Asian Jr. of Microbiol. Biotech. Env. Sc. Vol. 25, No. (3) : 2023 : 448-462

ISSN-0972-3005

DOI No.: http://doi.org/10.53550/AJMBES.2023.v25i03.010

REVIEW ON GRAFTING STATUS OF SOLANACEOUS VEGETABLES IN INDIA

PALANISAMY KARTHIGA[1], ALAGARSAMY RAMESH KUMAR[2] AND SUNDARESAN SRIVIGNESH[3]*

Department of Horticulture, School of Life Sciences, Central University of Tamil Nadu, Thiruvarur 610 005, Tamil Nadu, India

(Received 3 February, 2023; Accepted 13 April, 2023)

Key words: *Grafting, Solanaceous vegetables, India*

Abstract– Unfavourable soil and environmental factors, as well as biotic factors like soil-borne pests and diseases, are reducing the global capacity for cultivating vegetables. Vegetable grafting is regarded as the most environmentally safe management strategy for sustainable vegetable production since the resistant rootstock lessens the need for agrochemicals in the treatment of soil-borne diseases and has opened up new possibilities for organic vegetable farming. Given their ability to withstand both biotic and abiotic stresses, grafted solanaceous plants are being produced and grown in greater quantities across Asia, Europe, and North America. It increases the production of the cultivars in addition to their tolerance to biotic and abiotic stresses. Grafting is currently recognized as a quick replacement option for the rather lengthy breeding methodology and is useful in sustainable farming that requires less input for future agricultural systems. Also, innovations in robotic and mechanized grafting have encouraged the development of this creative eco-friendly strategy. In the future, mechanization has the potential to dramatically cut the cost of producing grafted seedlings. This method continues to be infancy in India due to the significant post-graft mortality of seedlings; therefore, for its commercial implementation in India, grafting skills need to be improved, and strategies to increase the graft success percentage has to be developed. This review focuses on research works conducted on the grafting of solanaceous crops throughout India and how these could be used to improve the current situation of grafted solanaceous vegetable cultivation in India.

INTRODUCTION

Vegetable crops are essential for a balanced diet and enough nourishment for human health on a global scale. Due to their nutritious value, vegetables are usually referred to as "Protective food," and they are profitable enough to replace subsistence farming (Kumar *et al*., 2018). India is, fortunately, the biggest producer of vegetables, followed by China. In India, around 10.96 million hectares are occupied towards vegetable production, which yields 197.2 million tonnes of vegetables annually. However, the area under cultivation is limited and relatively consistent from year to year, with a considerable amount of this land allocated to the solanaceous family of vegetables. Due to the ever-increasing population and the huge market demand for out-of-season vegetables, the farmers were compelled to continue cultivating the same plot of land under deplorable conditions. Furthermore, abiotic and biotic stresses can considerably reduce plant growth and yield when repeated cropping is widely practiced. Internationally significant vegetable crops such as tomato, brinjal, sweet pepper, watermelon, cucumber, and bitter gourd are endangered by global challenges such as flooding, drought, salt, plant parasitic nematodes, and soil-borne illnesses. Horticulturists must pay urgent attention to these challenges to find a solution through breeding or agronomic management strategies (Colla *et al*., 2008; King *et al*., 2010; Schwarz *et al*., 2010). However, genetic breeding and biotechnology do not always adequately reduce the aforementioned problems. Farmers are regularly compelled to use pesticides to combat the damage caused by pests and diseases. However, chemical pest management can be detrimental to the environment, is costly, and is not always effective due to the fast development of pest

([1]Ph.D. Scholar, [2]Associate Professor, [3]Assistant Professor)

and disease resistance. Although there are several ecologically friendly methods, they are time-consuming and involve extensive study and testing. In this situation, it is necessary to investigate alternative strategies. Grafted seedlings are currently recognized as a very reliable approach that fulfils all of these characteristics. Grafting is considered a faster alternative to the often-prolonged breeding process. For the past four decades, productive scions have been grafted onto resistant rootstocks to counteract biotic and abiotic stresses, namely in East Asia with solanaceous and cucurbitaceous crops (Lee, 1994; Schwarz *et al*., 2010). It permits organic production, reduces dependency on agrochemicals (Rivard and Louws, 2008), and facilitates organic farming.

Grafting has enhanced the fruit quality and productivity of several crops, including tomato (Kumar *et al*., 2015b; Singh *et al*., 2017; Singh *et al*., 2020), watermelon, cucumber, melon, capsicum, and eggplant (Lee and Oda, 2003; Colla *et al*., 2013). Grafted plants were also shown to exhibit better tolerance to abiotic stresses, such as drought (Kumar *et al*., 2017), flooding (Bhatt *et al*., 2015), heavy metals (Kumar *et al*., 2015a), and severe temperatures (Kumar *et al*., 2019; Rivero *et al*., 2003; Venema *et al*., 2008). Numerous studies have identified the powerful root system of the rootstock as the primary benefit of grafting since it enables plants to absorb water and nutrients more efficiently than ungrafted plants (Lee and Oda, 2003). Nematodes, bacteria, and fungus are the principal soil-borne pathogens that cause considerable yield losses in intensive vegetable cultivation. Grafted plants have demonstrated excellent resistance or limited the spread of soil-borne diseases when grafted onto resistant rootstocks (Kunwar *et al*., 2015; Johnson *et al*., 2014; Jang *et al*., 2012). Grafting has several advantages, yet it is a relatively new technology in India. Due to the importance of solanaceous crops to Indian cuisine, India must employ and adopt the relevant technologies. This review focuses on the significance of grafting solanaceous crops, the current state and challenges of grafting in the Indian vegetable seed industry, and how vegetable grafting can be used to address these issues and stimulate the vegetable sector in India, taking into account the global significance and applications of vegetable grafting.

Vegetable grafting in India

Vegetable grafting was first practiced in India in the 19th century, despite the fact that the technique was developed by ancient Chinese people and documented in a book during the fifth century BC (Lee and Oda, 2003). In recent years, Asia, Europe, and North America have witnessed an increase in the production and cultivation of grafted solanaceous and cucurbitaceous vegetable plants as a result of their resilience to biotic and abiotic challenges. However, India is still in its infancy with this technology.

In India, the Indian Institute of Horticultural Research (ICAR-IIHR), Bangalore, and the Indian Institute of Vegetable Research, Varanasi pioneered the practice of grafting in vegetable crops, primarily to reduce waterlogging and currently carrying out various research on rootstock breeding (Ashok Kumar and Sanket, 2017). The other pioneer institute Tamil Nadu Agricultural University, Coimbatore standardized the Brinjal grafting in 2016 using The other pioneer institute Tamil Nadu Agricultural University, Coimbatore has standardised the Brinjal grafting in 2016 using COBH1, CO_2, Dhruva as scions and Turkey berry (*Solanum torvum*) as a rootstock to confer the resistance against root-knot nematode (*Meloidogyne* sp.) and dry root rot (*Macrophomina phaseolina*) and currently Grafting tomato, chilli, bitter gourd, and cucumber plants is being researched to treat soil-borne diseases (Pugalendhi *et al*., 2019). Through an All India coordinated research project, Bidhan Chandra Krishi Viswavidyalaya (BCKV), West Bengal has successfully developed grafted brinjal and tomato *Solanum torvum* and *Solanum sisymbriifolium* respectively, against bacterial wilt pathogen (Ashok Kumar and Sanket, 2017). In the NBPGR regional station in Trissur, Kerala, a dioecious vegetable crop called *Momordica cochinchinensis* is used for grafting, with male plant serving as rootstock and female plant serving as scion. To increase production, the female plants were grafted onto the male plants (Maurya *et al*., 2019). The commercial production of grafted Solanaceous vegetables like tomato, brinjal, capsicum and cucurbitaceous vegetables like cucumber, watermelon, and muskmelon are carried out by private seed companies like VNR Seeds Pvt. Ltd., Raipur, Namdhari Seeds Pvt. Ltd., Bengaluru, Jarvi Seeds Pvt. Ltd., Bharuchand 'Takii Seed India Private Limited', Bengaluru by adapting the technology developed by the public institutes of above (Ashok Kumar and Sanket, 2017; Pugalendhi *et al*., 2019).

