torvum* Swartz. The highest yield per plant was 4.38 kg in ecotype B1 grafted on *Solanum torvum* Swartz and the lowest yield was 1.82 kg in the non-grafted B4 ecotype.

2.3.6 Total yield

Matsuzoe *et al.* (1992) grafted tomato scions (Momotaro) on soil-borne disease resistant wild *Solanum* species like *Solanum torvum*, *Solanum toxicarium* and *Solanum sisymbriifolium* at Kyushu University, Japan and found that tomato plants grafted on wild rootstocks produced fruit yields and quality that were comparable to or better than non-grafted plants.

Rahman *et al.* (2002) in a study on effect of grafting on shoot and fruit borer and yield in brinjal at Gazipur, Bangladesh. Brinjal variety Singnath was used as scion and rootstocks were wild *Solanum* spp. like *Solanum torvum*, *S. sisymbriifolium* and *S. amphidiploids*. Results depicted that grafted plants had the lowest borer-infested fruits and had a much higher yield than regular plants.

Bletsos *et al.* (2003) at ARC Macedonia and Thrace, Greece grafted brinjal cultivar Tsakoniki on *Solanum sisymbriifolium* and *Solanum torvum* and found that, when Tsakoniki seedlings were grafted on *Solanum torvum* Swartz it gave fruit yields of 2867 g and 993 g in 1998 and 1999, respectively.

Yetisir and Sari (2003) at University of Cukurova, Turkey employed Crimson Tide, a cultivar of watermelon, as scion and 10 different open pollinated and hybrid cultivars of cucurbits as rootstocks in a grafting experiment during 1999 and 2000. They recorded the highest fruit yield of 13.26 kg/m² with Skopje whereas, the lowest yield was recorded onto rootstock P360 (*Cucurbita* hybrid) about 1.89 kg/m².

Marsic and Osvold (2004) used the tomato cultivars Monroe and Belle as scions and PG 3 and Beaufort as rootstocks. Cleft grafting and tube grafting were employed as grafting procedures. The results showed that cultivar Monroe yielded

4718.0 g/plant under cleft grafting and around 3091.0 g/plant under tube grafting, whereas cultivar Belle yielded 3004.0 g/plant under cleft grafting and about 3591.3 g/plant under tube grafting.

Rashid *et al.* (2001) undertook a study to promote grafting technology at Jessore and Gazipur (Bangladesh) using two varieties of cultivated tomato (BARI Tomato-2 and BARI Tomato-3) as scion and bacterial wilt resistant wild brinjal species (*Solanum sisymbriifolium* and *Solanum torvum*) as rootstock. BARI Tomato-2 grafted onto *Solanum torvum* produced higher fruit yield (36.50 t/ha), followed by BARI Tomato-3 grafts (30.0 t/ha) and non-grafted control plants gave 22.23 and 23.4 t/ha.

Khah (2011) performed an experiment in Magnesia, Greece under both glasshouse and open-field conditions utilizing two tomato hybrids, Heman and Primavera, as rootstocks and the brinjal hybrid Rima as the scion. According to the study the maximum yield per plant (15.30 kg/plant) was obtained when hybrid Rima was grafted on tomato rootstocks Primavera, whereas the lowest yield (9.50 kg/plant) was obtained under the control.

Passam *et al.* (2005) investigated brinjal yield and fruit attributes in a glasshouse at the Agricultural University of Athens, where cultivar Delica (flask type fruit) was grafted onto rootstocks of Verticillium wilt-resistant brinjal cultivars (494 and 543) and tomato cultivars (515 and 516). Plants grafted onto tomato rootstocks cultivars 515 (1029.6 g/plant) and 516 (1740.3 g/plant) yielded more than the non-grafted (674.6 g/plant), whereas plants grafted onto brinjal rootstocks cultivars 494 (191.5 g/plant) and 543 (149.6 g/plant) yielded similar to the control (212.0 g/plant).

Colla *et al.* (2006) conducted a study in 2004 in Central Italy under glasshouse conditions using watermelon cultivar Tex, either un-grafted or grafted onto commercial rootstocks Macis (Bottle gourd) and Ercole (Interspecific *Cucurbita* hybrid). The highest mean yield of fruits (11.1 kg per plant) was obtained when cultivar Tex grafted onto rootstock Ercole (*Cucurbita maxima*) at salinity 2.0 dS/m² whereas, the lowest yield was recorded in control (4.90 kg per plant) at salinity 5.2 dS/m². Grafting watermelons with saline-tolerant rootstocks showed yield increases up to 81 per cent under greenhouse production in the Mediterranean (Colla *et al.*, 2006).

Alan *et al.* (2007) at Ege University Turkey in 2006 executed a comparative analysis of the performance of grafted and non-grafted plants of watermelon cultivar Crispy. They concluded that grafting in watermelon resulted in higher yield by increasing both fruit number and weight, however, no significant effect on fruit quality such as fruit index, rind thickness and soluble solid contents on grafted plants was observed.

Wang *et al.* (2006) from Beijing University of Agriculture evaluated brinjal graft combinations in greenhouses over the summer using three rootstocks (Chiqie, Nianmaoqie, and Tuolubamu) and one scion (Yuanqie). Results revealed that grafting eggplant onto heat-tolerant brinjal rootstock (Nianmaoqie) increased yield by 10%, indicating that rootstocks can improve brinjal's ability to withstand high temperatures.

Besri (2008) in a study on grafting as substitute to methyl bromide for cucurbits production in morocco recorded the average yield of melon and watermelon plants grafted on different Cucurbita hybrids (*C. maxima* x *C. moschata*) as rootstocks were much higher than the yields of the non grafted plants. The yield increase was (44 % and 84 %) for melon and watermelon, respectively.

Palada and Wu (2008) carried out experiments in 2003 (summer) and 2004 (autumn) with the objective of identifying a promising graft combination for the cultivation of bell pepper in Taiwan's hot summer and dry autumn seasons. They examined 23 bell pepper rootstock accessions and grafted Andalus (scion) to it and reported that the yield during the autumn season varied from 20.5 t/ha for accession C04751 to 49.2 t/ha for accession PBC631-A. The yield, however, varied from 4.3 t/ha for accession PBC204 to 34.7 t/ha for Toom-1 during the summer.

Rouphael *et al.* (2008b) conducted an experiment in Viterbo, Italy over the course of two growing seasons (2006 and 2007) under open field conditions to ascertain yield and water use efficiency of mini-watermelon hybrid Ingrid, which was grafted onto the commercial rootstock PS 1313 using the technique of tongue approach grafting. According to the findings, grafted plants produced a greater marketable yield (31.9 t/ha) than un-grafted plants (19.8 t/ha) and total yields were 115 per cent higher in grafted plants than in un-grafted plants.

Abdelmageed and Gruda (2009) at Humboldt University of Berlin, Germany used the heat-tolerant brinjal cultivar Black Beauty and tomato cultivar Summerset as

rootstock and the heat-sensitive tomato cultivar UC 82-B as scion. Studies showed that grafting brinjal onto heat-tolerant tomato rootstock increases vegetative development in conditions of supra-optimal temperature, but that yield is not statistically different from non-grafted controls.

Gisbert *et al.* (2011) performed an experiment in Valencia, Spain where brinjal cultivar Black Beauty (scion) were grafted onto five *Solanum* spp. rootstocks including the two interspecific hybrids (*S. incanum* x *S. melongena* and *S. aethiopicum* x *S. melongena*) as well as three species (*S. macrocarpon*, *S. torvum*, and *S. melongena*). The overall yield varied from 3.2 kg/m² for Black Beauty grafted onto *Solanum macrocarpon* rootstock to 8.6 kg/m² for plants grafted onto interspecific hybrids of *Solanum incanum* and *Solanum melongena*.

Turhan *et al.* (2011) investigated the effect of grafting on tomato fruit yield and quality, by using various rootstocks. Results showed that the fruit yield of Yeni Talya on Beaufort was 6.77 kg per plant and that grafting had a significant impact on the fruit index (diameter/length), number of fruits/truss and fruit weight.

Yarsi (2010) conducted an experiment on grafting in a commercial glasshouse of Silifke province of Mersin, Turkey. The plants were grafted using the cleft grafting technique using the Beaufort rootstock and the Cobra F₁ hybrid as the scion which reportedly had an impact on total yield. The grafted plants produced a greater overall yield (15.23 kg/m²) in comparison to the non-grafted plants (12.22 kg/m²).

El-Sayed *et al.* (2014) tested the influence of grafting on cucumber cultivar Hady using several rootstocks at the University of Cairo in Egypt during the summer and winter of 2013. When Hady grafted onto the rootstock Ferro in summer planting recorded the highest early fruit yield of 2.67 kg/m² and total yield of 11.67 kg/m² whereas, in winter planting early yield of 3.58 kg/m² and total yield of 14.75 kg/m² was recorded.

Kumar *et al.* (2016a) attempted grafting two cultivars namely Surati Ravaiya (pink) and Surati Ravaiya (purple) onto the rootstock of *Solanum torvum* employing cleft grafting in the Kharif seasons of 2014 and 2015 at NAU, Navsari, Gujarat. They reported the highest fruit yield in grafted Surati Ravaiya (Purple) *i.e.*, 44.46 t/ha followed by self-rooted Surati Ravaiya (Purple) *i.e.*, 31.67 t/ha whereas, lowest yield was recorded in control self-rooted Surati Ravaiya (Pink) *i.e.*, 17.60 t/ha.

Mišković *et al.* (2009) performed three year study in a poly-tunnel (2004-2006) at the Faculty of Agriculture in Novi Sad, Serbia, utilising cultivar Jeremy as a scion grafted onto rootstocks namely, Vigomax, Beaufort, Maxifort, Madona (F₁), *Solanumlycopersicum* var. *cerasifoirmae*, *Solanumlycopersicum* var. *pruniform* and *Solanumlycopersicum* var. *pyriformae*. Three-year average depicted that Vigomax rootstock generated highest yield (18.24 kg/m²) and the rootstock Madona produced minimum yield (6.06 kg/m²) when grafted on tomato scion.

Ochar *et al.* (2019), tested 10 tomato genotypes in greenhouse and field environments at the University of Ghana, in order to identify the best genotype for yield and yield component traits. The genotypes that performed the best in terms of fruit yield were Mongal F₁, Platinum F₁, Nkansah HT, Wosowoso, Roma and Sumo F₁ in both greenhouse and field conditions.

Chang-hua *et al.* (2011) in Hunan, China, assessed the yield and quality of four rootstocks grafted onto the bitter gourd scion Xiangzaoyou No. 1. They found that Weilong No. 1 rootstock had the best effect to have an increased yield of 63.20 per cent in grafted bitter gourd plants compared to self-rooted plants.

2.3.7 Equatorial Diameter (cm)

Davis and Perkins-Veazie (2005) at USDA-ARS, Oklahoma investigated effects of rootstocks like 1330 (hybrid squash), 1332 and 451 (*Cucurbita argyrosperma*) on plant vigour and fruit quality in watermelon (SF800 and SS5244). According to the research, the ratio of length and diameter did not change for either cultivar when grafted, indicating no influence of rootstock on direction of expansion.

Yamasaki *et al.* (1994) undertook a study in greenhouse in Fukuoka, Japan, using watermelon hybrid Fujihikari as scion and bottle gourd (Sakigake) and squash hybrid (Shintosa) as rootstocks which were grafted through scion-incision method. It was revealed that diameter of the watermelon (Fujihikari) grafted onto bottle gourd rootstocks was higher (24.0 cm) than non-grafted plants (18.50 cm).

El-Sayed *et al.* (2014) tested the influence of grafting on cucumber cultivar Hady using several rootstocks at the University of Cairo in Egypt during the summer and winter of 2013. When cucumber cv. Hady was grafted onto the rootstock Ferro it gave the highest average fruit diameter of 30.17 mm, 31.17 mm and 30.50 mm at 30, 60 and 90 days respectively in summer planting whereas, during winter planting an

average fruit width of 25.67 mm, 25.67 mm and 27.33 mm was recorded at 30th, 60th and 90th day after planting.

Kumar *et al.* (2016b) investigated the effect of chilli and brinjal rootstocks on commercial capsicum hybrid Indra for growth, yield and quality at CSK HPKV Palampur under protected environment during 2014. It was found that cv. Indra when grafted on to rootstock Pant C-1 gave maximum fruit width (7.31 cm) followed by Indra on Surajmukhi (7.29 cm).

Johnson *et al.* (2014) conducted a research at the Washington State University's Department of Horticulture with the brinjal variety Epic grafted on rootstocks Beaufort (*S. lycopersicum* × *S. habrochaites*) and *S. aethiopicum*. The largest fruit diameter (9.70 cm) was obtained when eggplant cv. Epic was grafted onto Beaufort, while the smallest fruit diameter (8.07 cm) was obtained when eggplant cv. Epic was grafted onto *Solanum aethiopicum* rootstock.

Paroussi *et al.* (2004) conducted a study at ARC of Macedonia and Thrace (Greece) on grafting watermelon cultivar Crimson Sweet on commercial Cucurbitaceae rootstocks such as Max-2, Astra, Calago, Mammouth and Dako that are resistant to soil-borne pathogens and used as a substitute for methyl bromide. The plants grafted on Mammouth had larger fruits, but the other plants showed no discernible difference.

Turhan *et al.* (2011) conducted a study at Uludag University in Turkey during the summers of 2009 and 2010 using Arnold and Beaufort cultivars as rootstocks and the tomato cultivars Beril, Swanson and Yeni Talya as scions. Swanson/Beaufort followed by Yeni Talya/Beaufort graft combinations had the largest fruit index (diameter/length) of 1.35 and 1.34 respectively. It is concluded that grafted plants on both rootstock cultivars had fruit indices that were substantially greater than non-grafted plants on either rootstock.

Donas-Uclés *et al.* (2014) undertaken research at the University of Almera in Anecoop (Spain) on the effects of three rootstocks (Oscos, AR40 and Tresor) on the yield and commercial quality of the Italian sweet pepper cultivar Palermo throughout the spring and summer seasons of 2011 and 2012. They noticed that Palermo onto Tresor produced the highest fruit diameter (50.19 mm), whereas Palermo without the graft produced the lowest fruit diameter (49.87 mm).

Kumar *et al.* (2016a) in the Kharif seasons of 2014 and 2015 at NAU, Navsari, Gujarat, attempted grafting two cultivars of Surati Ravaiya (pink) and Surati Ravaiya (purple) onto the rootstock of *Solanum torvum* employing cleft grafting. The maximum fruit diameter recorded in grafted Surati Ravaiya Purple (7.62 cm) followed by self-rooted Surati Ravaiya Purple (7.56 cm) whereas, minimum fruit diameter (6.00 cm) was recorded in control (self-rooted Surati Ravaiya Purple).

Singh *et al.* (2019a) conducted experiments under both field and protected structure during 2018-2019 at LPU, Punjab to assess grafting success (%) between different tomato cultivars Punjab Varkha Bahar-4, Sona NTH-2829 and Heemshikhar used as scions and Brinjal cv. Navkiran was used as rootstock. The Sona NTH 2829 + Navkiran grafting combination produced the largest fruit with diameter of 5.15 cm. The next largest fruit diameters were 4.71 cm for Punjab Varkha Bahar - 4 + Navkiran and 4.34 cm for Heemshikhar + Navkiran.

Arefin *et al.* (2019) in an experiment, investigated the compatibility of two tomato scions on three different potato rootstocks and came to the conclusion that BARI- Tomato-11 (25-day-old seedlings) produced the largest fruit, measuring 3.94 cm when used as scion and Cardinal as rootstock, followed by 3.18 cm when used as scion and Diamant as rootstock.

Romano and Paratore (2000) carried out a study in greenhouse on the impact of grafting on fruit production of tomato cultivar Rita and eggplant cultivar Mission bell grafted on three distinct rootstocks, namely Energy, PG 3 (tomato) and Beaufort (interspecific hybrid), on the island of Sicily (Mediterranean coast). The Beaufort rootstock boosted the vigour and output of grafted tomatoes but had no effect on fruit quality.

2.3.8 Polar Diameter (cm)

Davis and Perkins-Veazie (2005) at USDA-ARS, Oklahoma investigated effects of rootstocks like 1330 (hybrid squash), 1332 and 451 (*Cucurbita siceraria* and Ferro (*Cucurbita maxima* x *Cucurbita moschata*) in 2006, at Tehran University. It was reported that cv. Charleston gray grafted onto Ferro gave fruit length of 39.33 cm and on *Cucurbita pepo* recorded the lowest fruit length of 36.58 cm.

Johnson *et al.* (2014) in WSU, Washington during period of 2010-2011 tested the influence of brinjal cultivar Epic grafted on the rootstocks Beaufort

(*S. lycopersicum* × *S. habrochaites*) and *S. aethiopicum*. The longest fruit length (20.29 cm) was achieved when brinjal cv. Epic was grafted onto Beaufort, while the shortest fruit length (18.22 cm) was achieved when brinjal cv. Epic was grafted onto *Solanum aethiopicum*.

El-Sayed *et al.* (2014) reported that when cucumber cv. Hady grafted onto the rootstock Ferro it recorded the highest average fruit length of 15 cm, 14.17 cm and 15 cm at 30th, 60th and 90th day respectively, in summer planting whereas, in winter planting grafted cv. Hady recorded the highest fruit length of 15.17 cm, 15.00 cm and 15.00 cm.

Kumar *et al.* (2016b) investigated the effects of chilli and brinjal rootstocks on commercial capsicum hybrid Indra for growth, yield and quality at CSK HPKV Palampur under protected environment during 2014. The chilli rootstock AVPP0205 produced longer fruits (8.52 cm), whereas brinjal rootstocks produced fruit lengths ranging from 7.74 cm to 7.66 cm in capsicum hybrid Indra.

Kumar *et al.* (2016a) in the Kharif seasons of 2014 and 2015 at NAU, Navsari, Gujarat, attempted grafting two cultivars of brinjal *i.e.*, Surati Ravaiya (pink) and Surati Ravaiya (purple) onto the rootstock of *Solanum torvum* using cleft grafting. The grafted Surati Ravaiya (Pink) produced longest fruit (8.1 cm), followed by the self-rooted Surati Ravaiya (Pink) (8.06 cm), while the control self-rooted Surati Ravaiya Purple had the shortest fruit (6.71 cm).

Singh *et al.* (2019a) carried out studies at LPU in Punjab in both the field and a protected structure to measure the grafting success (per cent) between several tomato cultivars such as Punjab Varkha Bahar-4, Sona NTH-2829 and Heemshikhar utilised as scions and Brinjal cultivar Navkiran as the rootstock. Findings revealed that the grafting combination Sona NTH 2829 + Navkiran produced the longest fruit length (4.15 cm), which was comparable to the grafting combination Punjab Varkha Bahar-4 + Navkiran (3.94 cm).

Arefin *et al.* (2019) in a study on grafting compatibility of two tomato scions on three different potato rootstocks at Sher-e-Bangla Agricultural University, Dhaka, Bangladesh, concluded that BARI- Tomato-11 (25-day old seedlings) as scion and Cardinal as rootstock, recorded maximum fruit diameter of 5.18 cm followed by

BARI Tomato-11 (35-day old seedlings) used as scion and Cardinal as rootstock 4.60 cm.

2.4 Quality parameters as influenced by grafting

2.4.1 Pericarp thickness (mm)

Kumar *et al.* (2017) conducted an experiment using seven different rootstocks and horticulturally superior scion Avtar to study various attributes. They concluded that graft VI034845 + Avatar had the maximum pericarp thickness (4.16 mm) which was statistically at par with the graft combination VI047335 + Avatar (4.06 mm).

Sharma *et al.* (2018) examined the performance of grafted tomatoes in terms of growth, yield and quality. Plants grafted on rootstock Palam Pride had pericarp thickness of 6.60 mm, followed by Back Attack (6.26 mm), Hawaii-7998 (6.24 mm) and Hawaii-7996 (6.22 mm).

Sakata *et al.* (2007) in their study on the effects of various rootstock combinations and grafting techniques on water melon yield and quality, found that pumpkin (*Cucurbita* spp.) rootstocks can have a negative impact on the fruit quality of grafted watermelons, resulting in a thicker pericarp, poorer soluble solids, and an excessively firm fibrous texture.