Preferred grafting technique for solanaceous crops

The selection of scion and rootstock, graft union formation, healing of the union, and acclimatization of the grafted plant are the stages in the grafting process. Grafting processes vary greatly and widely based on the type of crop, the farmer's preference and experience, the facilities and equipment available, the number of grafts, and even the purpose of grafting, such as for personal use or commercial sale by the producers. Small-scale farmers with less ability like the tongue-approach method of grafting, but professional growers with more experience prefer the splice method.

It is widely accepted that splice grafting generates substantially superior quality seedlings than the tongue grafting method. The most common grafting procedures for solanaceous crops include cleft grafting, wedge grafting, splice grafting, tube grafting, and one cotyledon splice grafting (Maurya *et al*., 2019). Numerous nations have historically utilized cleft grafting for cucurbits, although presently it is more commonly done for solanaceous crops. Even though several grafting robots, semi-automatic and fully-automatic devices have been developed and are commercially available, manual or hand grafting is currently the most common grafting technique (Lee *et al*., 2010).

Potential rootstocks for grafting solanaceous crops

The key challenges in enhancing the production of solanaceous crops by grafting are the creation of rootstocks with resistance to a wide range of diseases, strong root vigor, and high compatibility, including the use of acceptable grafting techniques (Gaion *et al*., 2018). Even though other closely related species of Solanum can be utilized as rootstocks, the majority of tomato grafting has been performed on tomato genotypes and interspecific hybrids. Historically, tomato grafting was performed largely to promote resistance to soilborne pathogens such as *Ralstonia solanacearum*, *Verticillium spp*., *Fusarium spp*., and *Meloidogyne spp*. Increasingly, rootstocks are being utilized to develop resilience to abiotic stress and enhanced nutrient and water absorption. Due to intensive greenhouse production, the use of fertigation, and tomatoes' high evaporation requirements, salinity has been given the most attention among abiotic stresses.

Historically, natural species such as *S. integrifolium* or hybrid tomato rootstocks were utilized to graft eggplant. The former is used to confer resistance to soilborne pathogens including bacterial and Fusarium wilt, whilst the latter is better recognized among gardeners for tomato grafting (King *et al*., 2010). According to studies, grafting has detrimental effects on the yields of conventional rootstocks, including tolerance loss. Therefore, researchers began searching for alternative rootstocks, including interspecific hybrids and more closely related wild species. Due to their resistance to Fusarium wilt, bacterial wilt, Verticillium wilt, and root-knot nematode, wild species such as *S. torvum* and *S. sisymbriifolium* have shown promise as eggplant rootstock. None of the known brinjal varieties naturally resist pests and diseases. *S. torvum* has been shown to be resistant to the majority of serious eggplant diseases, including those caused by bacterial, fungal, and nematode pathogens, which is quite interesting.

Among solanaceous plants, less research has been done on grafting sweet peppers than on tomato and eggplant. This might be due to the low compatibility of sweet peppers with other species, which makes commercial grafting of these peppers uncommon (Gaion *et al*., 2018). In contrast to tomatoes and eggplant, peppers are exclusively grafted onto members of the genus Capsicum, which are immune to the virus *Phytophthora capsici*. Recently, interspecific pepper hybrids have been developed for use as rootstocks, and they exhibit exceptional resistance to viruses and Phytophthora. Selection within the genus Capsicum can provide nematode-resistant rootstocks with excellent compatibility with cultivated cultivars (Bletsos *et al*., 2008). In Table 1 and Table 2 are mentioned potential rootstocks that are widely used in solanaceous grafting.

Current status of solanaceous vegetable grafting in India

Tomato

Tomato is produced and consumed internationally and are grown in soil or soilless medium in both open-field and protected environments. However, there are several barriers to the cultivation of this crop, such as biotic and abiotic stress. Using breeding and biotechnology techniques, the public and private sectors are attempting to develop tomato cultivars that can thrive in protected environments, but this is a lengthy process (Singh *et al*., 2017). Grafting is a distinct strategy with the ability to boost the efficacy of high-yielding genotypes for increased flexibility or resistance to a variety of environmental situations (Kumar *et al*., 2017). The commercial production of grafted tomatoes began in the early 1960s (Lee and Oda, 2003) and is now a popular form of tomato cultivation around the globe. When grafted onto disease-resistant rootstocks, plants exhibit exceptional resistance to soil-borne pathogens.

Bacterial wilt (*Ralstonia solanacearum*) significantly lowers tomato yields, particularly under protected cultivation. It is more prevalent in India's hot, humid environment. Since infectious spores may remain viable and active in the soil for years, it is especially difficult to control the disease. Additionally, because environmental conditions have a large influence on bacterial wilt, it is extremely difficult to generate resistant varieties. A combination of inadequate disease management and complicated disease biology would aggravate yield losses. To prevent bacterial wilt in vegetable production, grafting using proper rootstocks is crucial (Rivard *et al*., 2012).

One of the most significant abiotic stress is salinity, which restricts plant development and agricultural output. Over 1100 million hectares of land are covered by saline and alkaline soils, which represent 7 percent of all soils impacted by salinity (Mandal *et al*., 2018). Approximately 20 to 33 percent of agricultural land is impacted by salinity worldwide. Since tomatoes are particularly susceptible to salt stress (threshold limit up to 2.5 dS m^{-1}), excessive salinity can dramatically impair crop yield by reducing plant height, shoot-root biomass, oxidative stress, and photosynthesis. Several physiological and biochemical systems are influenced by salinity rise. Because salt tolerance is a complex characteristic comprising a lot of quantitative and environmental components, breeding and biotechnology have made little success in improving tomato salt tolerance (Al-Harbi *et al*., 2017). The crop breeding program can thus be supplemented with a proper management strategy, such as grafting tomatoes onto salt-tolerant rootstocks.

Soil salinity has a severe negative effect on tomato yield. In the past, tomato scions were grafted onto tomato rootstocks to improve their tolerance to salt stress. Regarding salt tolerance, however, little information is available on tomato plants grafted onto eggplant rootstocks. In contrast, tomato plants

Table 1. Rootstocks commonly used for grafting tomato

Common name	Botanical name	Growth habits and features
		Tomato
Turkey berry	*S. torvum*	The plant is typically 2 to 3 m tall and 2 cm in diameter at the base. It is a bushy, upright, spiky perennial used as a rootstock for eggplant and tomato. The fruits are berries that develop in clusters of small, pea-like green spheres.
Yellow- berried nightshade	*S. xanthocarpum*	The fruits of this plant are globe-shaped, hanging berries. They are yellow or light in color, with green veins and a calyx that is enlarged. Seeds are glaborous.
Nightshade plant	*S. incanum*	The herbaceous or softwood shrub reaches a maximum height of 50 cm. Leaves range from unlobed to heavily lobed. The midrib and lateral vines may or may not have prickles. When mature, the fruit is green, typically striped or speckled with white, and turns yellow to orange-brown.
Ethiopian Nightshade	*S. aethiopicum*	The plants are deciduous, 2.5 M -tall shrubs. Flowers are hermaphrodites and fruits are berries; when ripe, they become a brilliant shade of red due to a high carotene content.
Sticky Nightshade	*S. sisymbrifolium*	Annual hedge plant. The fruits are tiny and delicious, having a red exterior and a yellow inside. Due to the presence of solasodine in the stem and leaves, it is very resistant to diseases and insects.
Tropical soda apple	*S. viarum*	Perennial herbaceous shrub with thorns. Fruit is a globose fruit, green with black veining, like a miniature watermelon.
Indian Nightshade	*S. violaceum*	The branches of this 0.3-1.5 m tall shrub bear curled prickles. The flowers are racemose extra-axillary cymes; the petal is eight mm long and light purple. Upon maturation, the fruits are 8 mm in diameter, globose, and dark red.
Brinjal	*S. melongena*	The AVRDC (World Vegetable Centre) suggests eggplant varieties EG195 and EG203. They are resistant to floods, bacterial wilt, root-knot nematode (*Meloidogyne incognita*), and tomato Fusarium wilt (*Fusarium oxysporum* f. sp. *lycopersici*)

grafted onto the brinjal rootstocks IC-111056 and IC-354557 demonstrated greater resistance to salt stress compared to ungrafted plants. By positively modifying salt ion partitioning in the scions, grafting tomato seedlings onto selected salt-tolerant eggplant rootstocks is a viable option for improving plant physiological condition and fruit output under salt stress (Sanwal *et al*., 2022).

The frequent, heavy rainfall during the growing season, particularly during the rainy season in the tropics and subtropics of India, can result in water logging, which reduces the soil's oxygen level and kills plants. Tomatoes grown in open fields are extremely susceptible to flooding (Petran and Hoover, 2014). Grafting tomatoes with suitable rootstocks can enhance their resistance to waterlogging. Bhatt *et al*. (2015) utilized interspecific tomato grafting to improve plant resilience to floods. Four eggplant rootstocks, including BPLH-1, Neelkanth, Mattu Gulla, and Arka Keshav, were grafted onto the commercial tomato cultivar Arka Rakshak . The results revealed that grafting had a significant effect on yield in both flooded and dry environments. Non-grafted and self-grafted plants died after five days of flooding, but Arka Rakshak/Arka Keshav and Arka Rakshak/BPLH-1 performed better and concluded that eggplant rootstocks are resilient to flooded environments and would serve as a suitable rootstock to boost tomato's tolerance to flooding. The World Vegetable Center (AVRDC) recommended utilizing the EG195 and EG203 eggplant accessions as rootstock for tomatoes to increase their resistance to flooding (Black *et al*., 2003).

Naik *et al*. (2021) investigated two cherry tomato hybrids ('Cheramy' and 'Sheeja') grafted onto three tomato and five eggplant native rootstocks in greenhouse soil contaminated with *Ralstonia solanacearum* (bacterial wilt). Except for 'Anagha,' which was utilized as a rootstock for the scion cultivar 'Cheramy,' none of the tomato rootstocks showed improved resistance to bacterial wilt. Whereas all eggplant rootstocks imparted moderate to high resistance to bacterial wilt in both scions, the

Table 2. Rootstocks commonly used for grafting brinjal

	Brinjal	
Turkey berry	*S. torvum*	Immature fruits are eaten raw or cooked but are regarded as invasive weeds. Resistant to bacterial, fungal wilts and nematodes.
Sticky nightshade	*S. sisymbrifolium*	Perennial shrub, edible fruits with resistance to plant parasitic nematodes
Tropical soda apple	*S. viarum*	Perennial shrub with prickles. Resistance source to shoot and fruit borer
Cockroach berry	*S. capsicoides*	Short lived, perennial plant
Thorn apple, bitter apple, bitter ball and bitter tomato	*S. incanum*	Herb or soft wooded shrub up to 1.8 m in height with spines on the stem. Resistance source for Fusarium Wilt and immune to shoot and fruit borer.
Weedy eggplant	*S. insanum*	Erect or prostrate branched shrub grows up to, 0.5 to 1.5 m in height, prickly. Resistance source for Bacterial wilt.
Devil's apple	*S. linnaeanum*	Upright or spreading shrub usually grows up to 1.5 m tall. Resistance source to Verticillium wilt.
African eggplant/ Vietnamese eggplant	*S. macrocorpon*	Tropical biennial plant. Resistance source to two-spotted spider mite, *Tetranychus urticae.* Tolerant to flooding.
African scarlet eggplant/Ethiopian nightshade	*S. aethiopicum*	Perennial plant with a stem that becomes more or less woody and persists. It forms a much-branched, deciduous plant that can grow up to 2.5 m tall.
Dutch eggplant	*S. acculeatissimum*	A weedy shrub that has small, 2–3 cm pale yellowish fruit. Resistance source to verticillium wilt.
Silver leaf bitter apple	*S. elaegnifolium*	Multi-stemmed grows up to 1 m tall, the aerial growth normally dying back during winter, with an extensive root system spreading to over 2 m deep. Resistant to drought.
Yellow - berried nightshade	*S. xanthocarpum*	A very spiky spreading plant produces globular drooping berries that are yellow or light in color and have green veins that are encircled by expanded calyx. Fruit and shoot borer-resistant
Scarlet eggplant	*S. integrifolium*	The most popular rootstock in Japan, it is resistant to Fusarium wilt and remains vigorous until the final stages of eggplant production. Little leaf disease, Verticillium wilt, and Root Knot Nematode resistance.

resistance was not uniform. The yield and revenue of both tomato and eggplant rootstocks improved overall. Specifically, "Cheramy" grafted onto "Anagha" rootstock cultivated in greenhouse soil infested with bacterial wilt was advantageous.