2.4.2 TSS (°B)

The TSS/TA ratio is regarded as one of the most important factors determining fruit flavour. The increase of TSS/TA in fruit means the flavour change from original sour to a sweeter taste (Zhang and Guo, 2019).

Zhang and Guo (2019) conducted experiment from spring to summer 2017 in a greenhouse at the Tuber and Root Crops Research Institute, Yunnan, China using tomato hybrid Zhongyan 988 as scion and four potato cultivars, Lishu 6, Qingshu 9, Hezuo 88 and Diantongshu 1 as rootstock using the cleft grafting approach. The potato rootstocks had a considerable impact on the TSS with values in each grafting combination being much greater than those in the fruits of self-rooted tomato plants.

Kumar *et al.* (2017 a) used the commercial hybrid tomato Avtar as a scion and seven different tomato and brinjal rootstocks-namely, Hawaii 7996, Hawaii 7998, Palam Pink, Palam Pride, VI034845, VI45276 and VI047335 in a greenhouse at CSK HPKV Palampur in 2012-2013. TSS content was highest (6.23%) in the graft

combination VI034845 + Avatar, followed by combination VI047335 + Avatar (5.96%).

Soare *et al.* (2018) examined the effects of tomato grafting on numerous morphological, yield and quality parameters in the University of Craiova, Romania between 2013 and 2014. When Lorely F₁ (scion) grafted onto Beaufort rootstock maintaining two stems the results determined that they had a higher TSS value of 4.3 per cent, whereas with one stem (training) had a value of 4.1 per cent.

Kumar *et al.* (2018) conducted an experiment which consisted of eight rootstocks that included 6 tomato (2123 A-1, Pumpkin Jalag, Hawaii 7998, Palam Pink, Palam Pride, Hawaii 7996) and 2 brinjal cultivars (Arka Nidhi and Arka Keshav), the scion involved were three tomato hybrids *viz.*, Naveen 2000+, Rakshita and GS-600. Results obtained indicated that treatment 2123 A-1 + Rakshita resulted in highest TSS of 6.13.

Sharma *et al.* (2018) conducted a study to examine the performance of grafted tomatoes in terms of yield and quality, where plants grafted on rootstock Arka Nidhi gave the highest TSS (5.48 ° Brix) and was found to be significantly superior to other rootstocks in terms of growth, yield and quality.

Singh *et al.* (2019a) in an experiment investigated the effect of several tomato scions grafted on brinjal rootstock and found that Punjab Varkha Bahar 4 + Navkiran combination gave the highest total soluble solids (5.90 ° Brix), followed by Sona NTH 2829 + Navkiran (4.72 ° Brix).

Alexopoulos *et al.* (2007) studied fruit yield and quality of watermelon in relation to grafting involving four rootstocks (Early Max, Long gourd, F-14 gourd and Max-2 hybrid) and a scion (Crimson Sweet) and reported that the fruits from grafted plants had a thicker rind and slightly lower total soluble solids content than the fruits from non- grafted plants.

2.4.3 Lycopene content (mg/100g)

Mišković *et al.* (2009) performed three year study (2004-2006) in a poly-tunnel at the Faculty of Agriculture in Novi Sad, Serbia, utilising the cultivar Jeremy as a scion that was grafted onto rootstocks Vigomax, Beaufort, Maxifort, Madona (an F₁ brinjal hybrid), *Solanum lycopersicum* var. *cerasifoirmae*, *Solanum lycopersicum* var. *pruniform* and *Solanum lycopersicum* var. *pyriformae*. The results showed that

rootstock Madona had the highest amount of lycopene (5.69 mg/ 100 g), whereas rootstock Maxifort had the lowest amount (2.90 mg/ 100 g).

Kumar *et al.* (2018) conducted an experiment which consisted of eight rootstocks and three tomato varieties as scions. They recorded that treatment Arka Nidhi + Rakshita had the highest lycopene contents of 22.90 mg/100 g.

Soare *et al.* (2018) carried out an experiment to determine the effects of tomato plant grafting on production, morphological and nutritional qualities. The Lorely F₁ cultivar was used as scion and Beaufort as rootstock. The results showed that Lycopene content was higher in the graft combination Beaufort + Lorely F₁ with two stems (112.4 mg/100 g) than in the graft combination Beaufort + Lorely F₁ with one stem (110.3 mg/100 g).

Özdemir and Çandır (2018) in Alata Horticultural Research Institute, Mersin (Turkey) evaluated watermelon scions Crisby and Crimson Tide in grafting experiment to assess their postharvest quality at 7 °C for 21 days when grafted onto rootstocks *viz.*, Macis, RS841, Argentario and Ferro and also un-grafted scions were compared with grafted ones. In the Crisby cultivar, all grafted fruits showed higher lycopene levels at harvest than non-grafted fruit, but after 21 days of storage, the lycopene levels of non-grafted and grafted fruit was found to be identical. After 21 days of storage, the lycopene concentration of fruit grafted on the RS841, Argentario, and Ferro rootstocks in the Crimson Tide cultivar was higher than that of fruit on Macis and non-grafted fruit.

2.4.4 Ascorbic acid content (mg/100 g)

Diwan and Sharma (2021) conducted an experiment to ascertain the degree of change in the qualitative content of tomato grafts utilising various rootstocks, scions and grafting techniques at IGKV's research farm in Raipur (Chhattisgarh). The experiment included two grafting techniques (cleft and the splice method) together with three tomato hybrids (Aviral, Yuvraj and Lakshmi) as scions and two potato cultivars (Kufri Jyoti and Kufri Pukhraj) as rootstocks. The maximum ascorbic acid level in tomato *i.e.*, 8.90 mg and 8.47 mg was observed when grafted on Kufri Pukhraj and Kufri Jyoti rootstocks, respectively. Comparing with three scions under research, Yuvraj had the highest concentration of ascorbic acid (9.07 mg), whereas

Aviral (8.67 mg) and Lakshmi's (8.33 mg). The splice approach of grafting gave highest ascorbic acid level (8.79 mg).

Mišković *et al.* (2009) undertook a three-year study in a polytunnel (2004-2006) at the Faculty of Agriculture in Novi Sad, Serbia, using the cultivar Jeremy as a scion that was grafted onto rootstocks Vigomax, Beaufort, Maxifort, Madona (brinjal F₁), *Solanum lycopersicum* var. *cerasifoirmae*, *Solanum lycopersicum* var. *pruniform* and *Solanum lycopersicum* var. *pyriformae*. The highest vitamin C content was observed in the combination of Jerney + Madona (26.15 mg/100 g) and lowest value was measured in Jerney + Vigomax (22.22 mg/100 g).

Kumar *et al.* (2017) conducted an experiment using seven different rootstocks and the horticulturally superior Avtar as scion and found that plants grafted with brinjal rootstock VI034845 recorded the highest levels of ascorbic acid (31.20 mg/100g), which was statistically higher than all other rootstocks in the study, followed by rootstock VI047335 (30.00 mg/100 g).

Soare *et al.* (2018) evaluated the effects of tomato grafting on morphological, production and nutritional qualities. The Lorely F₁ cultivar was grafted onto the Beaufort rootstock and the results showed that Ascorbic acid concentration was higher in the graft combination Beaufort + Lorely F₁ with two stems (17.5 mg/100 g) followed graft combination Beaufort + Lorely F₁ with one stem (14.0 mg/100 g).

Sharma *et al.* (2018) examined the performance of grafted tomatoes in terms of quality, yield and growth and the results depicted that the plants grafted on the rootstock Palam Pink (21.94 mg/100 g) and VI-34845 (20.53 mg/100 g) gave the highest ascorbic acid content.

Zhang and Guo (2019) conducted a study in a poly-house at the Tuber and Root Crops Research Institute, Yunnan, China, utilising the potato cultivars Lishu 6, Qingshu 9, Hezuo 88, and Diantongshu 1 as rootstock and the tomato hybrid Zhongyan 988 (F₁) as the scion and grafting was carried out using the cleft approach. The ascorbic acid content in the graft combinations of Zhongyan 988/ Qingshu 9, Zhongyan 988/ Lishu 6 and Zhongyan 988/ Hezuo 88 significantly increased by 33.94%, 31.40% and 23.36%, respectively, compared to un-grafted tomato plants.

Kumar *et al.*, (2018) conducted an experiment which consisted of three tomato varieties as scions viz. Rakshita, Naveen 2000+ and GS-600 and eight rootstocks viz. Pumpkin Jalag, 2123 A-1, Hawaii 7996, Palam Pride, Hawaii 7998, Palam Pink (Tomato), Arka Nidhi and Arka Keshav (Brinjal). It was found that treatment Arka Keshav + Naveen 2000+ recorded highest ascorbic acid of 39.80 mg/100g.

Singh *et al.* (2019a) examined the effect of several tomato scions grafting on brinjal rootstock and found that Sona NTH 2829 + Navkiran gave highest vitamin C content (10.83 mg/100 g), followed by the Heemshikhar + Navkiran (9.31 mg/100g).

Ofori (2015) conducted an experiment in University of Ghana using three *Solanum* species namely, Gboma, Black Beauty and Obaapa as rootstocks and two tomato varieties Fadebege and Nkansah HT as scions. The results showed that grafting tomatoes onto Black Beauty outperformed non-grafted plants in terms of plant growth, yield quality and shelf life. Compared to non-grafted plants, grafted plants had considerably lower brix, TA, TSS:33TA, pH, vitamin C and lycopene contents.

Granges *et al.* (1998) found that grafted tomatoes had 65 per cent higher yield. Tomatoes from grafted plants contained more mineral salt but had a lower dry matter content. However, grafting had no effect on vitamin C levels.

MATERIALS AND METHODS

The present investigations entitled “Graft Compatibility Studies for Resistance to Root-Knot Nematode in Tomato (*Solanum lycopersicum* L.)” was conducted during spring and rainy season of 2020-21 and 2021-22 at the Experimental Research Farm-I and II of Division of Vegetable Science and Floriculture, Chatha as well as in the laboratory of Division of Vegetable Science and Floriculture, SKUAST - Jammu, J&K. The screening of nematodes was conducted at laboratory of AICRP Nematodes, Chatha. In this chapter, the materials used for the research and methods followed are described below.

3.1 Location and climate

The experimental site was located 32.69⁰ N latitude 74.65⁰ E longitude and at an altitude of 336 meters above the mean sea level. The maximum temperature goes up to 45°C during summers (May to June) and minimum temperature falls to 10°C during winter. The mean annual rainfall is about 1000-1200 mm. The mean meteorological observations recorded at Meteorological observatory of SKUAST, Jammu for the period during the crop growth period are presented in the Fig. 1.

3.2 Experimental material

The experimental material for the present investigation consisted of 18 genotypes/hybrids of *Solanaceous* spp. (fourteen varieties/hybrids of tomato and brinjal along with four wild species). The details of the material used and their sources are given below:

Table 3.1: List of genotypes along with their sources used in the study.

S. No.	Genotypes	Source
a. Varieties of tomato, cherry tomato and brinjal		
1.	Pusa Ruby	IARI, New Delhi
2.	Roma	IARI, New Delhi
3.	PKM 1	TNAU, Tamilnadu
4.	Hisar Arun	CCS HAU, Hisar
5.	SJCT-01	SKUAST, Jammu
6.	Pusa Cherry Tomato	IARI, New Delhi
7.	Punjab Kesar Cherry	PAU, Ludhiana
8.	Punjab Red Cherry	PAU, Ludhiana
9.	Punjab Raunak	PAU, Ludhiana
10.	Pusa Purple Cluster	IARI, New Delhi
11.	Punjab Varkha Bahar 4	PAU, Ludhiana
b. Hybrids of tomato		
12.	Arka Samrat	IIHR, Bengaluru
13.	Arka Rakshak	IIHR, Bengaluru
14.	Palam Tomato Hybrid 1	CSK HPKV, Palampur
c. Wild <i>Solanum</i> species under study		
1.	<i>Solanum torvum</i>	SKUAST, Jammu
2.	<i>Solanum xanthocarpum</i>	SKUAST, Jammu
3.	Interspecific Hybrids (<i>Solanum melongena</i> × <i>Solanum khasianum</i>)	SKUAST, Jammu
4.	<i>Solanum khasianum</i>	SKUAST, Jammu
5.	<i>Solanum indicum</i>	SKUAST, Jammu

3.3 Experimental Plan

3.4 Experiment no. 1: Evaluation of tomatogenotype(s) for horticultural traits and incidence of nematode (Scion).

No. of genotype(s)	: 08
Spacing	: 60 cm×45 cm
Design	: RCBD
Replications	: 03

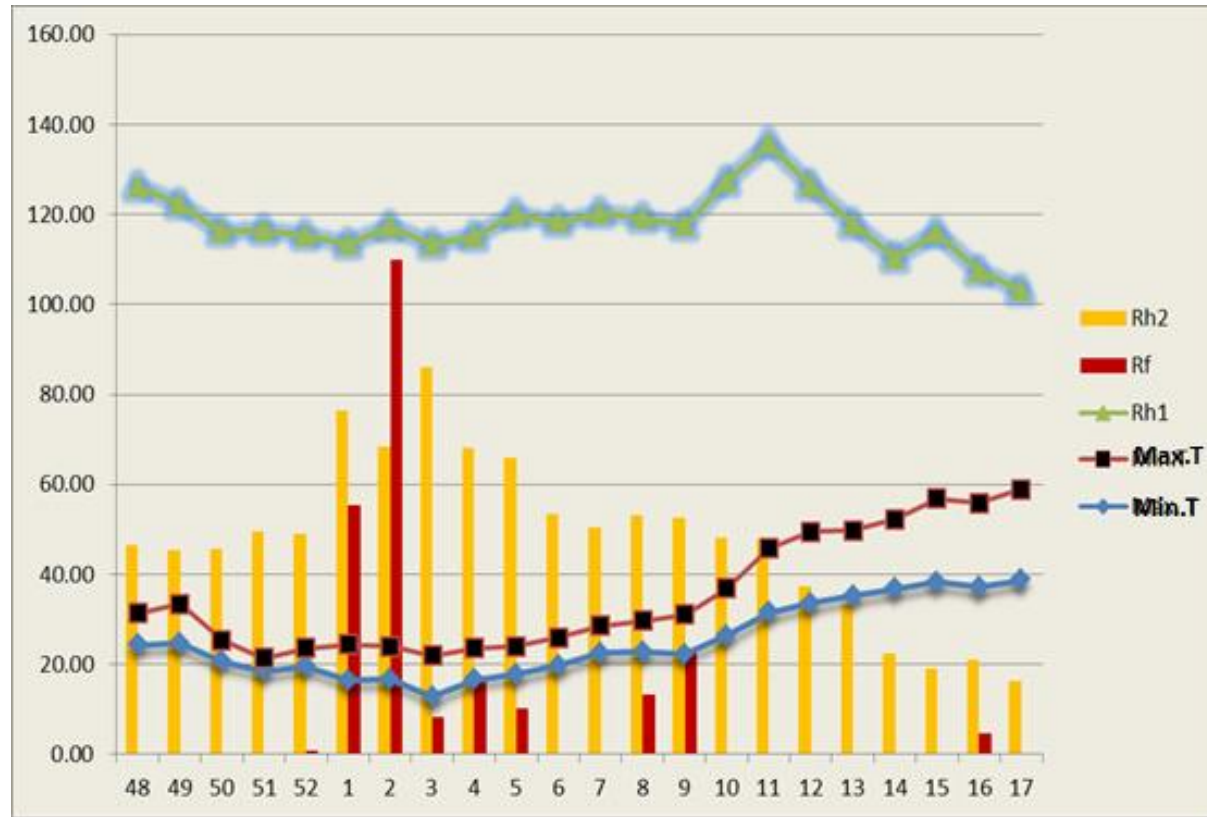


Fig. 1. Meteorological data recorded during the experimental period (Nov. 2021 to April 2022)



Plate.1. Survey for collection of root-knot infected plant samples

A. Chilli field, Badyal Brahmana, B. Tomato field, Badyal Brahmana, C. Brinjal field, Jhiri,

D. Tomato field, Chak Ghasian, E and F. Brinjal field, Lower Barnai



Typical symptom of root-knot nematode infection on cucumber roots
Plate.2. Survey in commercial polyhouse erected near village Shama Chak
Location: 32° 49'30''N latitude to 74° 44'39'' E longitude

3.4.1 Layout and design of the experiment

During 2020-21, seeds of the eight genotypes were sown in nursery bed. The transplanting was done in RCBD with three replications for evaluation of horticultural traits and incidence of nematode. All the cultural practices were followed as per recommendations specified in Package and Practices, SKUAST, Jammu (SKUAST, 2022) to raise a healthy crop.

Experiment 2: Screening of wild and cultivated *Solanum* spp. against resistance to root-knot nematode (stocks)

3.5.1 Survey

A detailed survey was conducted during the summer season of 2021 to collect the root-knot nematode infected plant samples in different vegetable growing areas of Jammu Division, viz., Shama Chak, Badyal Brahmana, Jhiri, Chak Ghasian and Lower Barnai (Plate 1). Soil and root samples were collected from the areas to identify the species, estimate nematode population and to create artificial disease epiphytotic conditions for the screening of genotypes for resistance against root-knot nematode (Plate 2).

3.5.2 Preparation and maintenance of pure culture of nematodes

Plant roots infected with root knot nematode galls were collected. Juveniles were extracted from infested plantroots using modified Baermann tray method (Whitehead and Hemming, 1965). The roots were chopped with a pair of scissors and 5 g weight of each entry was placed in a plastic sieve lined with a ply-two tissue paper placed in a plastic plate. Tap water was poured gently into the plastic plate in which the sieve was placed until the tissue became moist. The set up was left for 48 h and the plates were then poured separately into beakers and left overnight for the juveniles to settle. Each nematode water suspension was separately topped with tap water to 30 ml for standardization. Each suspension was homogenized by blowing air through with a pipette. Counting was done three times to obtain the mean number of juveniles.

For screening of different wild and cultivated *Solanum* rootstocks against *M. incognita*, seeds of *Solanum* germplasm were obtained from the Division of Vegetable Science and Floriculture, SKUAST, Jammu. Earthen pots of 15 cm diameter were used after washing them with water. 1-3 seeds/pot were sown in 1000g

clay pots filled with sterilized soil and after germination thinning to one seedling/pot was practised.

Freshly hatched second stage juveniles (J₂) of *Meloidogyne incognita* were isolated and were counted in rectangular counting dish under a stereoscopic microscope (Plate 3). Number of Juveniles per ml of suspension was counted by taking at least three counts in average before inoculations. In order to add the same amount of nematode suspension to all of the replications the level of juveniles was adjusted with water. Each pot was inoculated with infective J₂ of root-knot nematode, *M. incognita* @ 1000 J₂/kg soil on 15 days after sowing. Inoculation was done by removing top 1 cm of soil near seedling, then pouring the nematode suspension and covering it with freshly autoclaved soil.

3.5.3 Assessment of the tomato plants for root knot nematode infection

Seeds were sown in pots and each pot was inoculated J₂'s on 15 days after sowing and observations were recorded 30 days after sowing (45-days old seedlings). The 45-days old seedlings were uprooted carefully with minimum damage to roots and were washed under running tap water to remove soil. Galling was scored on scale of 1-5 rating chart by Heald *et al.*, 1989. From each treatment of each replication, observations on numerous parameters, including the quantity of galls per plant, the weight of fresh and dried shoots and roots, the number of galls per plant, and the lengths of the shoots and roots, were recorded.

3.5.4 Fresh shoot and root weight

After 30 days of inoculation, test plants were uprooted gently. In order to ensure easy removal of soil from the plants, the sides of the soil pressed to loosen the soil. The soil was then removed from the roots by gently shaking the plants. Root portion was separated from the top (cut at soil line) and fresh shoot and root weight of each entry was separately measured using an electronic balance by placing the plant on the scale and readings were taken.