The tomato variety "PKM 1" graft compatibility with various solanaceous rootstocks was studied at TNAU, Coimbatore. The PKM 1 tomato grafted with *S. torvum* resulted in 95% success percentage. The successfully grafted plants grew faster due to vascular bundle regeneration across the graft interface, which increased nutrition and water delivery via the graft union. The rootstocks such as LE 828, LE 523, and *Solanum aculeatissimum* grow quicker than *Solanum sisymbriifolium* (Priyanka *et al*., 2019). In a similar study, where eight different rootstocks were used, *S. sisymbrifolium*, *P. peruviana*, and *S. torvum* showed strong resistance to the pathogens that cause Fusarium wilt and the root-knot nematode, whereas *S. incanum* and *S. aethiopicum* showed only moderate resistance. The incompatibility of *S. sisymbrifolium* and *P. peruviana* with tomato scions outweighed their benefit in terms of resistance to Fusarium wilt and root-knot nematode. On the other hand, *S. torvum* and *S. incanum* rootstocks were resistant and compatible with tomato scions. *S. torvum* was reported to be the finest rootstock for grafting tomato, followed by *S. incanum*. The investigation found that the TNAU tomato hybrid CO-3 was superior to the other two hybrids utilized (Divya, 2013). In addition, a comparable study showed that the TNAU tomato hybrid CO 3 grafted onto *Solanum sisymbrifolium* rootstock performed well in terms of yield and yield-attributing attributes when cultivated in the field (Pugalendhi *et al*., 2021).

Recently, a study on the growth, yield, and quality of tomato grafted onto 18 different rootstocks under polyhouse was elucidated. The yield of plants grafted onto the tomato rootstock Green Gourd was greater. Grafted tomato plants outperformed non-grafted tomato plants in terms of quality. Ascorbic acid concentrations were greatest in plants grafted onto the Palam Pink rootstock, whereas TSS concentrations were greatest in plants grafted onto the Arka Nidhi rootstock (Sharma *et al*., 2018).

Thompson and Morgan, a British horticultural company, invented the "TomTato," a double-crop plant consisting of a tomato grafted onto a potato rootstock, via innovative thinking and years of research and development. This plant is capable of producing both potatoes and tomatoes after a successful graft (Lee *et al*., 2010). In India, not much research has been performed, and there is currently a dearth of technical knowledge in this field. Given this fact, a recent study was done at CSK HPKV, Palampur to investigate the compatibility of tomato cultivars grafted onto various potato rootstocks. Negi *et al*. (2016) conducted an inter-specific grafting study in a naturally ventilated Quonset polyhouse, using Kufri Himsona, Kufri Himalini, and Kufri Giriraj as rootstocks, as well as Avtar -7711 and GS-600 tomato hybrids. Regardless of the grafting strategies used, Kufri Himalini+GS-600 was shown to have the greatest survival rate and grafting success rate for grafted plants. When appropriate tomato and potato plants were grafted together, their chances of survival increased significantly. The highest documented survival rate for the best rootstock-scion combination was 93.25 percent, illustrating the tight genetic affinity and excellent graft compatibility of tomato and potato plants. Peres *et al*. (2005) reported similar findings. This research will help in the development of this technology, which has the potential to provide a viable and ecologically friendly alternative to meet the demands of the growing population of India.

It is popular to graft vegetables to withstand various biotic and abiotic stresses. The concept of grafting closely related crop species to produce two crops from a single plant, however, is a relatively recent technology that is becoming more and more popular among professionals and farmers. In terms of farming economics, yield is the most significant component from the grower's perspective. Grafting strengthens scions, improves resource usage effectiveness (e.g., water, fertilizer), and lengthens the harvest period, all of which directly increase yield. Compared to the usage of self-rooted vegetables, it also contributes to lowering the cost of plant protection measures. To increase production and quality while also offering resilience to biotic and abiotic challenges, research must be expanded to identify the appropriate scions and rootstocks.

Brinjal

Solanum melongena L., generally known as aubergine/ egg plant, is a member of the Solanaceae family. In terms of brinjal production, India is second only to China, with 7.33 million hectares and 13 million tonnes (NHB, 2019). It accounts for approximately 26% of global production (Kumar *et al*., 2017). Eggplant is commonly cultivated under a variety of climatic conditions worldwide and is considered suitable for grafting (King *et al*., 2010). In the late 1950s, wild species of Solanum were used as rootstocks in eggplant grafting (Lee and Oda, 2003). Several unexploited wild Solanum species with high graft compatibility with cultivated eggplant genotypes have been identified (Davis *et al*., 2008; Bletsos *et al*., 2008).

The dry root rot or charcoal rot caused by *Macrophomina phaseolina*, a significant root parasitic plant pathogen that infects more than 500 hosts worldwide, is one of the greatest obstacles to the production of brinjal in India and other countries that cultivate the vegetable. This disease is known to affect dry gastrointestinal tracts in India, specifically in Tamil Nadu. The yield loss caused by the disease can range between 50 and 71%. (Sherly *et al*., 2010). To reduce the need for excessive pesticide use, tolerance to these biotic stresses can be developed through grafting. In the majority of instances, interspecific grafting is utilized in eggplant. Turkey berry (*S. torvum*) and scarlet eggplant (*S. integrifolium*) are two widespread eggplant rootstocks. No known brinjal cultivar exhibits natural resistance to pests and diseases. It is interesting to note that *S. torvum* is resistant to the vast majority of important eggplant diseases, especially those caused by bacteria, fungi, and nematodes.

The root-knot nematode (*Meloidogyne spp*.) is a significant problem for the vast majority of solanaceous vegetables, particularly in sandy soils and under protected cultivation. Although chemical nematode management is a common practice, there is an urgent need for an alternative method to prevent the overuse of chemicals (Singh *et al*., 2017). In some crop production systems, grafting can be an excellent IPM tool and a viable alternative to soil fumigation (Kubota *et al*., 2008). Screening study for root-knot nematode resistance in wild Solanum species revealed that *S. torvum* exhibited the reaction category of resistance based on reduced root-knot index (RKI) value, and COBH 2 on *S. torvum* exhibited the lowest nematode infestation values. The *S. torvum* accessions and COBH 2 were found to be superior in terms of dry root rot disease, both in container culture and in the field, with no disease symptoms. It was deemed immune because it exhibited no symptoms of root rot. *S. torvum* had the highest concentrations of phenols, ortho-dihydroxy phenols, protein, and ascorbic acid among the three wild solanum species tested against the root-knot nematode using biochemical methods. This was the first report on the sustainable management of dry root rot incidence in brinjal published in India (Sherly, 2010).

In a study conducted in a low-cost polyhouse, Kumar *et al*. (2017) compared grafted and non-grafted eggplant plants to determine the effects of various rootstocks on growth, yield, and quality. *Solanum torvum* and *S. khasianum* outperformed all other rootstocks utilized for grafting in terms of yield and yield-attributing characteristics. To precisely track the various quantitative, qualitative, and yield-related traits, the research can be expanded to include a greater variety of eggplant cultivars and wild species. Bacterial wilt, which is caused by *Ralstonia solanacearum*, is a severe, soil-borne disease that prevents the global cultivation of eggplants. In India, the prevalence of bacterial wilt has a substantial negative impact on brinjal cultivation (*Solanum melongena* L.). Bacterial wilt is one of the top five diseases and a significant constraint on brinjal yield (Ramesh *et al*., 2016). This pathogen is difficult to control due to the availability of numerous *R. solanacearum* strains and the pathogen's ability to survive longer in unfavorable soil conditions. *Solanum torvum* (Turkey Berry) has been identified as a rootstock for managing bacterial wilt in eggplant. Ramesh *et al*. (2016) conducted a study to evaluate *S. torvum* as a rootstock in brinjal in relation to bacterial wilt incidence and yield by grafting onto local brinjal varieties, Agassaim, Taleigao, and other lines from a segregated population. The grafted plants displayed complete resistance to bacterial wilt and produced fruit identical to that of the seedling variety, indicating growers' and consumers' acceptance. In a similar study, Rahman *et al*. (2002) used *Solanum torvum* as the rootstock and found a grafting success rate of 95% in controlling the incidence of bacterial wilt in brinjal.

In the coastal regions of India, Ramesh *et al*. (2022) evaluated the effect of rootstocks on the control of bacterial wilt disease in eggplant and tomato. It was discovered that tomato and eggplant grafts made on *Solanum torvum* (Turkey berry), S0004, and Surya reduced the incidence of bacterial wilt in both field and greenhouse conditions. The incidence of wilt was lowest when *S. torvum* was used as a rootstock for tomato (0 to 15%) in greenhouse conditions and brinjal (0 and 15-40%) in field conditions. Grafts of the polyhouse-grown tomato hybrid (GS-600) developed from *S. torvum* exhibited a reduced incidence of bacterial wilt (23 to 40 percent). This study demonstrates that grafting susceptible tomato and eggplant varieties onto resistant rootstocks such as *S. torvum* and Surya may be an effective method for managing bacterial wilt. This could be used to control bacterial wilt in tomato and eggplant wherever resistant strains are lacking. Other rootstocks in the study area exhibited varying degrees of disease resistance that could be utilized in regions with a moderate disease incidence. Therefore, it is necessary to understand the rootstock's level of resistance to *R. pseudosolanacearum*, as this level of resistance may vary depending on the strain present in the region. When evaluated against two *R. pseudosolanacearum* strains, Namisy *et al*. (2019) found varying levels of resistance in cultivated and wild relatives of eggplant.

Kumbar *et al*. (2021) assessed eggplant rootstocks for grafting eggplant in order to increase fruit yield and control bacterial wilt disease. In terms of yield characteristics, *Solanum melongena* cv. "Haritha" emerged as the most promising rootstock for grafting eggplant. Grafting technology could therefore be successfully applied to eggplant to produce a higher yield of highly nutritious fruits that are also resistant to bacterial wilt. Haritha performed significantly better than *Solanum torvum* in terms of yield. Because the rootstock and scion are of the same species, there may be greater compatibility and nutrient transfer between them in Haritha than in *S. torvum* (Lee and Oda, 2003). Therefore, Haritha can be utilized on a commercial scale as a dependable alternative to the widely accepted *Solanum torvum* rootstock. Not only does this replacement rootstock hold the promise of inexpensive, regular, and uniform rootstock production for grafting purposes, but it also has the enormous potential to produce high yields of high-quality fruit. Agribusinesses can also benefit from this because grafted plants can be produced rapidly and in response to the needs of the farmer community.

Water is essential for plants, but too much can deplete the root zone's oxygen supply and hinder root respiration, causing rotting and disease. These challenges caused by excessive water availability or flooding can be overcome by grafting onto tolerant/resistant plants. According to Petran (2013), grafting tomatoes onto *Solanum torvum* rootstock significantly improved their flood resistance and yield. Kumar *et al*. (2019) conducted a field experiment on grafting two brinjal cultivars, Surati Ravaiya Pink and Surati Ravaiya Purple, onto the rootstock of *Solanum torvum* Swartz to illustrate the impact of high moisture stress on plant life and other horticultural factors. The South Gujarat region of the Indian subcontinent is located in an area with high rainfall, and the locals there has a special affinity for brinjal cultivars of It was discovered that grafting brinjal onto wild species alters a plant's physiological processes, giving it a greater chance of surviving and thriving in harsh climates (Davis *et al*., 2008). In addition to the successful performance of the grafted plants, yield-enhancing characteristics were also acquired. This increase in yield may be a result of the grafted plants' more vigorous growth, as noted by Leonardi and Giuffrida (2006), who studied the effect of interspecific tomato rootstock on tomatoes. According to the results of the experiment, grafting brinjal onto the *Solanum torvum* Swartz rootstock increases plant survival during the rainy season, crop duration, fruit set, infestation by shoot and fruit borer, yield, and net returns (Kumar *et al*., 2019).

Over the years, Solanum has made advancements in numerous research fields. Due to the significance of brinjal farming in India and the advantages of grafting over wild rootstock, Subba *et al*. (2021) conducted a study to characterize *Solanum* spp. for grafting and assess its effects on the morphological, production and nutritional quality of fruit grown in a polyhouse. *S. torvum, S. macrocarpon, S. incanum,* and *S. viarum* were chosen among the seven wild species of solanum grafted into three cultivated brinjal scions because of their likely compatibility and high success rate with two of the scions, namely Patakata and Pusa Shyamla. Three brinjal scions that were grafted onto the species *S. aethiopicum, S. indicum,* and *S. sisymbrifolium* failed to graft due to the absence of cellular recognition, wounding reactions, the presence of growth regulators or incompatible toxins, an unfavorable grafting environment, or a combination of these factors. In terms of quality and yield, Pusa Shyamla grafted onto *S. torvum* and *S. macrocarpon* performed superiorly to all other graft combinations in the field. These findings corroborate previous research by Alexios *et al*. (2007), which demonstrated that the yield of grafted plants was significantly greater than that of non-grafted controls, regardless of rootstock.

Pepper

Compared to tomato and eggplant, pepper is the solanaceous crop that is grafted the least frequently. This is likely because the available commercial rootstocks offer only marginal benefits (Lee *et al*., 2010). Consequently, there is an urgent need to develop new rootstocks to support initiatives to meet the rising demand for fresh sweet pepper. The most commonly used rootstocks today are intraspecific hybrids or cultivars of *Capsicum annuum*; however, accessions of the domesticated Capsicum species, including *Capsicum baccatum L., Capsicum chacoense Hunz., Capsicum chinense Jacq., Capsicum frutescens L.,* and their interspecific hybrids *Capsicum annuum, C. chinense* (Lee *et al*., 2010). As predicted, resistance to soilborne diseases and nematodes as well as abiotic stresses has been the most important factor in pepper grafting; however, very little research has been conducted to examine the effects of grafting on pepper fruit quality.

Bacterial wilt, caused by *Ralstonia solanacearum*, is the most destructive disease in both protected and open field conditions, and it reduces capsicum yield to extremely low levels. Numerous attempts have been made to develop bacterial wilt-resistant cultivars, but no resistant hybrid has been created. Grafting scions of cultivars of superior hybrids onto hardy rootstocks is the optimal solution. Rana *et al*. (2015) evaluated the ability of five chili and three brinjal rootstocks to protect bell peppers from bacterial wilt. According to the results, brinjal rootstocks were deemed unsuitable for bell pepper scions, whereas the chilli rootstock PI-201232 was deemed the best bell pepper rootstock for bacterial wilt resistance.

In CSK Himachal Pradesh Krishi Vishwavidyalayaa, Palampur, Kumar *et al*. (2017) evaluated the growth, yield, and quality of bell peppers grown on chilli and brinjal rootstocks. On five chili and three brinjal, rootstocks were grafted the commercial hybrid bell pepper Indra. The best rootstock for bell pepper was PI-201232, a chili rootstock. As a method of propagation, PI-201232 rootstock with tongue grafting produced a high yield of marketable fruit. The bell pepper rootstocks PI-201232, AVPP0205, VI-037556, Surajmukhi, and Pant C-1 were determined to be more suitable than the brinjal rootstocks.Before selecting scion and rootstock genotypes for grafting, a comprehensive analysis is required to achieve the desired outcome. Table 3 and 4 provides an overview of the scions and rootstocks used for grafting solanaceous crops in various countries.