3.5.5 Dry shoot and root weight

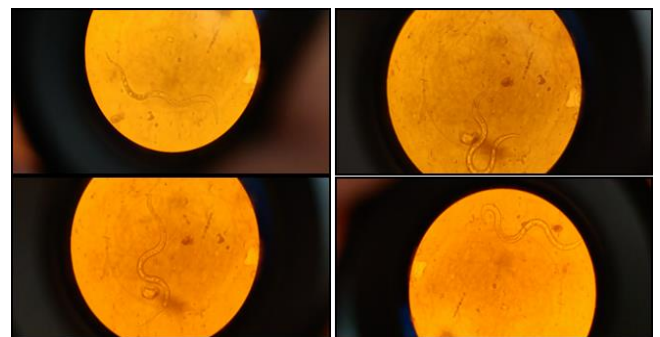
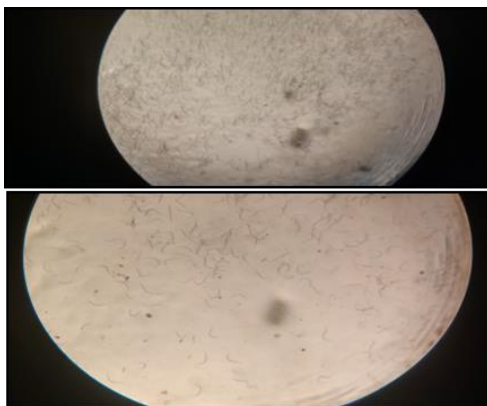
After taking the fresh shoot and root weight, the samples were subjected to blot for the removal of surface moisture. The samples were oven dried overnight at low heat (100° F). Later the samples were let to cool in a dry environment (a Ziploc



1. Roots were washed, chopped into small pieces and then transferred to blender
2. Contents were poured into a tissue paper net assembly



3. Nematodes were collected daily from petri-plates and fresh water was added



4. Catch was examined for nematodes under stereoscopic microscope

Plate. 3. Extraction of nematodes from infected roots (Modified Baermann Funnel Technique). -Whitehead and Hemming, 1965

bag keeps moisture out) because in a humid environment the tissue takes up water. Once the samples were cooled, they were weighed on an electronic balance.

3.5.6 Shoot length and root length

45-days after sowing, shoot length in cm was measured from the collar region to the tip of the plant and for root measurement, root length was measured on intact roots from the soil contact point to the tip using a centimetre ruler.

Table 3.2: Root-knot Index Scale (Heald *et al.*, 1989)

Gall Index	Observation	Reaction
1.	No galls & egg masses	Highly Resistant
2.	13-19galls/egg masses	Resistant
3.	35-53 galls/egg masses	Moderately Resistant
4.	58-64 galls/egg masses	Susceptible
5.	79-88 and above galls/egg masses	Highly Susceptible

3.6 Experiment 3: Graft compatibility studies and evaluation of successful graft combinations

Eight varieties/hybrids of tomato collected from diverse agro-climatic regions of India were evaluated for horticultural traits and two promising genotypes out of eight were chosen as scion. Artificial screening of ten wild and cultivated brinjal and cherry tomato genotypes were performed against resistance to root-knot and six tolerant genotypes were identified and utilised in the study. Thus selected scion and rootstock genotypes were used in the graft compatibility studies.

Table 3.3: The detail of rootstocks and scions used along with their sources

Sl. No.	Variety/ Species	Source
a. Rootstocks		
1.	<i>Solanum torvum</i>	SKUAST, Jammu
2.	<i>Solanum xanthocarpum</i>	SKUAST, Jammu
3.	<i>Solanum indicum</i>	SKUAST, Jammu
4.	<i>Solanum khasianum</i>	SKUAST, Jammu
5.	SJCT-01	SKUAST, Jammu
6.	Punjab Raunak	PAU, Ludhiana
b. Scion		
1.	Arka Samrat	IIHR, Bengaluru
2.	Arka Rakshak	IIHR, Bengaluru

3.6.1 Design and layout

During 2021-22, the experiment was laid out in Randomized Block Design with 14 treatments which were replicated thrice at 0.6 m x 0.45 m spacing. All the recommended cultural practices to raise a healthy crop were followed as per the recommendations of Package of Practices of Vegetable crops (SKUAST, 2022).

3.6.2 Details of treatment combination

The details of treatment combinations are given in Table 3.4.

Table 3.4: List of graft combinations and non-grafted checks used in grafting studies

Treatments	Root and scion combination
T ₁	Arka Samrat on SJCT 01
T ₂	Arka Rakshak on SJCT 01
T ₃	Arka Samrat on Punjab Raunak
T ₄	Arka Rakshak on Punjab Raunak
T ₅	Arka Samrat on <i>Solanum indicum</i>
T ₆	Arka Rakshak on <i>Solanum indicum</i>
T ₇	Arka Samrat on <i>Solanum xanthocarpum</i>
T ₈	Arka Rakshak on <i>Solanum xanthocarpum</i>
T ₉	Arka Samrat on <i>Solanum khasianum</i>
T ₁₀	Arka Rakshak on <i>Solanum khasianum</i>
T ₁₁	Arka Samrat on <i>Solanum torvum</i> Swartz
T ₁₂	Arka Rakshak on <i>Solanum torvum</i> Swartz
T ₁₃	Arka Samrat (Check-1)
T ₁₄	Arka Rakshak (Check-2)

3.6.3 Sowing

The seeds of wild rootstocks were soaked in water overnight before sowing to facilitate early and good germination. Seeds of wild rootstocks were sown 3-4 weeks before the scion seeds and the seeds of cultivated rootstocks were sown a week before sowing scion seeds. To overcome the problem of uneven germination in wild seeds,

the seeds were sown in plastic trays with sterilized coco peat and then transplanted to 98 celled pro-trays at two true leaf stages.

3.6.4 Grafting and care of grafted seedlings

The seedlings of scion and stocks were raised under partial shade and then exposed to direct sunlight for 1-2 days before grafting (Plate 4a & b).

Grafting was carried out when the scion seedlings attained 2-3 true leaf stage (20-25 days) with stem diameter of 3-4 mm, the wild rootstocks at 3-4 true leaf stage (55-60 days) and the cultivated rootstocks at 3-4 true leaf stage with the stem diameter of 3-4 mm. Grafting was carried out under shade during cool hours preferably in the evening (Plate 4c).

Two cultivated hybrids *viz.*, Arka Samrat and Arka Rakshak were grafted onto the six rootstocks using wedge grafting and cleft grafting methods (Plate 5). Non-grafted seedlings of Arka Samrat and Arka Rakshak were used as a control for assessing the growth and yield of tomato.

For five to six days, the grafted seedlings were covered with transparent polythene bags as a relative humidity of 85 to 95 per cent required in order to promote the healing of the graft union. The polythene bags covered over grafted seedlings were punched with 3-4 holes after successful graft union to gradually decrease the relative humidity inside. Then, the healed grafts were transferred to the normal nursery and allowed for further healing for a week under the shade. The grafts were gradually exposed to sunlight for one to two days prior to transplant. After transplanting of the graft combinations along with the non-grafted checks in the field data were recorded for various characters.

3.6.5 Observations recorded

Observations on various parameters of vegetative, flowering and yield parameters were recorded on randomly selected five plants for each treatment in each replication and selected plants were used for recording data. The selected plants were worked out to give means in respect of all parameters, which were used in statistical analysis for under mentioned characters. The details of observations recorded were as follows:

3.6.5.1 Plant height (cm)

Plant height was recorded by measuring the length from base to the tip of the plant in the labelled plants in each graft combination and each replication with the help of meter rod, average was worked out and expressed in centimetres.

3.6.5.2 Days taken for 50 % flowering

Days to 50 per cent flowering was recorded by counting days from the day of transplanting to the day when at least 50 % of the plants had started flowering in the labelled plants.

3.6.5.3 Number of primary branches

Number of primary branches arising from the main stem above the ground level at the end of season on labelled plants in each replication was noted as number of primary branches and expressed as numbers.

3.6.5.4 Number of clusters per plant

Five clusters in each tagged plant were marked and numbers of trusses/clusters per plant were recorded. Observations were averaged to get the number of clusters per plant.

3.6.5.5 Number of flowers per cluster

Five clusters in each tagged plant were marked and numbers of flowers per cluster were recorded at 50 % flowering stage. Observations were averaged to get the number of flowers per cluster.

3.6.5.6 Number of fruits per cluster

Five clusters in each of the tagged plants were marked and fruits per cluster were counted observations were averaged to get the number of fruits per cluster.

3.6.5.7 Total number of fruits per plant

The number of fruits from each picking of each tagged plant was pooled and the total number of fruits per plant was recorded.

3.6.5.8 Average fruit weight (g)

The weight of five random marketable sized fruits of the labelled plants were recorded and averaged to calculate the average fruit weight and expressed in grams.



1. Selection of scion

2. Selection of rootstocks

Plate 4a. Steps involved in the grafting

(a) Prepping seedling rootstock



(b) Preparing the scion



(c) Securing graft union



3. Creation of a graft union by physical manipulation

Plate 4b. Steps involved in the grafting



Maintaining very high RH (nearly saturation) by covering the graft union with polythene bags and keeping under shade to enhance healing



Following acclimatization, plants are hardened (2-3 days of reduced watering and exposure to outside temperature) before shipping or transplanting to the open field.



4. Healing of graft union and acclimatization of the grafted plant

Plate 4c. Steps involved in the grafting



A. Wedge Grafting (Cleft Grafting)



B. Splice grafting



C. Tongue Approach/ Approach Grafting

Plate 5. Different methods of grafting

3.6.5.9 Yield per plant (kg)

The fruits at each harvest were weighed using an electronic balance and the cumulative weights over all the harvests were recorded and the mean was expressed as kilogram per plant.

3.6.5.10 Nematode gall per plant and eggs per egg mass

The plant samples from each treatment were uprooted, and any galls or other signs of a root-knot nematode infection were visually inspected on each plant sample. The plant roots showing any symptom of nematode infection were further underwent additional testing in the laboratory. The galling was scored on the scale of 1-5, using a rating chart by Heald *et al.*, 1989 and galls obtained were counted under the compound microscope and recorded.

3.6.6 Observations recorded from the graft combinations

3.6.6.1 Graft success (%)

Graft success was recorded on 7th day and 15th day after grafting and on the day transplanting and 15 days after transplanting based on wilting of the grafts and drying of healing region. It was calculated by number of plants died to the total number plants multiplied by hundred and it is expressed in percentage.

3.6.6.2 Equatorial diameter of fruit

Fruit equatorial diameter was measured from fruit breadth at highest bulged portion of the fruit with the help of digital Vernier Callipers.

3.6.6.3 Polar diameter of fruit

Fruit polar diameter was measured from stalk end to blossom end with the help of digital Vernier callipers.

3.6.6.4 Total Soluble Solids (⁰B)

Tomato juice was extracted from red ripe fruits, and a drop of juice was placed over the prism of hand refractometer. Digital ATAGO, sancu, pocket refractometer of a Japanese company having a reading range of 0 to 50° Brix was used for TSS analysis. The total soluble solids recorded were averaged over five fruits for each genotype separately.

3.6.6.5 Pericarp thickness (mm)

Pericarp thickness of 5 randomly picked fruits was measured after cutting the fruits transversely. Measurement was done with digital Vernier Calliper in millimeters and mean value was worked out.

3.6.6.6 Lycopene content (mg/100 g)

The analysis lycopene content in the tomato fruits was estimated by using method of Bunghez *et al.*, 2011. Absorption determination for lycopene content was made by using Spectrophotometer. Lycopene in the tomato and the tomato products samples was extracted with hexane:ethanol:acetone (2:1:1)(v/v) mixture following the method of Sharma and Le Maquer (1996). One gram of the homogenized samples and 25 ml of hexane:ethanol:acetone, which were then placed on the rotary mixer for 30 min., adding 10 ml distilled water and was continued agitation for another 2 min. The solution was then left to separate into distinct polar and non-polar layers. The absorbance was measured at 472 nm and 502 nm, using hexane as a blank. The lycopene concentration was calculated using its specific extinction coefficient (E 1%, 1 cm) of 3450 in hexane at 472 nm and 3150 at 502 nm. The lycopene concentration was expressed as mg/100g product.

All determinations were repeated for three times.

At $\lambda = 472$ nm: lycopene content (mg/100g) =

$$\frac{E}{3,45} \cdot \frac{20}{m}$$

At $\lambda = 502$ nm: lycopene content (mg/100g) =

$$\frac{E}{3,45} \cdot \frac{20}{m}$$

m – The weight of the product (g)

E – Extinction coefficient

3.6.6.7 Ascorbic acid content (mg/100 g of fresh fruit weight)

The ascorbic acid content in tomato fruits was determined by following the 2, 6 dichlorophenol indophenols titration method (A.O.A.C., 1975) and was expressed in mg per 100 g of the fresh fruit weight.

Principle

The effective reducer is vitamin C. It oxidizes dehydro ascorbic acid after reducing 2, 6-dichloroindophenol dye to a colourless solution. When vitamin C is placed in an acidic media, oxalic acid is added to help it dissolve and become stable. The dye itself serves as an indication and produces a light pink colour as the end product.

Reagents

4% oxalic acid, 2, 6-dichlorophenol indophenol dye, standard ascorbic acid

Procedure

Ascorbic acid standard preparation

Weigh 100 mg of the ascorbic acid and dissolve in 100 ml of 4% oxalic acid solution. This is the stock solution. For the preparation a working standard, pipette out 10 ml of standard and make up to 100 ml using 4% oxalic acid.

Preparation of 4% oxalic acid solution

Weight 4g oxalic acid and dissolve in 100 ml of distilled water. This gives 100 ml of 4% oxalic acid. To obtain 2.5 liter of 4% oxalic acid dissolve 100g of oxalic acid in 2.5 liters of distilled water.

Preparation of Dye solution

50 mg of sodium 2, 6-dichlorophenol indophenol salt and 42 mg of sodium bicarbonate should be dissolved in 200 ml of distilled water and allowed to cool for a few minutes.

Standardization of dye

Add 5 ml of oxalic acid to 5 ml of standard ascorbic acid solution. The dye should be put into a micro burette. Use the dye solution to titrate to a pink color that should last for 15 seconds. Utilize the formula to calculate the dye factor, or the mg of ascorbic acid per ml of the dye.

Dye factor = $0.5 / \text{Titre Value}$

Preparation of sample

4% oxalic acid should be added to 5 g of the sample before grinding. Use oxalic acid to make up to 100 ml. Take 5 ml of the sample for the titration after filtering the solution, which will yield a clear filtrate.

Titration

Titrate against the dye using 5ml of the sample and 5ml of 4% oxalic acid until a persistent pale pink color appears. Titrate against the dye using 5ml of the working standard and 5ml of 4% oxalic acid until a stable pale pink color is achieved. This is repeated as well with a blank.

Calculation

The Ascorbic acid content of the sample was calculated by using the formula:

$$\text{Ascorbic acid (mg/ 100g FW)} = \frac{\text{Titre} \times \text{Dye factor} \times \text{Volume made}}{\text{Aliquot of extract} \times \text{Volume of sample}} \times 100$$

Where,

Volume of sample taken for estimation = 20 ml

Volume made up = 100 ml

Aliquot of extract taken for estimation = 5 ml

Reagents used

(i) Metaphosphoric acid-acetic acid solution: Metaphosphoric acid 15 g was dissolved in distilled water and 40 ml glacial acetic acid was added to it and final volume was made up to 500 ml.

(ii) Indophenols standard solution: 50 mg of 2,6 dichlorophenol indophenols and 42 mg of NaHCO₃ was dissolved in distilled water and filtered, and the final volume was made to 100 ml with distilled water.

(iii) Ascorbic acid standard solution (1 mg/ml): 50 mg of ascorbic acid was dissolved in metaphosphoric acid solution and final volume was made up to 50 ml by adding metaphosphoric acid. It was kept in desiccators away from sunlight.

Procedure for extraction of tomato fruit juice

The juice of tomato was extracted by squeezing the pulp, and then, it was filtered rapidly. The extracted juice was added to equal volume of metaphosphoric acid (acetic acid) and total volume was made up to 100 ml.

Determination

Three samples each of 2.0 ml aliquots ascorbic acid standard were transferred each of 50 ml conical flask containing 5 ml of metaphosphoric acid (acetic acid) solution. It was then rapidly titrated against the indophenols solution until distinct rose colour persisted for more than five seconds.

RESULTS

The results of the present investigation entitled “Graft Compatibility Studies for Resistance to Root-Knot Nematode in Tomato (*Solanum lycopersicum* L.)” under field and laboratory conditions are presented in this chapter. Observations were recorded for growth and yield characters namely, root and shoot growth parameters from nematode infected treatments from five tagged plants in each replication. The graft combinations were evaluated to determine their effects on various traits like days taken for germination, days taken to reach grafting stage, days taken by different graft combinations for healing and success rate, plant height (cm), number of primary branches per plant, Days to 50% flowering, number of clusters per plant, number of flowers per cluster, number of fruits per cluster, number of fruits per plant and average fruit weight (g), polar diameter (cm), equatorial diameter (cm) and yield per plant (kg), Pericarp thickness (mm), TSS (°B), Lycopene content (mg/100g) and Ascorbic acid (mg/100g). The data were subjected to statistical analysis to get information on the mean performance. The analysis of variance showed significant differences among the treatments for all the characters. The results on various parameters were recorded under different heads as given below.

- 4.1 Survey
- 4.2 Screening of different *Solanum* genotypes (wild and cultivated) for resistance against root- knot nematode (*Meloidogyne incognita*).
- 4.3 Mean Performance
- 4.4 Graft compatibility studies
- 4.5 Effect of grafting on horticultural traits in tomato

4.1 Survey

4.1.1 Survey for collection of root-knot nematode infested plant samples

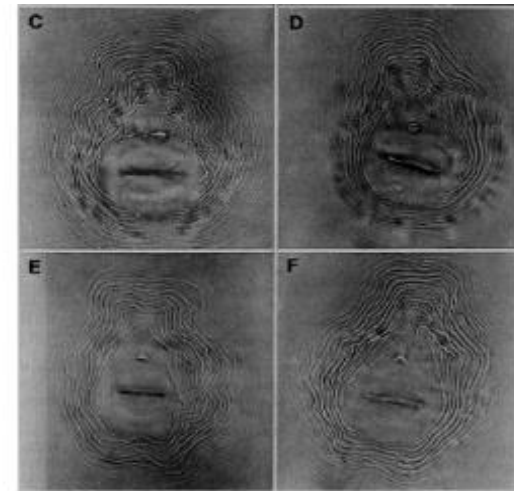
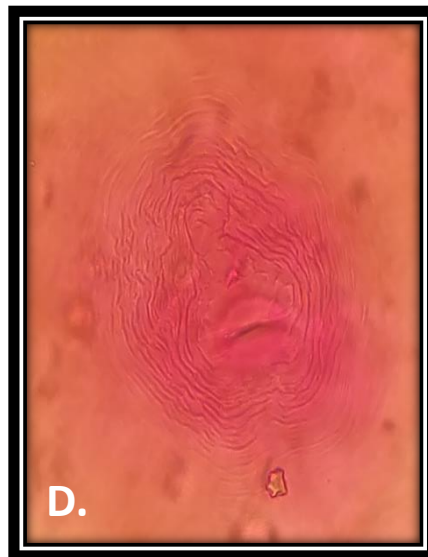
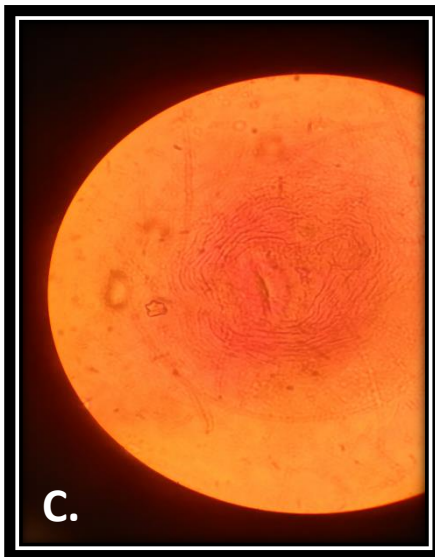
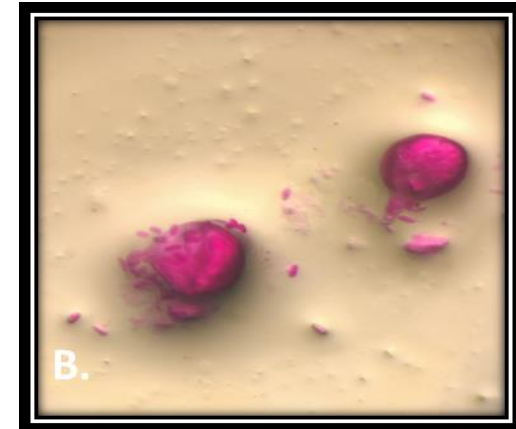
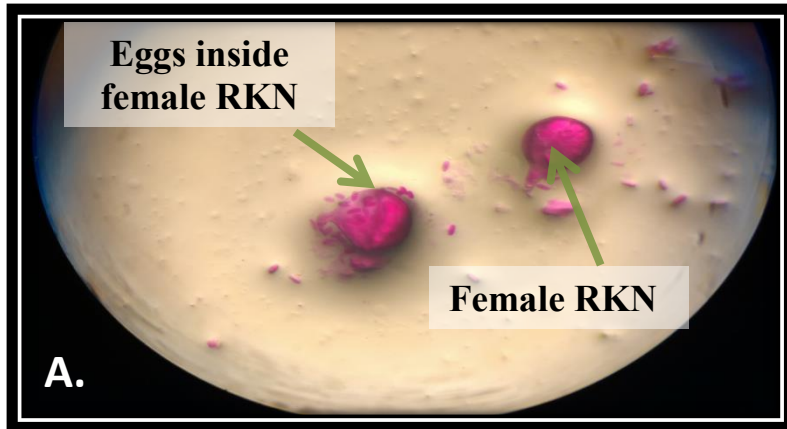
A detailed survey was conducted during the summer season of 2021 to isolate the samples of root-knot nematode in different vegetable growing areas of Jammu Division, *viz.*, Shama Chak, Badyal Brahmana, Jhiri, Chak Ghasian and Lower

Barnai. However, in all of the open-field areas surveyed there showed no to very little prevalence of RKN, making it unfeasible to gather root samples for future research. While, maximum nematode incidence was identified in a commercial polyhouse erected in the village of Shama Chak, located at 32° 49'30''N latitude to 74° 44'39'' E longitudes, which had a standing crop of cucumber that was at its final stage of harvest. Soil and root samples were collected from the polyhouse to identify the nematode species and to estimate nematode population. Thorough examination of cucumber roots, uprooted from the polyhouse indicated severe galling with innumerable knots in the root systems indicating high population densities of root-knot nematodes and severe damage to the cucumber crop (Plate 2).