Challenges in adopting grafting

Production and management of grafted plants are associated with various problems. Because of the labour-intensive nature of the method, skilled employees are needed. It also requires time management for sowing the rootstock and scion seeds, efficient grafting instruments and robots, and a controlled environment for graft healing. Under field conditions, overgrowth of transplants is possible, and scion fruit quantity and quality may be reduced considerably (Huang *et al*., 2015). When transplanting plants in the field, rootstock-scion incompatibility can occasionally be seen during the

Table 3. Rootstocks and scions used for tomato grafting in various nations

Rootstock	Scion	Aim of study	Country	Reference
		Tomato		
Goji berry	TA209 and Zhongshu 5	Growth and fruit quality	China	Huang *et al*. (2015)
Beaufort and	Profitto	Quality traits	Italy	Nicoletto *et al.* (2013)
Big power	German	Bacterial wilt and	United States	Rivard and Louws (2008)
CRA66, Hawaii 7996, and Maxifort	Johnson	fusarium wilt		
Beaufort, Big power, and Maxifort	Cherokee Purple and German Johnson	Southern blight and root-knot nematodes	United States	Rivard *et al*. (2010)
BHN 998, BHN 1054, and RST-04-106-T	BHN 602	Nematode and bacterial wilt	United States	Kunwar *et al*. (2015)
Arka Keshav, Arka Neelkanth, BPLH-1, and Mattu Golla	Arka Rakshak	Flooding stress	India	Bhatt *et al*. (2015)

early stages or after the transplantation. Rootstock and scion must be carefully selected based on local soil conditions and environmental factors. It is necessary to use both rootstock and scion seeds, as well as hybrid and expensive special seed varieties. During the healing process or in the field, it is necessary to remove rootstock suckers and offshoots that appear (after transplanting). In addition, grafting may increase the risk of disease transmission, especially for seed-borne diseases in the nursery, such as tomato mosaic virus and Pepino mosaic virus infections, and bacterial canker caused by *Clavibacter michiganensis* subsp. *michiganensis.* This is because grafted plants are grown from seeds and are cut with tools during the grafting process. Adopting measures to prevent the spread of infections in the nursery is crucial for the aforementioned reasons. Using certified pathogen-free seeds, routinely disinfecting cutting tools, mandating clean clothing and disinfected hands for grafting workers, routinely disinfecting grafting areas and environments, and continuously monitoring the phytosanitary status of seedlings are examples of these measures. Grafting is time-consuming and costly because the aforementioned procedures require a specialized workforce (Sen *et al.,* 2018).

Recent trends in vegetable grafting

a) Robotics and automation

The utilization of grafting robots or machines has increased in recent years. Iam Brain in Japan developed the first robotic "one-cotyledon grafting device" for cucurbit crops during the 1980s. The prototype was created in 1987 and modified in 1989. In the Netherlands, a fully autonomous grafting robot with a capacity of one thousand grafts per hour has been developed and is used to graft tomatoes. A similar robot with a capacity of 750 grafts per hour and a 90% success rate has been developed in Japan. Currently on the market are six semi- or fully-automated grafting robot models, three of which were developed in Japan, one each in Korea, the Netherlands, and Spain (Bie *et al*., 2017). The developed grafting robots are listed in table 5.

b) Micro-grafting

Micrografting is the technique of grafting in vitro using micro explants (less than 1/1000 mm^3) from meristematic tissues. This method permits the rapid propagation of virus-free plants. Micrografting has been used for herbaceous plants.

c) Double-grafted and single-grafted tomatoes

By grafting a tomato (*Solanum lycopersicum* L.) scion onto a potato (*Solanum tuberosum* L.) rootstock, a

Table 4. Rootstocks and scions used for grafting brinjal and pepper in various nations.

Rootstock	Scion	Aim of study	Country	Reference
		Brinjal		
S. torvum	Bianca, Sciacca, Marsala and Sicilia	Yield and quality	Italy	Sabatino *et al*., 2016
Interspecific hybrids of *S. melongena* with *S. incanum* and *S. aethiopicum*	Black Beauty(BB)	Yield and fruit quality	Spain	Gisbert *et al*., 2011
Beaufort and *S. aethiopicum*	Epic	Yield and verticillium wilt	United States	Johnson *et al*., 2014
S. torvum, and Surya, S0004, Agassaim and Taleigao	S00019 (EG 195), S00022 (EG 203), TS02257 (EG 190	S00004 (EG 219), Bacterial wilt	India	Ramesh *et al*., 2022
S. torvum, S. xanthocarpum, S. khasianum and *S. surattense*	Pusa shyamala, Pusa Hybrid 6	Yield and quality	India	Kumar *et al*., 2017
Pepper				
A25 (COMAV Genebank)	Adige (A)	Salt stress	Spain	Penella *et al*., 2016
Oscos and AR40 (Ramiro 2014 Arnedo), Tresor (Nunhems)	Palmero	Yield and Quality	Spain	Donas-Ucles *et al*.,

hybrid plant known as a "pomato" is developed. Tomatoes grow on the vine, and potato tubers develop beneath the plant surface in the soil (Arefin *et al*., 2019). In 2020–21, following a successful field demonstration of Grafted Pomato (Potato + Tomato) at the ICAR-Indian Institute of Vegetable Research in Varanasi, Uttar Pradesh, Dual Grafting of Brinjal and Tomato (Brimato) was demonstrated in the field. On the brinjal rootstock IC 111056, the improved tomato cultivar Kashi Aman and the brinjal hybrid Kashi Sandesh were successfully grafted. Tomato plants produced approximately 36.0 fruits with a yield of 2.38 kilograms per plant, while brinjal plants produced 9.2 fruits with a yield of 2.68 kilograms per plant. The Dual Grafted Brimato Technology would be particularly beneficial in urban and suburban areas with limited space for growing vegetables in vertical gardens or pot cultures over terraces and compounds. At the ICAR-IIVR in Varanasi, Uttar Pradesh, ongoing research is being conducted on the commercial production of Grafted Brimato. Nonetheless, this innovative pilot study demonstrated the potential for developing harvestable rootstock-scion pairings as a means of reducing waste and conserving growth space. Such unique grafting model systems may be useful for elucidating sink competition and scion-rootstock synergy in horticultural plants.