4.1.2 Identification of the species

On the basis of perineal pattern characteristics, it was confirmed that the species of root-knot nematode infecting the cucumber plants was *Meloidogyne incognita*. It was observed that *M. incognita* was the only species that infected cucumber plants in the polyhouse from where the samples were drawn. Though there were insignificant differences between females, all perineal patterns of the populations showed typical *M. incognita* features. The perineal region was characterized by an angularly oval structure with a high dorsal arch. The striae were smooth to wavy, sometimes zig-zagged. Distinct lateral lines were absent but lateral field were marked by breaks and forks in the striae (Plate 6). The population density of *M. incognita* in sampled soils of the polyhouse was in the range of 1024 J2s /200cc soil to 680 J2s /200cc soil.

The cucumber plants in polyhouse examined during the survey/visit were also severely infected with the leaf miner insect. The plants exhibited typical symptoms of leaf miner infection. The young leaves depicted zig-zag mines in leaf lamina whereas the lamina was completely distorted and dried in the older leaves. Furthermore, symptoms like stunted growth, yellowing, drooping of the main stem and the cross section showed browning in vascular bundles and completely wilted plants indicated an infection by the soil-borne pathogen *viz.*, *Fusarium* spp.



E.

Eisenback *et al*, 1980

Plate 6. Microscopic study of RKN infected root samples.

A and B. Female RKN and eggs inside RKN, C and D. Perineal patterns of *Meloidogyne incognita* collected from protected structure in Shama Chak, Jammu and E. Reference image for perineal patterns of *Meloidogyne incognita*.

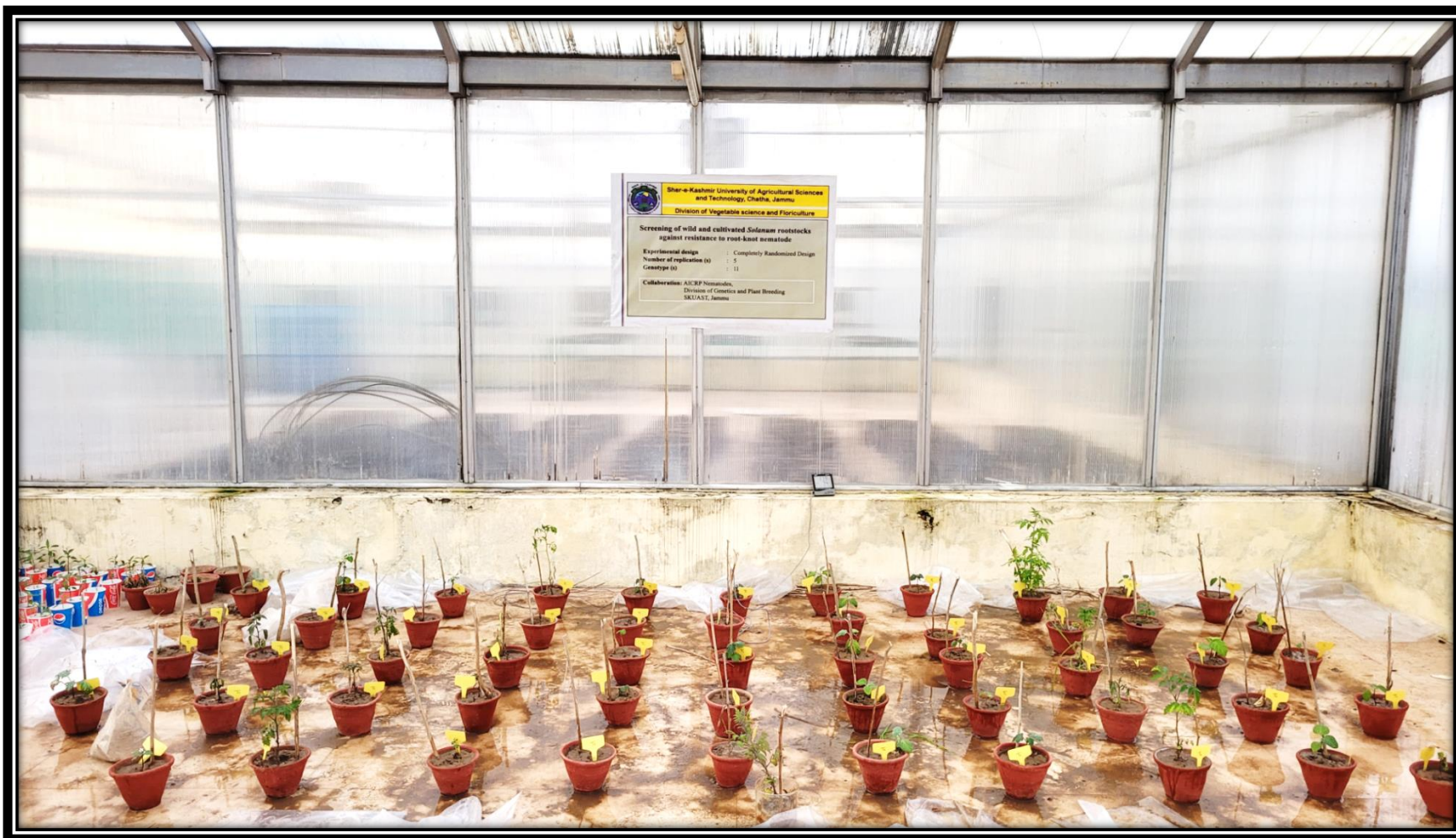


Plate 7. Overview of an experiment on screening of *Solanum* genotypes against resistance to RKN.

Table 4.1: Categorization of genotypes as per host susceptibility (Heald *et al.*, 1989)

Disease Reaction	Genotypes	No. of galls/ plant
Highly Resistant (HR)	<i>S. torvum</i>	0
Resistant (R)	<i>S. xanthocarpum</i> , <i>S. indicum</i> and <i>S. khasianum</i>	13-19
Moderately Resistant (MR)	SJCT-01, Punjab Raunak and Interspecific Hybrids (<i>Solanum melongena</i> × <i>Solanum khasianum</i>)	35-53
Susceptible (S)	Punjab Red Cherry and Punjab Kesar Cherry	58-64
Highly Susceptible (HS)	Pusa Cherry Tomato and Pusa Purple Cluster	79-88



Plate. 8. Levels of RKN infection in different *Solanm* species

A. Healthy roots of tomato, B. Roots of tomato infected with RKN, C. Healthy roots of *Solanum* and D. Roots of *Solanum* infected with RKN.

4.2 Screening of different *Solanum* genotypes (wild and cultivated) for resistance against root-knot nematode (*Meloidogyne incognita*)

Studies were conducted in screen house of AICRP, Nematodes, Division of Plant Breeding and Genetics, SKUAST-Jammu, to evaluate eleven species/varieties of *Solanum* against *M. incognita* (Plate 7). The reaction of these genotypes was recorded on the basis of number of galls formed on the roots. The seeds of wild *Solanum* species were procured from Division of Vegetable Science and Floriculture, SKUAST, Jammu. These seeds were sown in sterilized soil and were inoculated with second stage juveniles (J2) of *M. incognita* @ 1000 larva/1000g of soil at two leaf stages. Numbers of galls on roots were recorded after 45 days of sowing. The plants were uprooted 45 days after inoculation keeping entire root system intact and these were washed free off soil. The number of root-knot galls and egg masses were assessed replication wise.

4.2.1 Reaction of root-knot nematode infection on genotypes

Perusal of data (Table 4.1) of reaction of root-knot nematode infection on genotypes revealed that number of galls per plant ranged from 0 to 88 galls per plant. *Solanum torvum* (wild species) showed highly resistance reaction to *Meloidogyne incognita*, as no galls were observed. Other genotypes showed variable number of galls on their roots. *S. xanthocarpum*, *S. indicum* and *S. khasianum* recorded 13, 16 and 19 galls per plant respectively. The genotypes namely Punjab Raunak (35 galls per plant) and SJCT-01 (42 galls per plant) produced less galls than Interspecific hybrid (*Solanum melongena* × *Solanum khasianum*), Punjab Red Cherry, Punjab Kesar Cherry and Pusa Cherry Tomato which produced 53, 58, 64 and 79 galls per plant respectively. However, brinjal cultivar namely Pusa Purple Cluster recorded maximum gall infestation *i.e.* 88 galls per plant when compared with the other genotypes (Plate 9).

The presence or absence of galls on the roots of different genotypes under study determined their resistance or susceptibility against root-knot nematodes. However, significant variations in the number of galls seen on roots, amounts to their varying degrees of resistance and susceptibility. Data revealed that *Solanum torvum* was found highly resistant while *S. xanthocarpum* was found resistant followed by *S. indicum* and *S. khasianum*. The genotypes Punjab Raunak and SJCT-01 showed

moderately resistant reaction, whereas the genotype interspecific hybrid (*Solanum melongena* × *Solanum khasianum*) recorded a susceptible reaction followed by Punjab Red Cherry, Punjab Kesar Cherry and Pusa Cherry Tomato. The genotype Pusa Purple Cluster showed a highly susceptible reaction when compared with the other genotypes.

4.2.2 Effect of nematode infections on shoot growth parameters

Perusal of data (Table 4.2) depicted that shoot length was maximum in genotype SJCT-01 (42.31 cm) followed by Punjab Kesar Cherry (39.56 cm), Pusa Cherry Tomato (38.40 cm), Interspecific hybrid (*Solanum melongena* × *Solanum khasianum*) (27.09 cm), Punjab Raunak (26.82 cm), Pusa Purple cluster (26.28 cm) and *Solanum indicum* (20.55 cm) and genotype Punjab Red Cherry (41.10 cm) was found to be statistically at par with SJCT-01. The genotype *Solanum xanthocarpum* was found to have the shortest shoot length of 16.82 cm and the overall mean value recorded was 29.93 cm.

Punjab Kesar Cherry accumulated highest and significant ($P \leq 0.05$) amounts of plant biomass, with respect to its fresh and dry shoot weights of 13.27 g and 2.57 g respectively followed by SJCT-01 (13.11 g and 2.54 g), Punjab Red Cherry (12.57 g and 2.46 g), Pusa Cherry Tomato (12.00 g and 2.26 g), *Solanum torvum* (7.83 g and 1.10 g), *Solanum xanthocarpum* (6.12 g and 1.07 g), Punjab Raunak (5.23 g and 0.94 g), Pusa Purple Cluster (5.14 g and 0.90 g), Interspecific hybrid (*Solanum melongena* × *Solanum khasianum*) (4.86 g and 0.83 g) and *Solanum khasianum* (4.13 g and 0.77 g) of fresh and dry shoot weights respectively (Table 4.2). The lowest fresh and dry shoot weight of 3.99 g and 0.69 g respectively was recorded in the genotype *Solanum indicum*. The values of highest fresh and dry shoot weight in genotype Punjab Kesar Cherry (13.27 g and 2.57 g) and SJCT-01 (13.11 g and 2.54 g) were at par with each other.

4.2.3 Effect of nematode infections on root growth parameters

The data for effect of nematode infections on root growth parameters (Table 4.2) revealed that the maximum root length of 8.64 cm was observed in *Solanum torvum* followed by Punjab Raunak (8.27 cm), Pusa Purple Cluster (7.93 cm), *Solanum xanthocarpum* (7.31 cm), *Solanum indicum* (6.49 cm), Interspecific hybrid (*Solanum melongena* × *Solanum khasianum*) (6.34 cm), *Solanum khasianum*

Table 4.2: Evaluation of different *Solanum* genotypes against *Meloidogyne incognita*

Rootstocks	Shoot length (cm)	Shoot weight (g)		Root length (cm)	Root weight (g)	
		Fresh	Dry		Fresh	Dry
<i>Solanum torvum</i>	25.33	7.83	1.07	8.64	2.49	0.42
<i>Solanum xanthocarpum</i>	16.82	6.12	0.92	7.31	2.29	0.40
Interspecific Hybrids (<i>Solanum melongena</i> × <i>Solanum khasianum</i>)	27.09	4.86	0.81	6.34	2.38	0.39
<i>Solanum khasianum</i>	24.92	3.99	0.91	6.22	2.12	0.39
<i>Solanum indicum</i>	20.55	4.13	0.73	6.49	1.82	0.26
SJCT-01	42.31	13.11	2.54	5.40	1.90	0.31
Pusa Cherry Tomato	41.10	12.57	2.46	3.79	1.42	0.21
Punjab Kesar Cherry	39.56	13.27	2.57	3.87	1.49	0.21
Punjab Red Cherry	38.40	12.00	2.26	4.29	1.76	0.22
Punjab Raunak	26.82	5.14	0.79	7.93	2.12	0.42
Pusa Purple Cluster	26.28	5.23	1.10	8.27	2.60	0.52
Mean	29.93	8.03	1.47	6.24	2.03	0.35
CD (0.05)	1.650	1.597	0.226	0.820	0.242	0.044
±SE (m)	0.577	0.558	0.079	0.287	0.084	0.015
CV	4.310	14.559	12.007	10.281	9.265	9.900



Plate. 9. Categorization of roots as per root indexing scale given by Heald *et al.*, 1989.

(6.22 cm), SJCT-01 (5.40 cm), Pusa Cherry Tomato (4.29 cm) and Punjab Kesar Cherry (3.87 cm). The minimum root length was observed in the genotype Punjab Red Cherry (3.79 cm). Genotype Punjab Red Cherry (3.79 cm) and Punjab Kesar Cherry (3.87 cm) were found to be statistically at par with each other.

Data depicted that maximum fresh root weight was recorded in Punjab Raunak (2.60 g) followed *Solanum torvum* (2.49 g), Interspecific hybrid (*Solanum melongena* × *Solanum khasianum*) (2.38 g), *Solanum xanthocarpum* (2.29 g), *Solanum khasianum* (2.12 g), Pusa Purple Cluster (2.12 g), SJCT-01 (1.90 g), *Solanum indicum* (1.82 g), Pusa Cherry Tomato (1.76 g) and Punjab Kesar Cherry (1.49 g) whereas Punjab Red Cherry reported minimum fresh root weight of 1.42 g. The highest dry root weight of 0.52 g was recorded in genotype Punjab Raunak followed by *Solanum torvum* (0.42 g), Pusa Purple Cluster (0.42 g), *Solanum xanthocarpum* (0.40 g), Interspecific hybrid(*Solanum melongena* × *Solanum khasianum*) (0.39 g), *Solanum khasianum* (0.39 g), SJCT-01 (0.31 g), Pusa Cherry Tomato (0.22 g). The lowest dry root weight was recorded in genotypes Punjab Kesar Cherry and Punjab Red Cherry *i.e.*, 0.21 g each.

4.3 Evaluation of tomato varieties/hybrids for horticultural traits.

4.3.1 Plant height

Data for plant height revealed significant differences among the genotypes for the character (Table 4.3). Plant height ranged from 42.50 cm (Pusa Ruby) to 145.43 cm (Palam Tomato Hybrid 1) with overall mean value of 83.51 cm. None of the genotypes were found to be statistically at par with Palam Tomato Hybrid 1 whereas genotypes namely PKM 1(86.23 cm), Arka Rakshak (85.87 cm) and Punjab Varkha Bahar 4 (82.47 cm) were found to be statistically at par with an overall mean value of 83.51 (Plate 10).

4.3.2 Number of primary branches

Perusal of data for number of primary branches (Table 4.3) depicted that maximum number of primary branches were recorded in Arka Rakshak (9.11) and minimum in Pusa Ruby (4.44) with overall mean value of 6.08. No genotype was found statistically at par with Arka Rakshak (9.11) while, genotypes namely, Arka Samrat (7.33), Punjab Tomato Hybrid 1 (6.44), PKM 1 (6.22), Roma (5.22), Punjab

Varkha Bahar 4 (5.11) and Hisar Arun (4.78) were statistically at par with an overall mean value *i.e.* 6.08.

4.3.3 Days to 50% flowering

Data for days to 50 % flowering (Table 4.3) differed significantly among genotypes and ranged from 35.44 days in Pusa Ruby to 52.56 days in genotype Arka Samrat with overall mean value of 42.39. None of the genotypes were observed to be statistically at par with Pusa Ruby while two genotypes namely Punjab Varkha Bahar 4 (41.78 days) and Arka Rakshak (44.44 days) were statistically at par with overall mean value of 42.39.

4.3.4 Number of flower clusters per plant

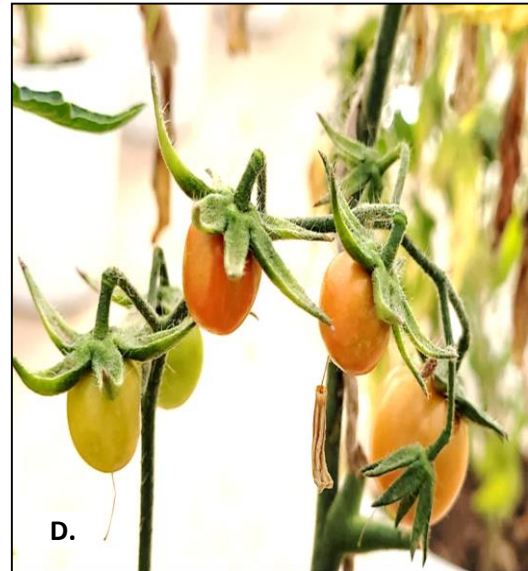
Data pertaining to number of flower clusters per plant (Table 4.3.) in different tomato genotypes under study varied significantly. The maximum number of flower clusters per plant were seen in Arka Rakshak (16.11) and the minimum were recorded in Hisar Arun (6.11) with overall mean value of 10.55. Genotype Pusa Ruby (13.00) and Arka Samrat (12.33) were found to be statistically at par with Arka Rakshak (16.11). Further, genotypes Punjab Varkha Bahar 4 (8.17), Roma (9.00), PKM 1 (9.45), Palam Tomato Hybrid 1 (10.22), Arka Samrat (12.33) and Pusa Ruby (13.00) had statistical parity with overall mean value (34.96).

4.3.5 Number of flowers per cluster

The information about the number of flowers per cluster (Table 4.3.) revealed that studied genotypes differed significantly from each other. Maximum number of flowers per cluster were recorded in genotype Arka Samrat (9.00) and minimum in Pusa Ruby (3.27) with overall mean value of 5.91. Arka Rakshak (7.60) was statistically at par with Arka Samrat (9.00) while genotypes Roma (7.00), PKM 1 (6.20) and Punjab Varkha Bahar 4 (5.67) had statistical parity with overall mean value (5.91).

4.3.6 Number of fruits per cluster

Data for number of fruits per cluster (Table 4.3) varied from 2.60 (Pusa Ruby) to 6.33 (Arka Rakshak) with overall mean value of 4.25. The highest number of fruits per cluster were recorded in Arka Rakshak (6.33) and genotype Arka Samrat (6.23) was found to be statistically par with this. Genotype Pusa Ruby had lowest number of



**Plate. 10. Different treatments at the time of harvest:
A. PTH-1, B. PKM-1, C. Hisar Arun, D. Punjab Varkha Bahar 4.**

Table 4.3: Mean performance of various horticultural traits in tomato (*Solanum lycopersicum* L.)

Varieties/Hybrids	Plant Height (cm)	Number of primary branches	Days to 50% Flowering	Number of flower clusters per plant	Number of flowers per cluster
Pusa Ruby	42.50	4.44	35.44	13.00	3.27
Palam Tomato Hybrid 1	145.43	6.44	38.78	10.22	4.47
Punjab Varkha Bahar 4	82.47	5.11	41.78	8.17	5.67
Arka Rakshak	85.87	9.11	44.44	16.11	7.60
Arka Samrat	91.40	7.33	52.56	12.33	9.00
PKM 1	86.23	6.22	38.33	9.45	6.20
Roma	63.23	5.22	47.78	9.00	7.00
Hisar Arun	70.97	4.78	40.00	6.11	4.07
Mean	83.51	6.08	42.39	10.55	5.91
CD (0.05)	7.347	1.468	2.230	3.814	1.281
±SE(m)	2.399	0.479	0.728	1.245	0.418
CV	4.975	13.646	2.975	20.406	12.258

Table 4.3: Mean performance of various horticultural traits in tomato (*Solanum lycopersicum* L.) (contd...)

Varieties/Hybrids	Number of fruits per cluster	Number of fruits per plant	Average fruit weight (g)	Yield per plant (kg)
Pusa Ruby	2.60	20.10	33.17	0.79
Palam Tomato Hybrid 1	3.60	31.9	47.50	1.34
Punjab Varkha Bahar 4	4.13	62.22	27.31	1.54
Arka Rakshak	6.33	37.33	58.79	1.90
Arka Samrat	6.23	42.53	77.24	2.23
PKM 1	3.77	22.60	43.21	0.81
Roma	4.00	27.67	61.13	1.42
Hisar Arun	3.33	35.3	35.20	1.25
Mean	4.25	34.96	47.95	1.41
CD (0.05)	1.176	6.708	9.744	0.272
±SE(m)	0.384	2.190	3.182	0.089
CV	15.684	10.852	11.452	10.895

fruits per cluster (2.60). The genotypes namely Roma (4.00), PKM 1 (3.77), Palam Tomato Hybrid 1 (3.60) and Hisar Arun (3.33) were statistically at par with overall mean value (4.25).

4.3.7 Number of fruits per plant

The analysis of data (Table 4.3) exhibited a large variation across genotypes for number of fruits per plant, which ranged from 20.10 (Pusa Ruby) to 62.22 (Punjab Varkha Bahar 4), with an overall mean value of 34.96. The genotype Punjab Varkha Bahar 4 had the highest number of fruits per plant (62.22) followed by Arka Samrat (42.53), Arka Rakshak (37.33), Hisar Arun (35.30), Palam Tomato Hybrid 1 (31.90), Roma (27.67) and PKM 1 (22.60). None of the genotypes were observed to be statistically at par with Punjab Varkha Bahar 4 (62.22). The genotype Pusa Ruby showed lowest number of fruits per plant (20.10) while genotypes Arka Rakshak (37.33), Hisar Arun (35.30) and Palam Tomato Hybrid 1 (31.90) had statistical parity with an overall mean value (34.96).

4.3.8 Average fruit weight (g)

Perusal of data for average fruit weight (Table 4.3) revealed significant differences amongst the genotypes which ranged from 27.31 g (PVB 4) to 77.24 g (Arka Samrat) with overall mean value of 47.95. The genotype Roma showed average fruit weight of 61.13 g per plant followed by Arka Rakshak (58.79 g), Palam Tomato hybrid 1 (47.50 g), PKM 1 (43.21 g), Hisar Arun (35.20 g) and Pusa Ruby (33.17 g). None of the genotypes were observed to be statistically at par with Arka Samrat (77.24) while genotypes Palam Tomato Hybrid 1 (47.50) and PKM 1 (43.21) were statistically at par with overall mean value of 47.95.

4.3.9 Yield per plant (kg)

The data recorded for yield per plant (Table 4.3) ranged from 0.79 kg in Pusa Ruby to 2.23 kg in Arka Samrat with overall mean value 1.41 kg. Arka Rakshak recorded 1.90 kg fruits per plant followed by Punjab Varkha Bahar 4 (1.54 kg), Roma (1.42 kg), Palam Tomato Hybrid 1 (1.34 kg), Hisar Arun (1.25 kg) and PKM 1 (0.81 kg). None of the genotypes were statistically at par with Arka Rakshak (1.90 kg) while genotypes Punjab Varkha Bahar 4 (1.54 kg), Roma (1.42 kg) Palam Tomato Hybrid 1 (1.34 kg) and Hisar Arun (1.25 kg) had statistical parity with overall mean value (1.41 kg).

4.3.10 Nematode gall per plant and eggs per egg mass

The plant samples from each treatment were visually inspected for galls or other indications of a root-knot nematode infection that may have occurred naturally. Further laboratory experiments to calculate gall per plant or eggs per egg mass were thus not taken into consideration because the findings from the visual examination of plant roots revealed no evidence of a natural infection by nematodes.

4.4 Graft compatibility studies

4.4.1 Days taken for seed germination in wild and cultivated *Solanum* genotypes

The data pertaining to days taken for seed germination (Table 4.4) ranged between 4.33 days in Arka Rakshak to 26.00 days in *Solanum xanthocarpum* with an overall mean value of 13.56 days. The genotype Arka Samrat took 4.67 days for seed germination which was statistically at par with the Arka Rakshak (4.33 days) while, Interspecific hybrid (*Solanum melongena* × *Solanum khasianum*) (14.67 days) and *Solanum indicum* (14.33 days) were statistically at par with the overall mean value of 13.56 days (Plate 11).

4.4.2 Days taken to reach grafting stage

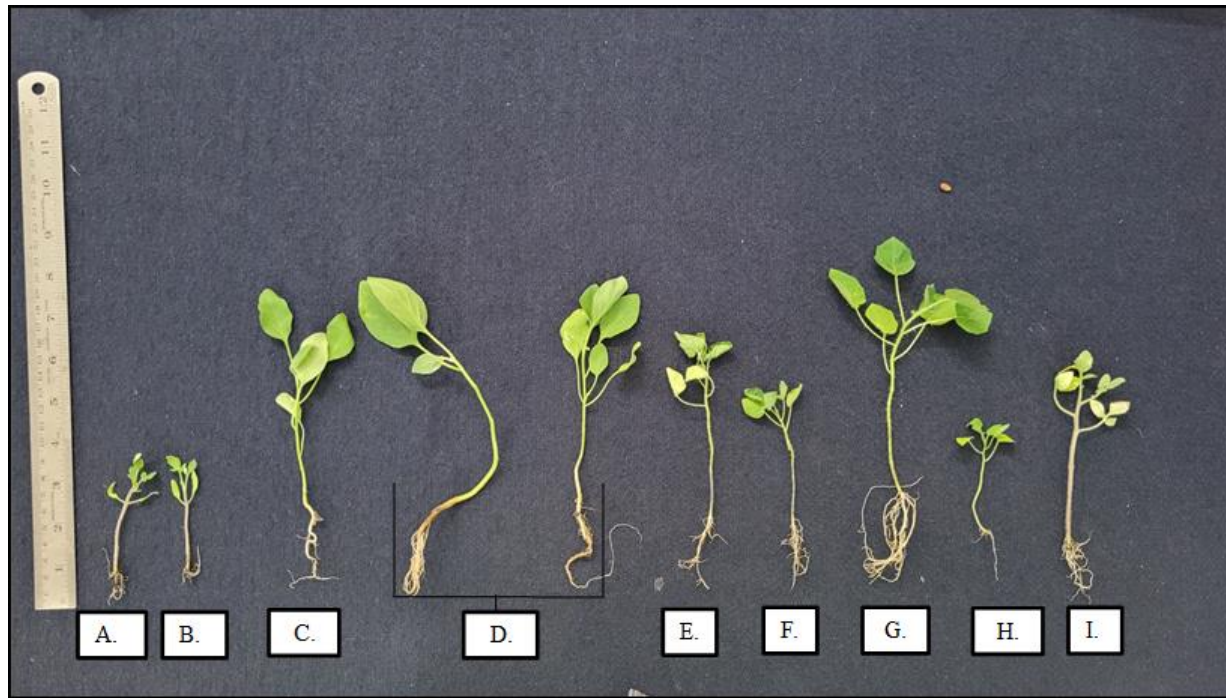
Significant differences were recorded in the values for days taken to reach grafting stage amongst all rootstocks and scions taken under consideration. Data pertaining to days taken to reach grafting stage (Table 4.4) ranged from 23.67 days in Arka Samrat to 61.33 days in *Solanum torvum*. The value of days taken to reach grafting stage in Arka Rakshak (25.67 days) was statistically at par with Arka Samrat (23.67 days) while, *Solanum xanthocarpum* (46.67 days) and Interspecific hybrid (*Solanum melongena* × *Solanum khasianum*) (43.00 days) had statistical parity with an overall mean value (42.83).

4.4.3 Days taken for graft healing

The data regarding days taken for graft healing presented in Table 4.5, depicted that there were considerable differences in the number of days for graft healing amongst the graft combinations and the data ranged between 3.33 days in Arka Samrat on SJCT 01 to 9.00 days in Arka Rakshak on *Solanum indicum* with the overall mean value of 6.06. The graft combination Arka Samrat on rootstock SJCT 01

Table 4.4: Days taken for seed germination and to reach grafting in wild and cultivated *Solanum* genotypes

Genotypes	Days taken for germination	Days taken to reach grafting stage
Stocks		
<i>Solanum xanthocarpum</i>	26.00	46.67
Interspecific Hybrids	14.67	43.00
<i>Solanum khasianum</i>	21.33	59.00
SJCT-01	10.00	31.33
<i>Solanum indicum</i>	14.33	57.33
Punjab Raunak	7.33	37.50
<i>Solanum torvum</i>	19.33	61.33
Scions		
Arka Rakshak	4.33	25.67
Arka Samrat	4.67	23.67
Mean	13.56	42.83
CD (0.05)	2.783	4.098
±SE(m)	0.920	1.355
CV	11.761	5.482



- A. Arka Samrat
- B. Arka Rakshak
- C. Interspecific Hybrids-1
- D. Punjab Raunak
- E. *Solanum torvum*
- F. *Solanum indicum*
- G. *Solanum khasianum*
- H. *Solanum xanthocarpum*
- I. SJCT-01

Plate 11. Rootstocks and scions used for graft compatibility studies.

Table 4.5: Days taken by different graft combinations for healing and success rate (%)

Treatments	Days taken for graft healing	Graft success (%)
Arka Samrat on SJCT 01	3.33	100.00
Arka Rakshak on SJCT 01	3.67	94.44
Arka Samrat on Punjab Raunak	4.00	100.00
Arka Rakshak on Punjab Raunak	4.33	100.00
Arka Samrat on <i>Solanum indicum</i>	8.33	74.29
Arka Rakshak on <i>Solanum indicum</i>	9.00	75.48
Arka Samrat on <i>Solanum xanthocarpum</i>	6.33	93.33
Arka Rakshak on <i>Solanum xanthocarpum</i>	6.67	92.50
Arka Samrat on <i>Solanum khasianum</i>	7.67	84.87
Arka Rakshak on <i>Solanum khasianum</i>	8.33	88.33
Arka Samrat on <i>Solanum torvum</i> Swartz	5.67	96.29
Arka Rakshak on <i>Solanum torvum</i> Swartz	5.33	96.29
Mean	6.06	91.32
CD (0.05)	1.273	8.119
±SE(m)	0.610	3.890
CV	12.337	5.217

was seen to take the minimum number of days to heal (3.33 days) followed by Arka Rakshak on SJCT 01 (3.67 days), Arka Samrat on Punjab Raunak (4.00 days), Arka Rakshak on Punjab Raunak (4.33 days), Arka Rakshak on *Solanum torvum* (5.33 days), Arka Samrat on *Solanum torvum* (5.67 days), Arka Samrat on *Solanum xanthocarpum* (6.33 days), Arka Rakshak on *Solanum xanthocarpum* (6.67 days), Arka Samrat on *Solanum khasianum* (7.67 days). The graft combinations Arka Samrat on *Solanum indicum* and Arka Rakshak on *Solanum khasianum* took equal days for healing of graft union *i.e.*, 8.33 days. The scion Arka Rakshak grafted on rootstock *Solanum indicum* recorded maximum number of days (9.00 days) to heal the union. It was also observed that for Arka Rakshak on SJCT 01 (3.67 days), Arka Samrat on Punjab Raunak (4.00 days), and Arka Rakshak on Punjab Raunak (4.33 days), the number of days required for graft healing were statistically similar to that of Arka Samrat on SJCT-01 (3.33 days).

4.4.4 Graft success (%)

The data presented in Table 4.5 revealed the grafting success of tomato scions on solanum root stocks. The outcomes showed that there was significant variation across combinations for grafting success rate (%) which ranged from 75.48 per cent to 100 per cent with an overall success rate of 91.32 per cent. Grafting success rate was 100 per cent in the graft combinations namely Arka Samrat on Punjab Raunak, Arka Samrat on SJCT 01, and Arka Rakshak on Punjab Raunak followed by graft combinations Arka Samrat on *Solanum torvum* Swartz (96.29 %), Arka Rakshak on *Solanum torvum* Swartz (96.29 %), Arka Rakshak on SJCT (94.44 %), Arka Samrat on *Solanum xanthocarpum* (93.33 %), Arka Rakshak on *Solanum xanthocarpum* (92.50 %), Arka Samrat on *Solanum khasianum* (84.87 %) and Arka Rakshak on *Solanum khasianum* (88.33 %). However, the graft combination Arka Samrat on *Solanum indicum* showed the lowest grafting success rate of 74.29 per cent. It was duly noted that the graft combinations namely Arka Samrat on *Solanum torvum* Swartz (96.29 %), Arka Rakshak on *Solanum torvum* Swartz (96.29 %), Arka Rakshak on SJCT 01 (94.44 %), Arka Samrat on *Solanum xanthocarpum* (93.33 %), Arka Rakshak on *Solanum xanthocarpum* (92.50 %), Arka Samrat on *Solanum khasianum* (84.87 %) and Arka Rakshak on *Solanum khasianum* (88.33 %) were at par with the overall mean value of 91.32 per cent (Plate 12 & 13).

4.5 Performance of graft combinations on various horticultural traits in tomato (*Solanum lycopersicum* L.)

4.5.1 Plant height

The data related to effect of *Solanum* rootstocks on tomato scions regarding plant height is presented in Table 4.6. The clear variation was observed in plant height which ranged from 41.53 cm in Arka Samrat on *Solanum indicum* to 143.51 cm in Arka Samrat on SJCT 01 with the overall mean value of 105.61 cm whereas the checks Arka Rakshak and Arka Samrat recorded plant height of 101.67 cm and 90.13 cm respectively. The data was recorded at the time of last harvest and it was observed that the maximum plant height was recorded in graft combination Arka Samrat on SJCT 01 (143.51 cm) followed by Arka Samrat on Punjab Raunak (134.50 cm), Arka Rakshak on SJCT 01 (132.58 cm), Arka Rakshak on Punjab Raunak (128.43 cm), Arka Samrat on *Solanum torvum* Swartz (124.37 cm) and Arka Rakshak on *Solanum torvum* Swartz (119.77 cm) and Arka Samrat on *Solanum khasianum* (110.94 cm). All the graft combinations were found to be statistically superior for the trait than both the checks *i.e.* Check-2 Arka Rakshak (101.67 cm) and Check-1 Arka Samrat (90.13 cm). Graft combination namely, Arka Rakshak on *Solanum khasianum* (105.77 cm), Arka Rakshak on *Solanum xanthocarpum* (98.57 cm) and Arka Samrat on *Solanum xanthocarpum* were found to be at par with Check-2 Arka Rakshak (101.67) while statistically higher in plant height than check Arka Samrat (90.13 cm).

4.5.2 Number of primary branches per plant

The data for number of primary branches per plant was recorded at 90 DAP (Table 4.6) in tomato and it differed significantly as influenced by different *Solanum* rootstocks which ranged from 3.58 (Arka Rakshak on *Solanum indicum*) to 9.47 (Arka Samrat on SJCT 01) with overall mean value of 7.37 whereas checks Arka Samrat (Check-1) and Arka Rakshak (Check-2) recorded 9.11 and 7.33 number of primary branches per plant respectively. The graft combinations namely Arka Samrat on SJCT 01 (9.47) and Arka Samrat on Punjab Raunak (9.44), Arka Samrat on *Solanum xanthocarpum* (8.67) and Arka Samrat on *Solanum torvum* Swartz (8.67) were found statistically at par with Check-1 Arka Samrat (9.11) and superior to Check-2 Arka Rakshak (7.33). Graft combinations namely Arka Rakshak on SJCT 01 recorded 8.17 number of primary branches per plant followed by Arka Rakshak on



Grafted seedlings transferred from hardening unit to field



Grafted seedlings carefully transplanted in the field without disturbing the graft union

Plate 12: Transplanting of the graft combinations along with the non-grafted checks

Table 4.6: Mean performance of graft combinations for plant height (cm), number of primary branches per plant (growth parameters), Days to 50% flowering and number of clusters per plant

Graft Combination	Plant height (cm)	Number of primary branches per plant	Days to 50% flowering	Number of flower clusters per plant
Arka Samrat on SJCT 01	143.51	9.47	39.25	9.53
Arka Rakshak on SJCT 01	132.58	8.17	36.83	13.81
Arka Samrat on Punjab Raunak	134.50	9.44	44.58	15.89
Arka Rakshak on Punjab Raunak	128.43	6.58	42.83	11.83
Arka Samrat on <i>Solanum indicum</i>	41.53	3.58	47.17	11.67
Arka Rakshak on <i>Solanum indicum</i>	50.77	3.89	49.58	15.55
Arka Samrat on <i>Solanum xanthocarpum</i>	96.00	8.67	40.25	17.08
Arka Rakshak on <i>Solanum xanthocarpum</i>	98.57	7.00	38.08	13.89
Arka Samrat on <i>Solanum khasianum</i>	110.94	7.33	39.58	13.00
Arka Rakshak on <i>Solanum khasianum</i>	105.77	6.33	39.08	14.11
Arka Samrat on <i>Solanum torvum</i> Swartz	124.37	8.67	42.08	11.67
Arka Rakshak on <i>Solanum torvum</i> Swartz	119.77	7.67	40.92	15.83
Arka Samrat (Check-1)	90.13	9.11	37.58	10.89
Arka Rakshak (Check-2)	101.67	7.33	33.75	13.56
Mean	105.61	7.37	40.83	13.45
CD(0.05)	7.791	0.852	0.839	3.438
±SE (m)	2.665	0.291	0.287	1.176
CV	4.372	6.846	1.218	15.144



Plate.13: Layout of field trial conducted at Experimental Research Farm-I, Division of Vegetable Science, SKUAST-Jammu.