Way to popularize grafting technology in India

1. Based on locally conducted trials and research, it is necessary to collect data regarding the resistance or tolerance of commercially available rootstocks and potential germplasm for new rootstock breeding.
2. It is crucial to document, evaluate, and utilize weed species that could serve as potential rootstock for various solanaceous vegetables. As an illustration, selected lines of *Solanum torvum* Swartz grown as a notable rootstock.
3. Researchers from multiple nations have also attempted to develop rootstock using biotechnology; India should support this concept. To cultivate grafted vegetable seedlings on a large scale, it is necessary to reduce the cost of grafting, such as by introducing robots for mass production.
4. Farmers will be more motivated if the central government and state agriculture institutions regularly provide them with awareness and training programs that include the most recent information on grafting techniques. It will be easier for farmers to transform to grow grafted seedlings if the government provides them with initial subsidies and helps them establish a modest manufacturing facility. As part of the ICRISAT-led project, "Doubling farmers' income through grafted vegetable seedlings in Andhra Pradesh, India," farmers in the villages surrounding Kuppam town in Chitoor district have recently received grafted seedlings. This project's objective was to establish a high-tech grafted seedlings nursery for solanaceous and cucurbitaceous vegetables, to provide technical support and guidance with documentation to cluster farmers to increase their productivity and to raise farmers' awareness of grafting technology and train them to use it. As a result of this program, more than 400 vegetable growers in Andhra Pradesh, India have begun farming grafted vegetables to double their profits through higher yields. The usage of grafted types over conventional varieties is resulting in a yield increase of around 30 and 50 percent, according to farmers. This will encourage the farming community to adopt grafting in vegetable crops.
5. It is imperative that all sectors of society, including the public and corporate sectors, as well as non-governmental organizations, become aware of the necessity for grafted plants to resist pesticide-laden farming practices in modern times. India is the second-largest producer of vegetables in the world but uses very little grafted planting material in commercial agriculture. Over fifty percent of vegetable crop seedlings utilized in Japan, Korea, and China were grafted. In several nations throughout the world, grafted seedlings of various solanaceous

Table 5. The grafting robots developed for vegetables

Robots	Model	Developed by	Vegetable crops
AG1000 robot	Fully automated	Yanmar Agricultural Equipment Co.Japan	Solanaceous
Iseki's GR800, GR-600	Semi-automated	Helper Robotech Co. Gimhae, Korea	Cucurbits
Arnabat S.A.	Semi-automated	Barcelona, Spain	Cucurbits, Solanaceous

vegetables are being promoted. Given the encouraging results of numerous worldwide studies on solanaceous crop grafting, it is estimated that even if only 25 to 30 percent of the solanaceous vegetable cultivation area can be converted to grafted plant cultivation, a significant amount of money can be saved on chemicals such as fungicides, pesticides, insecticides, etc., making farming not only more environmentally friendly but also allowing the farmer to invest the savings in other farming practices.

The way forward and prospects

Researchers, extension specialists, and seed companies must collaborate to implement this advanced technology as a tool for the production of high-quality vegetables. For commercial applications, grafting techniques must be improved and the reparative environment must be standardized. The development of rootstocks, the establishment of acclimatization facilities, and the improvement of grafting robot efficiency require additional research. The management and production of nurseries are labour-intensive endeavours. To increase the efficacy of grafting and reduce labor costs, researchers should concentrate on developing and popularizing grafting facilities, tools, and robots. The development of grafted vegetable-specific software, databases, mobile applications, and crop models will aid in the management of nurseries and the selection of suitable scion and rootstock cultivars by farmers. The global trade in grafted transplants is expanding rapidly, and with the growth of the grafted vegetable industry in India, this option can be utilized. Future production of grafted seedlings must be significantly less expensive. However, the variety of commercial rootstocks is limited; consequently, further research should focus on the development of rootstocks utilizing unidentified wild relatives in order to reduce unpredictable biotic and abiotic stresses.

After severing the vascular threads, plants can adhere to tissues and repair their vasculature. The majority of plants, however, were unable to completely or partially dedifferentiate their vascular tissues during wound healing due to a variety of factors, such as improper hormone movement on graft union sites to induce callus, non-translocation of wounding hormones, self-incompatible molecules, etc. At low concentrations, auxin, cytokinin, and traumatic acid are well-documented for inducing callus, enhancing graft union, and promoting wound healing. Nevertheless, a greater concentration of auxin (often applied exogenously in a single dose) may result in root degeneration. Consequently, neither in India nor anywhere else is a strategy for the gradual release of hormones into the graft union been proposed. Consequently, a smart delivery vehicle can be created by encapsulating plant hormones (IAA, Kinetin, and Traumatic acid) using nanotechnological approaches. The multilayer nanofiber matrix encapsulated with plant hormones can aid in prolonged release in a regulated pattern, thereby reducing financial loss and stress for nurseries and increasing crop yield through improved graft establishment. To reduce post-graft seedling mortality and increase farmers' use of grafted plants, it is necessary to develop a variety of technologies that limit post-grafting losses by enhancing graft union.

CONCLUSION

In Asia, vegetable grafting has been utilized effectively for decades, and it is gaining popularity worldwide. Numerous international seed firms are eager to produce and market rootstock seeds through their catalogues of commercial seeds. Rootstocks with multiple disease resistance and tolerance to biotic and abiotic stresses must be selected as a fundamental requirement for long-term success. Vegetable grafting, which has numerous applications around the world, has the potential to benefit India's vegetable industry and increase farmers' income by boosting crop yield and reducing the costs associated with using large quantities of fertilizer and pesticides. Grafting is an eco-friendly technique that promotes the cultivation of organic vegetables. Even though grafted vegetables are not widely used in India, the growth of private farms to sell their produce on domestic and international markets is encouraging. Opportunities exist for Indian breeders and businesses to develop resilient rootstocks. The agencies should be responsible for marketing these rootstocks in the field. Dai power is the rootstock for chili and capsicum. It is resistant to Phytophthora blight, Mosaic virus, and Bacterial wilt, among others. Although there are still some issues with grafting vegetables, they are outweighed by the benefits gained, so this technique will continue to spread and be utilized globally. More research is required to develop grafting techniques that are ideal for the dependable, cost-effective, and year-round production of seedlings to make this technology more widely accessible to farmers around the globe. Even though the benefits of using grafted seedlings are now widely recognized on a global scale, the key to their widespread adoption, especially in developing nations, is the production of healthy, uniform, and inexpensive grafted seedlings.

ACKNOWLEDGEMENTS

This work was supported by the UGC-BSR Startup grant (No.F.30-565/2021 (BSR)) by the Government of India, awarded to Dr. S. Srivignesh

Declaration of competing interest

All the authors declare there is no conflict of interest

REFERENCES

Arefin, S.A., Zeba, N., Solaiman, A.H., Naznin, M.T., Azad, M.O.K., Tabassum, M. and Park, C. H. 2019. Evaluation of compatibility, growth characteristics, and yield of tomato grafted on potato ('pomato'). *Horticulturae.* 5(2): 37.

Al-Harbi, A., Hejazi, A. and Al-Omran, A.2017. Responses of grafted tomato (*Solanum lycopersiocon* L.) to abiotic stresses in Saudi Arabia. *Saudi Journal of Biological Sciences.* 24(6): 1274-1280.

Alexios, A., Alexopoulos, Angelos, K. and Harold, C.P. 2007. Fruit yield and quality of watermelon in relation to grafting. *J. of Food, Agri. and Env.* 5(1): 178-179.

Horticultural Statistics at a Glance, 2021. Horticulture Statistics Division Department of Agriculture, Cooperation and Farmers Welfare Ministry of Agriculture and Farmers Welfare Government of India. New Delhi, India.