Solanum torvum Swartz (7.67), Arka Samrat on *Solanum khasianum* (7.33), Arka Rakshak on *Solanum xanthocarpum* (7.00), Arka Rakshak on Punjab Raunak (6.58) and were found at par with check Check-2 Arka Rakshak (7.33).

4.5.3 Days to 50% flowering

The data related to number of days to 50 per cent flowering (Table 4.6) revealed considerable variation in the graft combinations and it varied from 33.75 days in Arka Rakshak (Check-2) to 49.58 days in graft combination Arka Rakshak on *Solanum indicum* with an overall mean value of 40.83 days. Two checks namely, Arka Rakshak (Check-2) took 33.75 days to 50 % flowering while Arka Samrat (Check-1) took 37.58 days to 50 % flowering. Minimum days to 50% flowering were recorded in Check-2 Arka Rakshak (33.75 days) and none of the graft combinations were found statistically on par with it, while, Arka Rakshak on SJCT-01 (36.83 days) and Arka Rakshak on *Solanum xanthocarpum* (38.08 days) were found at par with Check-1 Arka Samrat (37.58 days). However, Arka Rakshak on *Solanum indicum* (49.58 days) took the maximum number of days to 50% flowering.

4.5.4 Number of flower clusters per plant

The data pertaining to number of flower clusters per plant is presented in Table 4.6. Number of flower clusters per plant varied from 9.53 in Arka Samrat on SJCT 01 to 17.08 in Arka Samrat on *Solanum xanthocarpum* with an overall mean value of 13.45 whereas Check-2 Arka Rakshak and Check-1 Arka Samrat had 13.56 and 10.89 number of flower clusters per plant. The graft combination Arka Samrat on *Solanum xanthocarpum* (17.08) was found to have statistically higher number of flower clusters per plant than both the checks, Check-2 Arka Rakshak (13.56) and Check-1 Arka Samrat (10.89). Further, the graft combinations Arka Samrat on Punjab Raunak (15.89), Arka Rakshak on *Solanum torvum* Swartz (15.83), Arka Rakshak on *Solanum indicum* (15.55), Arka Rakshak on *Solanum khasianum* (14.11), Arka Rakshak on *Solanum xanthocarpum* (13.89), Arka Rakshak on SJCT 01 (13.81), Arka Samrat on *Solanum khasianum* (13.00), Arka Rakshak on Punjab Raunak (11.83), Arka Samrat on *Solanum indicum* (11.67), Arka Samrat on *Solanum torvum* Swartz (11.67) had statistical parity with Check-2 Arka Rakshak (13.56).

4.5.5 Number of flowers per cluster

Perusal of data for number of flowers per cluster (Table 4.7) delineated the variation from the lowest value of 1.89 (Arka Samrat on *Solanum indicum*) to highest value of 6.23 (Arka Rakshak on SJCT 01) with an overall mean value 4.44 and check Arka Rakshak (Check-2) and Arka Samrat (Check-1) recorded 6.01 and 5.540 number of flowers per cluster (Plate 14). The graft combination viz., Arka Rakshak on SJCT 01 (6.23) and Arka Samrat on Punjab Raunak (5.99) were statistically at par with Check-2 Arka Rakshak (6.01) and superior to Arka Samrat (5.50) (Check-1), whereas Arka Samrat on SJCT 01 (5.47) was found to be at par with the Check-1 Arka Samrat (5.50).

4.5.6 Number of fruits per cluster

The data recorded for number of fruits per cluster differed significantly as influenced by different *Solanum* rootstocks (Table 4.7). Number of fruits per cluster varied from 1.42 (Arka Samrat on *Solanum indicum*) to 5.56 (Arka Rakshak on SJCT 01) with overall general mean value of 3.71. Among the checks, Arka Rakshak (5.00) (Check-2) had maximum number of fruits per cluster followed by Arka Samrat (4.75) (Check-1). The graft combination namely, Arka Rakshak on SJCT 01 (5.56) recorded statistically highest number of fruits per cluster than Check-2 Arka Rakshak (5.00) while, Arka Samrat on Punjab Raunak (5.25) and Arka Samrat on SJCT 01 (4.62) were found statistically on par with it.

4.5.7 Number of fruits per plant

The data associated with effect of *Solanum* rootstocks on tomato scions regarding number of fruits per plant is presented in Table 4.7. The number of fruits per plant in different combinations ranged from 11.00 in Arka Samrat on *Solanum indicum* to 46.67 in Arka Samrat on Punjab Raunak with the overall mean value of 27.09. Among the checks, Arka Rakshak (Check-2) had 29.33 whereas Arka Samrat had 25.33 (Check-1) number of fruits per plant. Graft combinations, Arka Samrat on Punjab Raunak (46.67) and Arka Rakshak on SJCT 01 (44.17) were found to have significantly higher number of fruits per plant than Check-2 Arka Rakshak (29.33). Further, Arka Samrat on *Solanum xanthocarpum* (34.50), Arka Rakshak on *Solanum torvum* Swartz (33.00), Arka Rakshak on Punjab Raunak (27.50), Arka Samrat on

Table 4.7: Mean performance of graft combinations for number of flowers per cluster, number of fruits per cluster, number of fruits per plant and average fruit weight (g)

Treatments	Number of flowers per cluster	Number of fruits per cluster	Number of fruits per plant	Average fruit weight (g)
Arka Samrat on SJCT 01	5.47	4.62	23.40	82.83
Arka Rakshak on SJCT 01	6.23	5.56	44.17	87.40
Arka Samrat on Punjab Raunak	5.99	5.25	46.67	106.67
Arka Rakshak on Punjab Raunak	4.38	4.00	27.50	81.92
Arka Samrat on <i>Solanum indicum</i>	1.89	1.42	11.00	63.17
Arka Rakshak on <i>Solanum indicum</i>	2.26	1.56	15.67	38.22
Arka Samrat on <i>Solanum xanthocarpum</i>	3.80	2.89	34.5	87.53
Arka Rakshak on <i>Solanum xanthocarpum</i>	4.06	3.13	20.33	69.20
Arka Samrat on <i>Solanum khasianum</i>	4.02	3.33	27.00	53.23
Arka Rakshak on <i>Solanum khasianum</i>	4.26	3.40	18.33	85.11
Arka Samrat on <i>Solanum torvum</i> Swartz	4.54	3.93	23.00	149.40
Arka Rakshak on <i>Solanum torvum</i> Swartz	3.77	3.17	33.00	75.19
Arka Samrat (Check-1)	5.50	4.75	25.33	90.95
Arka Rakshak (Check-2)	6.01	5.00	29.33	81.28
Mean	4.44	3.71	27.09	82.29
CD (0.05)	0.486	0.485	6.572	4.59
±SE(m)	0.166	0.166	2.248	1.57
CV	6.490	7.744	14.377	3.30

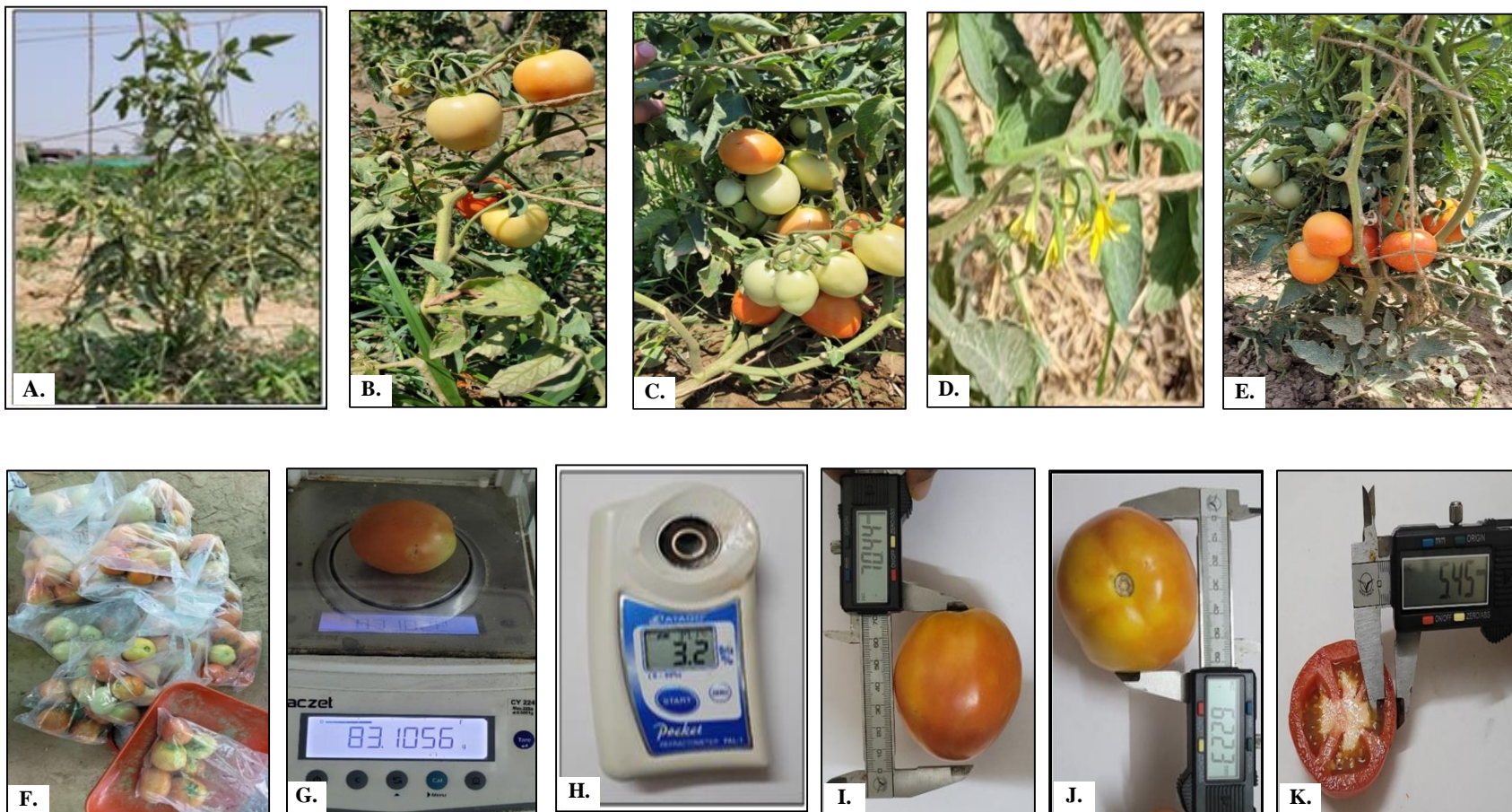


Plate.14. Pictures depicting data recorded for various parameters, A. Plant height, B. Number of primary branches, C. Number of clusters per plant, D. Number of flowers per cluster, E. Number of fruits per cluster, F. Number of fruits per plant, G. Average fruit weight, H. Polar diameter, I. Equatorial diameter, J. Pericarp thickness and K. TSS.

Solanum khasianum (27.00), Arka Samrat on SJCT 01 (23.40) and Arka Samrat on *Solanum torvum* Swartz (23.00) were at par with the Check-2 Arka Rakshak (29.33).

4.5.8 Average fruit weight (g)

The data pertaining to average fruit weight (Table 4.7) exhibited a large variation across graft combinations, which varied from 63.17 g in Arka Samrat on *Solanum indicum* to 149.40 g in Arka Smarat on *Solanum torvum* with overall mean value of 82.25 g. Whereas Check 1 Arka Samrat and Check 2 Arka Rakshak recorded average fruit weight of 90.95 g and 81.28 g respectively. The maximum average fruit weight was obtained in graft combination Arka Smarat on *Solanum torvum* (149.40 g) followed by Arka Samrat on Punjab Raunak (106.67 g) which performed superior to check-1 Arka Samrat (90.95 g), while graft combinations Arka Samrat on *Solanum xanthocarpum* (87.53 g) and Arka Rakshak on SJCT 01 (87.40 g) were found at par with the check-1 Arka Samrat (90.95 g) and superior to Check-2 (81.28 g). Further, Arka Rakshak on *Solanum khasianum* (85.11 g), Arka Samrat on SJCT 01 (82.83 g) and Arka Rakshak on Punjab Raunak (81.92 g) were found at par with Check-2 (81.28 g) for the trait.

4.5.9 Polar diameter (cm)

The results for polar diameter of fruit (Table 4.8) ranged from 3.10 cm (Arka Rakshak on *Solanum indicum*) to 5.82 cm (Arka Rakshak on Punjab Raunak) with overall mean value of 4.95 cm, whereas Check-1 Arka Samrat and Check-2 Arka Rakshak recorded polar diameter of 5.11 cm and 5.50 cm respectively. The graft combinations namely Arka Rakshak on Punjab Raunak (5.82 cm), Arka Rakshak on Punjab Raunak (5.58 cm), Arka Samrat on *Solanum torvum* Swartz (5.60 cm), Arka Samrat on Punjab Raunak (5.31 cm), Arka Rakshak on SJCT 01 (5.30 cm), Arka Rakshak on *Solanum torvum* Swartz (5.04 cm), Arka Samrat on SJCT 01 (5.01 cm), Arka Samrat on *Solanum xanthocarpum* (4.96 cm) and Arka Rakshak on *Solanum xanthocarpum* (4.63 cm) were found to be statistically at par with both Check-2 Arka Rakshak (5.50 cm) and Check-1 Arka Samrat (5.11 cm) while graft Arka Samrat on *Solanum indicum* (4.40 cm) was found at par with Check-1 Arka Samrat (5.11 cm) only. The lowest polar diameter was found in the graft combination Arka Rakshak on *Solanum indicum* (3.10 cm) followed by Arka Samrat on *Solanum khasianum* (3.89 cm).

4.5.10 Equatorial diameter (cm)

Perusal of data for equatorial diameter of fruit (Table 4.8) exhibited variation from 2.89 cm (Arka Rakshak on *Solanum indicum*) to 6.18 cm (Arka Samrat on *Solanum torvum* Swartz) with overall mean value of 4.80 cm. Arka Samrat (Check-1) and Arka Rakshak (Check-2), the two non-grafted checks, yielded fruits with equatorial diameters of 5.34 cm and 4.67 cm, respectively. Per se results of all graft combinations showed that Arka Samrat on *Solanum torvum* Swartz (6.18 cm) recorded significantly superior performance than both check-1 Arka Samrat (5.34 cm) and check-2 Arka Rakshak (4.67 cm). All other graft combinations namely, Arka Samrat on *Solanum xanthocarpum* (5.44 cm), Arka Samrat on SJCT 01 (5.50 cm) and Arka Samrat on Punjab Raunak (5.63), Arka Samrat on *Solanum torvum* Swartz (6.18 cm). Arka Rakshak on *Solanum xanthocarpum* (3.98 cm) were reported to be statistically at par with both check-1 Arka Samrat (5.34 cm) and Check-2 Arka Rakshak (4.67 cm) with the exception of Arka Rakshak on *Solanum indicum* (2.89 cm) which recorded lowest fruit diameter.

4.5.11 Yield per plant (kg)

The data recorded for yield per plant (Table 4.8) differed significantly as influenced by different *Solanum* rootstocks. Fruit yield per plant ranged from 0.12 kg in Arka Rakshak on *Solanum indicum* to 3.37 kg in Arka Rakshak on SJCT 01, with an overall mean value of 1.10 kg. Check-1 Arka Samrat produced 1.00 kg and Check-2 Arka Rakshak produced 1.10 kg fruit yield per plant. The graft combinations Arka Rakshak on SJCT 01 (3.37 kg), Arka Samrat on Punjab Raunak (2.22 kg), Arka Samrat on SJCT 01 (1.51 kg), Arka Samrat on *Solanum torvum* Swartz (1.46 kg) and Arka Rakshak on Punjab Raunak (1.33 kg) performed statistically superior to both the checks.

4.5.12 Pericarp thickness (mm)

Data for pericarp thickness (Table 4.9) showed that different graft combinations influenced the pericarp thickness significantly. The results indicated that pericarp thickness ranged from 4.28 mm (Arka samrat on *Solanum khasianum*) to 7.41 mm (Arka samrat on *Solanum torvum* Swartz) with mean value of 5.90 mm. Among the checks, Arka Rakshak (Check-2) had maximum pericarp thickness of 7.02 mm followed by Arka Samrat (Check-1) with 6.02 mm. None of the graft

Table 4.8: Mean performance of graft combinations for polar diameter (cm), equatorial diameter (cm) and yield per plant (kg)

Treatments	Polar diameter (cm)	Equatorial diameter (cm)	Yield per plant (kg)
Arka Samrat on SJCT 01	5.01	5.50	1.51
Arka Rakshak on SJCT 01	5.30	4.51	3.37
Arka Samrat on Punjab Raunak	5.31	5.63	2.22
Arka Rakshak on Punjab Raunak	5.58	4.83	1.33
Arka Samrat on <i>Solanum indicum</i>	4.40	4.84	0.18
Arka Rakshak on <i>Solanum indicum</i>	3.10	2.89	0.12
Arka Samrat on <i>Solanum xanthocarpum</i>	4.96	5.44	0.85
Arka Rakshak on <i>Solanum xanthocarpum</i>	4.63	3.98	0.58
Arka Samrat on <i>Solanum khasianum</i>	3.89	4.16	0.21
Arka Rakshak on <i>Solanum khasianum</i>	5.82	4.97	0.70
Arka Samrat on <i>Solanum torvum</i> Swartz	5.60	6.18	1.46
Arka Rakshak on <i>Solanum torvum</i> Swartz	5.04	4.30	0.71
Arka Samrat (Check-1)	5.11	5.34	1.00
Arka Rakshak (Check-2)	5.50	4.67	1.10
Mean	4.95	4.80	1.09
CD (0.05)	0.885	0.961	0.10
±SE (m)	0.303	0.329	0.04
CV	10.606	11.861	5.62

combinations recorded more pericarp thickness than Check-1 Arka Rakshak. However, the graft combination Arka Samrat on *Solanum torvum* Swartz (7.41 mm) recorded significantly higher pericarp thickness than Check-1 Arka Samrat (6.07 mm). The graft combinations Arka Rakshak on *Solanum khasianum* (6.75 mm), Arka Rakshak on Punjab Raunak (6.49 mm), Arka Rakshak on SJCT 01 (6.45 mm), Arka Rakshak on *Solanum torvum* Swartz (6.45 mm), Arka Samrat on Punjab Raunak (6.42 mm), were found to be statistically at par with Check-2 Arka Rakshak (7.02 mm) and Check-1 Arka Samrat (6.07 mm) while Arka Samrat on *Solanum xanthocarpum* (6.02 mm), Arka Rakshak on *Solanum xanthocarpum* (5.72 mm) and Arka Samrat on SJCT 01 (5.42 mm) were statistically at par with Check-1 Arka Samrat (6.07 mm) only.

4.5.13 TSS (°B)

Perusal of data (Table 4.9) for TSS showed that the TSS varied from 3.72 °B to 5.32 °B with overall mean value of 4.59. Fruits from the two checks, Arka Samrat (Check-1) and Arka Rakshak (Check-2), showed TSS values of 4.55 °B and 5.12 °B, respectively. None of the graft combinations recorded TSS higher than Check-2 Arka Rakshak (5.12 °B). However, the graft combinations Arka Rakshak on SJCT-01 (5.32 °B), Arka Samrat on SJCT-01 (5.08 °B), Arka Rakshak on *Solanum torvum* Swartz (5.05 °B), Arka Rakshak on *Solanum xanthocarpum* (5.01 °B) and Arka Rakshak on Punjab Raunak (4.87 °B) showed statistically higher TSS value than Check-1 Arka Samrat (4.55 °B) and at par with Check-2 Arka Rakshak (5.12 °B). Graft combinations which generated TSS value at par with Check-1 Arka Samrat (4.55 °B) were Arka Samrat on *Solanum khasianum* (4.31 °B), Arka Samrat on *Solanum torvum* Swartz (4.38 °B) and Arka Rakshak on *Solanum khasianum* (4.67 °B). Meanwhile, graft combination Arka Samrat on *Solanum indicum* reported lowest TSS of 3.72 °B.

4.5.14 Lycopene content (mg/100g)

Data for lycopene content revealed that different graft combinations influenced the trait substantially as presented in Table 4.9. Results indicated that lycopene content in the graft combinations ranged from 3.70 mg/100 g (Arka Samrat on *Solanum indicum*) to 6.21 mg/100 g (Check-2 Arka Rakshak) with overall mean value of 4.87. Arka Samrat (Check-1) and Arka Rakshak (Check-2), the two non-grafted checks, exhibited lycopene content readings of 4.58 mg/100 g and 6.21

mg/100 g respectively. Lycopene content in graft combinations Arka Rakshak on SJCT-01 (6.10 mg/100 g), Arka Rakshak on *Solanum khasianum* (6.08 mg/100 g) and Arka Rakshak on Punjab Raunak (6.01 mg/100 g) was significantly higher than Check-1 Arka Samrat (4.58 mg/100 g) and at par with Check-2 Arka Rakshak (6.21 mg/100 g) while none of the graft combinations performed superior to it. Further, the graft combinations which performed statistically on par with Check-1 Arka Samrat (4.58 mg/100 g) were Arka Rakshak on *Solanum torvum* Swartz (4.60 mg/100 g), Arka Samrat on Punjab Raunak (4.45 mg/100 g) and Arka Samrat on *Solanum khasianum* (4.25 mg/100 g).

4.5.15 Ascorbic Acid (mg/100 g)

The data pertaining to ascorbic acid content in grafted tomato as influenced by different *Solanum* rootstocks is presented in Table 4.9. The results indicated that ascorbic acid content ranged from 15.10 mg/100 g to 25.94 mg/100 g with overall mean value of 20.16 mg/100 g. Among the checks, Arka Samrat (Check-2) had maximum ascorbic acid 25.27 mg/100 g followed by Arka Rakshak (Check-1) with 22.53 mg/100 g. The maximum ascorbic acid content of 25.94 mg/100 g was recorded in the graft combination Arka Samrat on SJCT 01 which was statistically at par with check-2 Arka Samrat (25.27 mg/100 g) and performed higher than Check-1 Arka Rakshak (22.53 mg/100 g). Graft combinations namely Arka Samrat on *Solanum torvum* Swartz (22.44 mg/100 g), Arka Samrat on Punjab Raunak (21.16 mg/100 g), Arka Rakshak on *Solanum torvum* Swartz (21.10 mg/100 g) Arka Rakshak on SJCT 01 (20.56 mg/100 g) and Arka Samrat on *Solanum khasianum* (20.11 mg/100 g) were found to be at par with Check-1 Arka Rakshak (22.53 mg/100 g).

Table 4.9: Mean performance of graft combinations for quality parameters of tomato (*Solanum lycopersicum* L.)

Treatments	Pericarp thickness (mm)	TSS (°B)	Lycopene content (mg/100g)	Ascorbic acid (mg/100g)
Arka Samrat on SJCT 01	5.42	5.08	4.62	25.94
Arka Rakshak on SJCT 01	6.45	5.32	6.10	20.56
Arka Samrat on Punjab Raunak	6.42	4.20	4.45	21.16
Arka Rakshak on Punjab Raunak	6.49	4.87	6.01	19.64
Arka Samrat on <i>Solanum indicum</i>	4.30	3.72	3.70	15.10
Arka Rakshak on <i>Solanum indicum</i>	3.74	3.85	3.98	13.57
Arka Samrat on <i>Solanum xanthocarpum</i>	6.02	4.12	4.11	19.42
Arka Rakshak on <i>Solanum xanthocarpum</i>	5.72	5.01	5.34	16.87
Arka Samrat on <i>Solanum khasianum</i>	4.28	4.31	4.25	20.11
Arka Rakshak on <i>Solanum khasianum</i>	6.75	4.67	6.08	18.54
Arka Samrat on <i>Solanum torvum</i> Swartz	7.41	4.38	4.15	22.44
Arka Rakshak on <i>Solanum torvum</i> Swartz	6.45	5.05	4.60	21.10
Arka Samrat (Check-1)	6.07	4.55	4.58	25.27
Arka Rakshak (Check-2)	7.02	5.12	6.21	22.53
Mean	5.90	4.59	4.87	20.16
CD (0.05)	0.876	0.284	0.351	2.666
±SE(m)	0.300	0.097	0.120	0.912
CV	8.796	3.670	4.266	7.836

DISCUSSION

In a country like India, vegetables play a crucial part in balanced diet since majority of the population is vegetarian primarily dependent on fruits and vegetables to meet dietary requirements of phytochemicals, including vitamins and minerals, in addition to carbohydrates and proteins. Vegetables are regarded as store house of nutraceuticals since they provide food security as well as nutritional and medicinal security. They also act as protective foods by shielding people against a wide range of ailments. Vegetable crops adapt successfully for majority of farming systems, given that they mature quickly from sowing to harvest, producing higher yields than cereal crops thus making them more affordable and lucrative for the agricultural community.

Tomato, being the most widely used and nutritive vegetable has a special importance worldwide and Indian subcontinent due to its inevitable use in almost all the dishes, processed products like pickle, jam, ketchup and also as a delicious salad. Tomato is a warm season crop reasonably resistant to heat and drought and grows under wide range of soil and climatic conditions. Even though India is the second largest tomato producer in the world next to China, the productivity lies large below the average productivity of many small countries due to number of reasons ranging from climatic conditions to technology employed in management of crop. Tomato is commonly affected by several fungi, bacteria, nematodes, and viruses. Soil borne infections have been a bigger threat in tomato cultivation in recent years. Nematodes are a significant biotic constraint in achieving global food security. *Meloidogyne* spp., often known as root-knot nematode (RKN), is the most widely distributed and yield-limiting plant-parasitic nematode in tomato production. RKNs interact with other plant diseases, causing greater damage to world food supplies in addition to direct losses (Sasser, 1980). RKNs cause losses ranging from 25-100 % in yield in tomatoes (Seid *et al.*, 2015).

Root knot nematodes are difficult to manage due to their wide host range. To control them, soil fumigants, contact-systemic nematicides, and resistant cultivars are commonly used. However, many of the chemicals employed/recommended (DD, EDB, Methyl bromide, Aldicarb and Carbofuron) to contain the pest are either banned

or in the verge of being banned world-wide due to their hazardous nature and newly introduced molecule are yet to prove their efficacy and acceptance. Thus, use of resistant cultivars is considered as one of the most safest and effective method in the integrated nematode management. Using nematode resistant genotypes or rootstocks can prevent nematode attacks in tomato crop, leading to reduction in infections. Grafting resistant rootstocks has proven to be an effective way to manage RKNs and improve tomato and eggplant yield when grown in naturally infested soil with nematodes. Grafting is a novel approach to improve fruit yield and quality under adequate growth conditions. Grafting increases yield, since plants have strong root system and vigorous growth increases photosynthesis. The positive effect of the rootstock on fruit yield and quality may depend on both the shoot and root genotypes making it a difficult task to select the optimum rootstocks.

Considering the above mentioned aspects, present study entitled “Graft Compatibility Studies for Resistance to Root-Knot Nematode in Tomato (*Solanum lycopersicum* L.)” was carried out in Experimental Research Farm-I and II of Division of Vegetable Science and Floriculture, Chatha as well as in the laboratory of Division of Vegetable Science and Floriculture, SKUAST - Jammu, J&K during the year 2020-21 and 2021-22. The study was carried out with the objectives of identifying rootstocks for resistance to root-knot nematode, assessing the graft compatibility and success rate of identified RKN resistant rootstocks and scion combinations. Further the effect of different *Solanum* rootstocks on growth and yield of tomato scions was studied. The results of the present investigations so interpreted are discussed in the chapter under following heads.

- 5.1 Survey
- 5.2 Screening
- 5.3 Mean performance of scion varieties and hybrids
- 5.4 Graft compatibility studies
- 5.5 Effect of grafting on horticultural traits in tomato

5.1 Survey

A detailed survey was conducted during the summer season of 2021 to collect the inoculum of RKN for creating artificial epiphytotic conditions (*in vitro*) in

different vegetable growing areas of Jammu Division, viz., Shama Chak, Badyal Brahmana, Jhiri, Chak Ghasian and Lower Barnai. However, in all of the open-field areas surveyed there showed no to very little prevalence of RKN, making it unfeasible to gather root samples for future research. While, maximum nematode incidence was identified in a commercial polyhouse erected near the village of Shama Chak, which had a standing crop of cucumber that was at its final stage of harvest.

The cucumber roots were carefully examined after being uprooted from the polyhouse at Shama Chak which revealed severe galling and numerous knots in the root systems, indicating high population densities of root-knot nematodes. After carefully studying and examining the perineal patterns of the nematodes in infected cucumber roots *Meloidogyne incognita* was identified. All perineal pattern features for *M. incognita* isolates were similar to those described as Jepson (1987) and the results are in accordance with the findings of Uysal *et al.* (2017) and Elling, A.A (2013).

The population density of *M. incognita* in the sampled soils taken from this polyhouse was found to range from 680 J2s/200cc soil to 1024 J2s/200cc soil. These findings are in complete agreement with earlier survey conducted by Bhati and Baheti (2020) who reported very high population of juveniles ranging from 705 to 1460 J2s/100cc soil in polyhouses surveyed from different villages in Rajasthan during 2016 and 2017.

5.2 Screening

Germplasm of *Solanum* species collected from different sources was screened under artificial epiphytotic conditions against root-knot nematode during the year 2021. Out of eleven wild and cultivated species of *Solanum* screened, the wild *Solanum* species *Solanum torvum* was found highly resistant to *Meloidogyne incognita*, as no galls were observed in this genotype while *Solanum xanthocarpum* was found resistant followed by *S. indicum* and *S. khasianum*. The genotypes Punjab Raunak and SJCT-01 showed moderately resistant reaction whereas the interspecific hybrid (*Solanum melongena* × *Solanum khasianum*) recorded a susceptible reaction followed by Punjab Red Cherry, Punjab Kesar Cherry and Pusa Cherry Tomato. However, genotype Pusa Purple Cluster showed a highly susceptible reaction. Present research revealed that *Solanum torvum* is highly resistant, while *Solanum*

xanthocarpum, *Solanum indicum*, and *Solanum khasianum* are moderately resistant rootstocks. These findings are consistent with research by Dhivya *et al.* (2014) who discovered that, among seven wild *Solanum* rootstocks, *Solanum torvum* and *Physalis peruviana* showed a resistant response after 60 days of inoculation, followed by *Solanum sisymbirifolium*. Similar results were obtained by Okorley *et al.* (2018) when they screened *Solanum* genotypes as potential rootstocks for the control of root-knot nematode (*Meloidogyne incognita*). They found that *Solanum macrocarpon* and *Solanuma ethiopicum* displayed tolerant responses with significantly lower root galling.

5.2.1 Effect of root-knot nematode on growth parameters

A reliable indicator of *Solanum* genotypes resistant to RKN infestation is the plant biomass in relation to its fresh and dry shoot and root characteristics (length and weight). The interspecific hybrid (*Solanum melongena* × *Solanum khasianum*), Punjab Raunak and *Solanum torvum* reported the longest shoot length among the wild and cultivated brinjal species. Among cherry tomato varieties SJCT-01 followed by Punjab Red Cherry, Punjab Kesar Cherry and Pusa Cherry Tomato recorded maximum shoot length. Punjab Kesar Cherry accumulated the highest and significant ($P \leq 0.05$) amount of plant biomass, with respect to its fresh and dry shoot weights followed by SJCT-01, Punjab Red Cherry, Pusa Cherry Tomato, *Solanum torvum*, *Solanum xanthocarpum*, Punjab Raunak, Pusa Purple Cluster, interspecific hybrid (*Solanum melongena* × *Solanum khasianum*) and *Solanum khasianum*.

The maximum root length was observed in *Solanum torvum* followed by Pusa Purple Cluster, Punjab Raunak, *Solanum xanthocarpum*, *Solanum indicum*, Interspecific hybrid (*Solanum melongena* × *Solanum khasianum*) and *Solanum khasianum* among the wild and cultivated brinjal species. Among cherry tomato varieties, SJCT-01 followed by Punjab Red Cherry, Punjab Kesar Cherry and Pusa Cherry Tomato recorded maximum root length. The maximum fresh root weight was recorded in Punjab Raunak followed by *Solanum torvum*, interspecific hybrid (*Solanum melongena* × *Solanum khasianum*), *Solanum xanthocarpum*, *Solanum khasianum*, Pusa Purple Cluster, SJCT-01, *Solanum indicum*, Pusa Cherry Tomato and Punjab Kesar Cherry. The highest dry root weight was recorded in genotype Punjab Raunak followed by *Solanum torvum*, Pusa Purple Cluster, *Solanum xanthocarpum*,

interspecific hybrid (*Solanum melongena* × *Solanum khasianum*), *Solanum khasianum*, SJCT-01 and Pusa Cherry Tomato.

The data showed that nematode infection affected almost all plant growth parameters, such as root length, shoot length, root weight and shoot weight in some susceptible *Solanum* genotypes, but the opposite was reported in certain cases.

The results indicated that, in susceptible genotype, Punjab Red Cherry, nematode infection had an adverse impact on the majority of the plant growth parameters assessed in the current study, including root length, shoot length, root weight and shoot weight. In certain instances, it was noted that the contrary was true and that the greater/increased shoot length and weight of some susceptible *Solanum* species compared to resistant ones is entirely due to their growth pattern.

In these cases, the greater shoot length and weight of some susceptible *Solanum* species compared to resistant ones is entirely due to their growth pattern. Similarly, insignificant differences in root length and weight were observed between resistant and susceptible *Solanum* genotypes. This could be due to the presence of galls, which increase the root fresh weight and/or stimulate the root to produce new rootlets to compensate for the infected useless ones, resulting in increased root weights and lengths. Similar results were reported by Jaiteh *et al.* (2012), Dhivya *et al.* (2014), Patra and Nayak (2019) in tomato varieties where the maximum average shoot length, fresh and dry shoot weight was recorded in resistant and moderately resistant varieties and decreased shoot length, fresh and dry shoot weight in susceptible varieties.

5.3 Mean performance of scion varieties and hybrids

To step up production, to enhance yield per unit area and to get quality tomato fruits, it is important to evaluate the varieties and hybrids for their mean performance. The experimental material comprising of eight different varieties and hybrids were evaluated in the field studies for various horticultural traits and the best performing genotypes were selected as scions for graft compatibility studies. The results depicted that Arka Samrat and Arka Rakshak recorded highest yield, maximum number of flower cluster per plant, flower per cluster and fruits per cluster as well as number of primary branches per plant, thus were selected as scion in the graft compatibility studies. However, Palam Tomato Hybrid 1 recorded highest plant height and Pusa

Ruby took minimum days to flower. Variation in these traits is attributed due to inherent genetic difference in the germplasm. Similar findings for plant yield, number of flower cluster per plant, flowers per cluster, fruits per cluster, number of primary branches per plant, plant height as well as days to 50 % flowering were reported by Mounica *et al.* (2022), Shukla *et al.* (2021), Swuro *et al.* (2021), Waiba *et al.* (2021) Sindhu *et al.* (2020), Sinha *et al.* (2020) and Singh *et al.* (2019b).

5.4 Graft compatibility studies

5.4.1 Days taken for seed germination

In the present study, it is critically important to keep record of the number of days required for seed germination in both rootstock and scion to optimise sowing time accordingly. On altering the sowing period, it was possible to create scion and rootstock with compatible stem sizes. Further, the success percentage of grafted plants increased by the consistent stem diameter of scion and stock. Due to their vigour and soft seeded characteristics, the hybrids and cultivated varieties namely, Arka Samrat, Arka Rakshak, and Punjab Raunak took less time to germinate in the current study. Wild *Solanum* species, such as *Solanum xanthocarpum*, *Solanum khasianum*, and *Solanum torvum* however, required an extended period to germinate because of their tough seed coats and prolonged dormancy of seeds. These results are parallel with the reports of Naik *et al.* (2020), Dhivya *et al.* (2013), Gousset *et al.* (2005), Hayati *et al.* (2005), Bletsos *et al.* (2003), Ibrahim *et al.* (2001).

It was also noted that tomato, wild and cultivated species of brinjal were warm season crops and optimum temperature for their germination ranged from 21°C to 27°C, perhaps seed were sown during winters and average temperature maintained was less than optimum temperature for germination and hence seeds took relatively longer time for germination in the present study. In addition, growth rate and germination period differ from variety to variety and from season to season (AVRDC, 2000).

5.4.2 Days taken to reach grafting in wild and cultivated *Solanum* genotypes

According to the data examined for Days taken to reach grafting in wild and cultivated *Solanum* genotypes depicted that wild *Solanum* seedlings required more number of days to reach the grafting stage than those of cultivars. In contrast to the other rootstocks and scions, *Solanum torvum* seedlings needed a longer period of time

to reach grafting stage followed by *Solanum khasianum*, *Solanum indicum* and *Solanum xanthocarpum*. This may occur as a result of slow growth rate of wild species. These findings are in line with those of Sudesh *et al.* (2021), Naik *et al.* (2020) and Ramesh *et al.* (2016).

5.4.3 Days taken for graft healing

The days taken for graft healing was least in graft combinations where rootstocks used were of cultivated varieties namely SJCT 01 and Punjab Raunak as they took lesser time for germinations and to attain grafting stage. Higher stem girth at the stage of grafting was observed in the tomato and brinjal rootstocks. In general rootstocks with larger diameter than the scion is more desirable, as the pressure increases a solution flows from a pipe with larger diameter to a pipe with smaller diameter, creating a rapid distribution of these solutes over the entire plant structure, resulting in a positive interaction between the various rootstock and scion material according to fluid mechanics (Franco *et al.*, 2018). However, in graft combinations involving wild *Solanum* genotypes as rootstocks especially *Solanum indicum*, *Solanum khasianum* and *Solanum torvum* Swartz recorded longer days for healing of graft union. This may be attributed to less stem girth and slower growth rate. These findings concur with those by Sudesh *et al.* (2021) and Sherly, 2011.

5.4.4 Graft success (%)

In the current study, scions were grafted on cultivated tomato and brinjal cultivars using splice grafting whereas scions were grafted on wild *Solanum* genotypes using cleft grafting. After grafting, a very high RH (almost saturation) was maintained to enhance healing by covering the graft union with plastic bags and keeping it in the shade. Graft success per cent was used to determine the compatibility between rootstock and scion. Among the twelve rootstocks and scion combination, rootstocks namely SJCT 01, Punjab Raunak and *Solanum torvum* Swartz imparted relatively higher graft success rate with scions (Arka Samrat and Arka Rakshak).

In order to create callus bridge, callus tissue spreads out from the cut stock and scion surfaces and expands in the gaps between the grafted section. The rapid development of new vascular tissue from callus cells and the production of secondary xylem and phloem are the reasons why graft combinations have a higher survival rate (Tamilselvi and Pugalendhi, 2017; Ogata *et al.*, 2005; Hartmann *et al.*, 2002). These

results are in conformity with the earlier findings of Priyanka *et al.* (2019), Sharma *et al.* (2019) and Singh *et al.* (2019), Kumar *et al.* (2017) and Johnson *et al.* (2014).

5.5 Performance of grafts for various horticultural traits in tomato.

5.5.1 Plant height (cm)

Plant height is an important trait in any crop as more will be the height more will be the yield and in the present study grafting had a significant impact on plant height throughout the crop growth stage. Plant height, a potential indicator of vigour, was highest in grafts with SJCT 01, Punjab Raunak and *Solanum torvum* as rootstocks and lowest in plants with *Solanum indicum* as rootstock. The cherry tomato variety SJCT 01 generated scions with the highest plant height by virtue of its indeterminate growth pattern. Due to their robust root systems and better assimilation of nutrients and water throughout the crop growth, Punjab Raunak and *Solanum torvum* had enhanced scion growth. However, *Solanum indicum* generated short-statured plants as a result of its shallow root system and bushy habit, since nutrients absorbed were redirected to generating lateral branches instead of scion growth. As a result, the rootstock's vigour plays a significant role in determining the vigour of the scion. These results are in agreement with Sabatino *et al.* (2019), Soare *et al.* (2018), Kumar *et al.* (2017a) and Yarsi (2010).

5.5.2 Number of primary branches per plant

Grafting had a significant impact on number of primary branches per plant during the study. The graft combination Arka Samrat on SJCT 01 had the highest number of primary branches per plant which was at par with Arka Samrat on Punjab Raunak, Arka Rakshak on *Solanum xanthocarpum* and Arka Samrat on *Solanum torvum* Swartz. This increase may be attributable to robust root system of the *Solanum* rootstocks rapidly and consistently absorbing nutrients and water, as well as greater compatibility of cherry tomato rootstock which enhanced the growth of the scion. Whereas, among the wild *Solanum* rootstocks, scions grafted on *Solanum indicum* showed poor performance, this might be due to shallow root system, bushy habit and incompatibility of the stock with the scion. The similar results were obtained by Arefin *et al.* (2019).

5.5.3 Days to 50% flowering

Days to 50 per cent flowering were significantly affected by different rootstocks used in the study. Days to 50 per cent flowering indicates earliness, which is one of important trait after yield. The outcome indicated that non-grafted check-2 Arka Rakshak took least number of days to 50 per cent flowering and none of the graft combinations were found statistically on par with it, which indicated late flowering in grafted plants. Prior to the development of the graft union, both the stock and the scion in grafted plants frequently endure stress. In particular, the scion ceases growth or slows down as it waits for food to go from the root system to the plant's apical sections for around 6-7 days which may be the cause of delayed flowering in grafted plants. Musa *et al.* (2020), Kumar *et al.* (2017), Moncada *et al.* (2013) and Ibrahim *et al.* (2001) observed a similar impact of delayed flowering in grafted plants of tomato and brinjal.

5.5.4 Number of flower clusters per plant

The graft combination Arka Samrat on *Solanum xanthocarpum* was found to have statistically higher number of flowers clusters per plant than both checks (Arka Rakshak and Arka Samrat). Arka Samrat on *Solanum xanthocarpum* was found on par with Arka Rakshak on SJCT 01, Arka Rakshak on *Solanum indicum*, Arka Samrat on Punjab Raunak and Arka Rakshak on *Solanum torvum* Swartz. Whereas minimum number of flower clusters per plant were observed in Arka Samrat grafted on SJCT 01. Grafted combinations had more nodes, which led to more flower clusters being produced by each plant. However, this occurrence was not consistent with Arka Samrat grafted on SJCT 01, which may be caused by longer internodal length instead of a higher proportion of nodes per plant. The results are in accordance with earlier work of Naik *et al.* (2021) and Voutsela *et al.* (2012).

5.5.5 Number of flowers per cluster

A vital trait of tomato is the number of flowers per cluster, which ultimately affects number of fruits per cluster and total number of fruits per plant. Number of flowers per cluster delineated variation from the lowest value of 1.89 (Arka Samrat on *Solanum indicum*) to highest value of 6.23 (Arka Rakshak on SJCT 01). However, none of the graft combinations outperformed non-grafted checks, and it was determined that grafting had little to no significant effect on the trait number of

flowers per cluster. This result is in conformity with findings of Naik *et al.* (2021) and Khah *et al.* (2006).

5.5.6 Number of fruits per cluster

The number of fruits per cluster directly influences the overall number of fruits on each plant as a whole and eventually, the yield. Number of fruits per cluster varied from 1.42 (Arka Samrat on *Solanum indicum*) to 5.56 (Arka Rakshak on SJCT 01). When compared to non-grafted checks (Arka Rakshak and Arka Samrat), the graft combination Arka Rakshak on SJCT 01 had significantly more fruits per cluster as this graft combination produced more number of flowers per cluster. The present results are in accordance with results of Naik *et al.* (2021) and Arefin *et al.* (2019).

5.5.7 Number of fruits per plant

The number of fruits per plant is strongly associated with yield, since more the fruits produced, greater will be the yield. The results for the total number of fruits per plant among graft combinations varied from 11.0 in Arka Samrat on *Solanum indicum* to 46.67 in Arka Samrat on Punjab Raunak. Graft combinations, Arka Samrat on Punjab Raunak and Arka Rakshak on SJCT 01 were found to have significantly higher number of fruits per plant than both the non-grafted checks (Arka Rakshak and Arka Samrat).

Great compatibility between the stock and scion, a longer harvest period, and strong root network, all contributed to the enhanced fruit production in these graft combinations. These factors also boosted the cytokinin content of the scion, which in turn raised the fruit load on the plants. Results of the present investigation are also in agreement with previous studies carried out on tomato by several workers (Naik *et al.*, 2021; Sudesh *et al.*, 2021; Singh *et al.*, 2019; Soare *et al.*, 2018; Sherly, 2011; Abdelmageed and Gruda, 2009; Alexopoulos *et al.*, 2007; Davis and Perkins-Veazie, 2005; Marsic and Osvald, 2004 and Yetisir and Sari, 2003)

5.5.8 Average fruit weight (g)

The average fruit weight data showed significant differences amongst graft combinations, ranging from 63.17 g in Arka Samrat on *Solanum indicum* to 149.40 g in Arka Smarat on *Solanum torvum*. Significantly maximum average fruit weight were recorded in graft combination Arka Smarat on *Solanum torvum* followed by Arka Samrat on Punjab Raunak which performed superior to other graft combinations

and non-grafted checks. This has indicated that effect of grafting for the trait average fruit weight was positive when Arka Samrat was used as scion and *Solanum torvum* and Punjab Raunak as rootstock. Higher average fruit weight in grafted as well as non-grafted Arka Samrat plants appeared to be due to inherent potential of this hybrid to produce fruits with a larger size (weight) than Arka Rakshak.

The improved macro and micronutrient absorption and water relations between successful rootstock and scion eventually resulted in an increase in average fruit weight in the grafted plants (Kumar *et al.*, 2015b and Ruiz *et al.*, 1999). These findings are in close conformity with previous works of Sudesh *et al.* (2021), Musa *et al.* (2020), Islam *et al.* (2019), Arefin *et al.* (2019), Kumar *et al.* (2016 a), Moncada *et al.* (2013) and Turhan *et al.* (2011).

5.5.9 Polar diameter (cm)

The polar diameter of tomato is an essential trait since it influences the fruit's size, shape and weight. The outcomes for polar diameter of fruit varied from 3.10 cm (Arka Rakshak on *Solanum indicum*) to 5.82 cm (Arka Rakshak on Punjab Raunak). Although the graft combinations, Arka Smarat on *Solanum torvum* and Arka Samrat on Punjab Raunak produced fruits with the highest average fruit weight, there was no appreciable increase in polar diameter in those graft combinations. When compared to non-grafted checks, it was found that grafting had no discernible impact on polar diameter. The similar results were obtained by Johnson *et al.* (2014).

5.5.10 Equatorial diameter (cm)

Equatorial diameter, which determines the size, shape, and weight of the fruit, is a crucial characteristic of tomato. The results for equatorial diameter of fruit exhibited variation from 2.89 cm (Arka Rakshak on *Solanum indicum*) to 6.18 cm (Arka Samrat on *Solanum torvum* Swartz). The graft combination Arka Samrat on *Solanum torvum* Swartz which had highest average fruit weight also recorded for significantly superior performance than both checks (Arka Samrat and Arka Rakshak). It could result from variations in the concentration of growth regulators brought on by the rootstock *Solanum torvum* Swartz. These observations are parallel to the findings of Sudesh *et al.* (2021), Kumar *et al.* (2016 b), Donas-Uclés *et al.* (2014), Johnson *et al.* (2014), Turhan *et al.* (2011) and Davis and Perkins-Veazie (2005).

5.5.11 Yield per plant (kg)

The identification of high yielding graft combinations with desirable fruit quality and resilience to biotic stress is critical for the successful cultivation of tomato. The high yield was directly influenced by flowers per cluster, fruits per plant and number of primary branches per plant. The results for fruit yield per plant varied from 0.12 kg in Arka Rakshak on *Solanum indicum* to 3.37 kg in Arka Rakshak on SJCT 01. In the graft combinations, the yield per plant increased significantly in Arka Rakshak on SJCT 01 followed by Arka Samrat on Punjab Raunak, Arka Samrat on SJCT 01, Arka Samrat on *Solanum torvum* Swartz and Arka Rakshak on Punjab Raunakin comparison with that of the non-grafted checks. In graft combination of Arka Rakshak on SJCT 01 and Arka Samrat on Punjab Raunak increased yield was due to higher number of flower clusters, flowers per cluster, fruits per cluster and fruits per plant however in Arka Samrat on *Solanum torvum* Swartz it was mainly due to higher average fruit weight.

In general, the higher fruit yield of grafted plants over non-grafted checks appeared to be caused by rootstocks resistance as reported by Martínez-Ballesta *et al.* (2010). Some of the rootstock's stronger and more widespread root development may eventually lead to an increase in the foraging capacity noted by Schwarz *et al.* (2013). It was also considered that the inherent qualities of some rootstocks might aid in promoting the vigour of the scion (Turhan, 2011). The availability of enough photosynthates and an increase in the production of endogenous hormones lead to an increased uptake of water and nutrients, as reported by Lee, J. M. (2003). Furthermore, Marsic and Osvald (2004) observed that prolonged harvesting and more pickings may have contributed to the enhanced output of grafted plants.

Similar results for positive effect of grafting on yield per plant were also accounted by the earlier workers like Naik *et al.* (2021), Sudesh *et al.* (2021), Musa *et al.* (2020), Sharma *et al.* (2018), Soare *et al.* (2018), Kumar *et al.* (2017a), Kumar *et al.* (2017b), Kumar *et al.* (2016b) and Sabatino *et al.* (2016)

5.5.12 Pericarp thickness (mm)

Pericarp thickness is an essential attribute since it has a strong correlation to the firmness of the fruit as well as preserving the fruit quality. In the present study pericarp thickness varied from 4.28 mm in Arka samrat on *Solanum khasianum* to

7.41 mm in Arka samrat on *Solanum torvum* Swartz. The pericarp thickness (mm) of the graft combinations and non-grafted checks (Arka Samrat and Arka Rakshak) did not differ significantly. The graft combination Arka Samrat on *Solanum torvum* Swartz (7.41 mm) had the thickest pericarp, but it was on par with the non-grafted Check-2, Arka Rakshak (7.02 mm) and that little increase in trait might be attributable to various interactions between rootstock and scion combinations. The findings of Naik *et al.* (2021), Sharma *et al.* (2018), Kumar *et al.* (2017a) and Sakata *et al.* (2007) corroborate the above results.

5.5.13 Total Soluble Solids (°B)

TSS (Total soluble solid) content is one of the most critical quality traits in the processing sector. The results for TSS showed that it varied from 3.72 °B in Arka Samrat on *Solanum indicum* to 5.32 °B in Arka Rakshak on SJCT-01. There was no statistically significant difference in TSS (°B) between graft combinations and non-grafted checks (Arka Samrat and Arka Rakshak) and our findings revealed that rootstocks had no effect on TSS (°B) levels. The decreased TSS concentration in the fruits of grafted plants compared to non-grafted plants was most likely owing to the increased water content in the fruits of grafted plants, indicating a diluting impact of the solids in the fruits (Pogonyi *et al.*, 2005). These findings are in close conformity with earlier works of Kumar *et al.* (2017a), Zhang and Guo (2018), Turhan *et al.* (2011), Alexopoulos *et al.* (2007) and Lee, J. M. (2003).

5.5.14 Lycopene content (mg/100g)

Lycopene, an antioxidant found in tomato fruit, is necessary for fruit colour and tomatoes with a greater lycopene level are chosen for fresh market. In the current study, results for lycopene content ranged from 3.70 mg/100 g (Arka Samrat on *Solanum indicum*) to 6.21 mg/100 g (Check-2 Arka Rakshak). Since none of the graft combinations outperformed non-grafted Check-2 (Arka Rakshak), which had the greatest lycopene levels (6.21 mg/100 g), in our analysis, proving that rootstocks had no impact on levels of lycopene (mg/100 g). The findings of the present study mainly concur with those of previous investigations who reported that grafting had no influence on the fruit's lycopene content (Naik *et al.*, 2021; Dhivya, R., 2013; Turhan *et al.*, 2011; Pék, *et al.*, 2007; Khah *et al.*, 2006).

5.5.15 Ascorbic Acid (mg/100g)

Ascorbic acid, generally known as vitamin C, is a powerful antioxidant that plays a significant role in the food processing sector. The ascorbic acid content in the current study ranged from 15.10 mg/100 g (Arka Samrat on *Solanum indicum*) to 25.94 mg/100 g (Arka Samrat on SJCT 01). Rootstocks grafted with Arka Samrat generated substantially more ascorbic acid than Arka Rakshak between the two scions. The graft combination, Arka Samrat on SJCT 01 recorded higher ascorbic acid content of 25.94 mg/100 g but it was statistically at par with Arka Samrat (25.27 mg/100 g) (Check 2) and none of the graft combinations were superior to the non-grafted checks, leading to the conclusion that grafting had an insignificant impact on the trait. This result supports the findings of Ofori (2015), Gioia *et al.* (2010) and Granges *et al.* (1998).

SUMMARY AND CONCLUSIONS

The present investigation was undertaken to identify *Solanum* rootstocks for resistance to root-knot nematode and tomato scion varieties/hybrids for horticultural traits with an objective to explore the possibilities of its utilization in the development of superior graft combinations with the goal to ascertain the most suitable graft combinations performing well in nematode infected soils.

The present investigation entitled “Graft Compatibility Studies for Resistance to Root-Knot Nematode in Tomato (*Solanum lycopersicum* L.)” was carried out during spring and rainy season of 2020-21 and 2021-22 at the Experimental Research Farm-I and II of Division of Vegetable Science and Floriculture, Chatha as well as in the laboratory of Division of Vegetable Science and Floriculture, SKUAST - Jammu, J&K. The screening of nematodes was conducted at laboratory of AICRP Nematodes, Chatha.

The study was accomplished in three phases, including field studies, laboratory work, and under screen house. Screening of cultivated and wild *Solanum* rootstocks for nematode resistance in laboratory and screen house (pot study). Studies were conducted in the field to identify tomato scion varieties and hybrids for horticultural traits. Standardization of graft compatibility between promising tomato scions and nematode-resistant *Solanum* rootstocks in protected conditions, as well as field research to evaluate the effectiveness of different graft combinations. The key conclusions and summary of the current study are as follows:

- An extensive survey of vegetable fields in Jammu conducted in the summer season of 2021 confirmed that the incidence of root-knot nematode was prevalent in polyhouse erected near the village of Shama Chak among all the locations surveyed. On the basis of perineal pattern characteristics, it was confirmed that the species of root-knot nematode was *Meloidogyne incognita*. The population density of *Meloidogyne incognita* was found to range from 1024 J2s/200cc soil to 680 J2s/200cc soil in the sampled polyhouse.
- Studies to assess the resistance of eleven wild species and cultivated varieties of *Solanum* against *M. incognita* were carried out in the screen house of the

AICRP, Nematodes. Results indicated that *Solanum torvum* was highly resistant to *Meloidogyne incognita*, as no galls were observed in this genotype while *Solanum xanthocarpum*, *S. indicum* and *S. khasianum* were resistant. The genotypes Punjab Raunak and SJCT-01 showed moderately resistant reaction whereas the genotype Interspecific hybrid (*Solanum melongena* × *Solanum khasianum*), Punjab Red Cherry, Punjab Kesar Cherry and Pusa Cherry Tomato recorded susceptible reaction. However, genotype Pusa Purple Cluster showed a highly susceptible reaction. Present research revealed that *Solanum torvum* is extremely resistant, while *Solanum xanthocarpum*, *Solanum indicum* and *Solanum khasianum* are moderately resistant rootstocks. These were employed as tomato rootstocks and can be used in future breeding projects focused nematode management.

- In the field studies on evaluation of tomato varieties/hybrids for horticultural traits Arka Samrat and Arka Rakshak recorded highest yield, maximum number of flower cluster per plant, flower per cluster and fruits per cluster as well as number of primary branches per plant and those two genotypes were selected as scion in the graft compatibility studies as they found superior for most of the horticultural traits under study. However, Palam Tomato Hybrid 1 recorded highest plant height and Pusa Ruby took minimum days to flower.
- Graft compatibility studies revealed that, highest percentage of grafting success *i.e.*, success rate of 100% was recorded in the treatments Arka Samrat on SJCT 01, Arka Samrat on Punjab Raunak and Arka Rakshak on Punjab Raunak with 3.33, 4.00 and 4.33 days taken for healing of graft union respectively.

The following findings were drawn from studies that examined the effects of grafting on tomato for horticultural qualities.

- Plant height was maximum in plants with SJCT 01 followed by Punjab Raunak and *Solanum torvum* rootstocks and lowest in those plants with *Solanum indicum* rootstock grafts. The graft combinations Arka Samrat on SJCT 01 had the highest number of primary branches per plant and in case of days to 50 per cent flowering none of the graft combinations were found statistically superior or on par with non-grafted check Arka Rakshak, which indicated late flowering in grafted plants. Further, number of flower clusters

per plant was found highest in Arka Samrat grafted on *Solanum xanthocarpum* (17.08). For number of flowers per cluster, none of the graft combinations outperformed the non-grafted checks. Highest number of fruits per cluster was reported in Arka Rakshak grafted on SJCT 01.

- Graft combinations namely, Arka Samrat on Punjab Raunak and Arka Rakshak on SJCT 01 recorded significantly higher number of fruits per plant. The maximum average fruit weight was obtained by the graft combinations namely Arka Smarat grafted on *Solanum torvum*. No graft combination fared better than the non-grafted checks for the trait polar diameter whereas, higher average values for equatorial diameter were exhibited by graft combinations Arka Samrat on *Solanum torvum* Swartz. The fruit yield was greatly influenced by grafting. Arka Rakshak grafted on SJCT 01 (3.37 kg), Arka Samrat grafted on Punjab Raunak (2.22 kg) recorded significantly superior yield per plant.
- Tomato fruit quality parameters such as pericarp thickness, TSS, lycopene content and ascorbic acid content were statistically lower or statistically at par in grafted plants as compared to non-grafted plants, but these measurements were still acceptable and fell within acceptable limits.

Based on the findings of the current study, it can be concluded that grafting is an efficient technique to enhance various horticultural traits in tomato plants thereby, increasing plant height, number of primary branches per plant, number of primary branches per plant, number of flowers per cluster, number of fruits per cluster, number of fruits per plant, average fruit weight, equatorial diameter and yield per plant in comparison to non-grafted plants. The scions (Arka Samrat and Arka Rakshak) grafted on SJCT 01 and Punjab Raunak as well as the graft combination Arka Samrat on *Solanum torvum* Swartz exhibited enhanced duration of crop and the frequency of picking and delivered higher yield in comparison to other graft combinations and non-grafted checks. But graft combinations which involved *Solanum indicum* rootstock, was under-performed compared to non-grafted plants. Therefore, beneficial effects of grafting on growth of plant and overall output indicate the viability of the technique as an alternative means for enhancing nematode tolerance in tomato genotypes cultivated in open fields.

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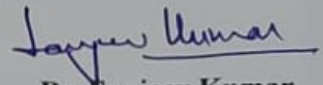
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CERTIFICATE- IV

Certified that all necessary corrections as suggested by the external examiner and advisory committee have been duly incorporated in the thesis entitled "**Graft compatibility studies for resistance to root-knot nematode in tomato (*Solanum lycopersicum* L.)**", submitted by **Mr. Sachin S. Chikkeri**, Registration No. **J-18-D-357-A**.



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