Ashok Kumar, B. and Sanket, K. 2017. Grafting of vegetable crops as a tool to improve yield and tolerance against diseases-A review. *International Journal of Agriculture Sciences, ISSN*, 0975-3710.

Bhatt, R.M., Upreti, K.K., Divya, M.H., Bhat, S., Pavithra, C.B. and Sadashiva, A.T. 2015. Interspecific grafting to enhance physiological resilience to flooding stress in tomato (*Solanum lycopersicum* L.). *Scientia Horticulturae,* 182: 8-17.

Bie, Z.H.I.L.O.N.G., Nawaz, M.A., Huang, Y., Lee, J.M. and Colla, G.I.U.S.E.P.P.E. 2017. Introduction of vegetable grafting. *Vegetable Grafting, Principles And Practices*. 1-21.

Bletsos, F. A. and Olympios, C. M. 2008. Rootstocks and grafting of tomatoes, peppers and eggplants for soil-borne disease resistance, improved yield and quality. *The European Journal of Plant Science and Biotechnology*. 2(1): 62-73.

Black, L.L., Wu, D.L., Wang, J.F., Kalb, T., Abbass, D. and Chen, J.H. 2003. Grafting tomatoes for production in the hot-wet season. *Asian Vegetable Research & Development Center. AVRDC Publication.* 3(2): 551-555.

Colla, G., Rouphael, Y., Jawad, R., Kumar, P., Rea, E. and Cardarelli, M. 2013. The effectiveness of grafting to improve NaCl and CaCl2 tolerance in cucumber. *Scientia Horticulturae.* 164: 380-391.

Colla, G., Rouphael, Y., Cardarelli, M., Temperini, O., Rea, E., Salerno, A. and Pierandrei, F. 2008. Influence of grafting on yield and fruit quality of pepper (*Capsicum annuum* L.) grown under greenhouse conditions. *ISHS Acta Horticulturae*: Proc. IVth IS on Seed, Transplant and Stand Establishment of Hort. Crops, 782: 359-368.

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

Divya, R. 2013. Screening studies of wild rootstocks for biotic stresses and its performance on grafting in tomato (*Solanum lycopersicum* L.). Ph.D Thesis submitted to TNAU, Coimbatore.

Gaion, L. A., Braz, L. T. and Carvalho, R. F. 2018. Grafting in vegetable crops: A great technique for agriculture. *International Journal of Vegetable Science*. 24(1): 85-102.

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

Doñas-Uclés, F., Jiménez-Luna, M., Góngora-Corral, J.A., Pérez-Madrid, D., Verde-Fernández, D., Camacho-Ferre, F. 2014. Influence of three rootstocks on yield and commercial quality of Italian sweet pepper. *Ciência e Agroteccnologia.* 38: 538–545.

Huang, W., Liao, S., Lv, H., Khaldun, A. B. M. and Wang, Y. 2015. Characterization of the growth and fruit quality of tomato grafted on a woody medicinal plant, *Lycium chinense*. *Scientia Horticulturae*. 197: 447-453.

Jang, Y., Yang, E., Cho, M., Um, Y., Ko, K. and Chun, C. 2012. Effect of grafting on growth and incidence of Phytophthora blight and bacterial wilt of pepper (*Capsicum annuum* L.). *Horticulture, Environment, and Biotechnology*. 53(1): 9-19.

Johnson, S., Inglis, D. and Miles, C. 2014. Grafting effects on eggplant growth, yield, and verticillium wilt incidence. *International Journal ofVegetable Science*, 20(1): 3-20.

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

Kubota, C., McClure, M.A., Kokalis-Burelle, N., Bausher, M.G. and Rosskopf, E.N. 2008. Vegetable grafting:

history, use, and current technology status in North America. *Hort Science*. 43: 1164–1669.

Kumar, B. A., Pandey, A. K., Raja, P., Singh, S. and Wangchu, L. 2017. Grafting in Brinjal (*Solanum melongena* L.) for Growth, Yield and Quality Attributes. *International Journal of Bio-Resource & Stress Management*. 8(5).

Kumar, P., Khapte, P. S., Saxena, A., Singh, A. and Panwar, N. R. 2019. Intergeneric grafting for enhanced growth, yield and nutrient acquisition in greenhouse cucumber during winter. *Journal of Environmental Biology*. (3): 295-301.

Kumar, P., Lucini, L., Rouphael, Y., Cardarelli, M., Kalunke, R. M. and Colla, G. 2015a. Insight into the role of grafting and arbuscular mycorrhiza on cadmium stress tolerance in tomato. *Frontiers in Plant Science*. 6: 477.

Kumar, P., Rana, S., Sharma, P. and Negi, V. 2015b. Vegetable grafting: a boon to vegetable growers to combat biotic and abiotic stresses. *Himachal Journal of Agricultural Research*. 41(1): 1-5.

Kumar, S., Bharti, N. and Saravaiya, S. N. 2018. Vegetable Grafting: A Surgical Approach to combat biotic and abiotic stresses-A review. *Agricultural Reviews*. 39(1).

Kumbar, S., Narayanankutty, C., Sainamole Kurian, P., Sreelatha, U. and Barik, S. 2021. Evaluation of eggplant rootstocks for grafting eggplant to improve fruit yield and control bacterial wilt disease. *European Journal of Plant Pathology*. 161(1): 73-90.

Kunwar, S., Paret, M. L., Olson, S. M., Ritchie, L., Rich, J. R., Freeman, J. and McAvoy, T. 2015. Grafting using rootstocks with resistance to *Ralstonia solanacearum* against *Meloidogyne incognita* in tomato production. *Plant Disease.* 99(1): 119-124.

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

Lee, J. M. and Oda, J. 2003. Grafting of herbaceous vegetable and ornamental crops. *Horticultural Reviews*. 28: 61–124.

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

Leonardi, C. and Giuffrida, F. 2006. Variation of plant growth and macronutrient uptake in grafted tomatoes and eggplants on three different rootstocks. *European Journal of HorticulturalScience*. 71(3): 97.

Mandal, S. U. B. H. A. S. I. S., Raju, R., Kumar, A., Kumar, P. and Sharma, P. C. 2018. Current status of research, technology response and policy needs of salt-affected soils in India—A review. *J. Indian Soc. Coast. Agric. Res*. 36: 40-53.

Maurya, D., Pandey, A. K., Kumar, V., Dubey, S. and Prakash, V. 2019. Grafting techniques in vegetable crops: A review. *International Journal of Chemical Studies*. 7(2): 1664-1672.

National Horticulture Board, 2021. Horticulture Statistics Division Department of Agriculture, Cooperation & Farmers Welfare Ministry of Agriculture & Farmers Welfare Government of India. New Delhi, India.

Naik, S. A., Hongal, S., Harshavardhan, M., Chandan, K., Kumar, A. J., Kyriacou, M. C. and Kumar, P. 2021. Productive characteristics and fruit quality traits of cherry tomato hybrids as modulated by grafting on different *Solanum* spp. rootstocks under *Ralstonia solanacearum* infested greenhouse soil. *Agronomy*. 11(7): 1311.

Namisy, A., Chen, J. R., Prohens, J., Metwally, E., Elmahrouk, M., & Rakha, M. 2019. Screening cultivated eggplant and wild relatives for resistance to bacterial wilt (*Ralstonia solanacearum*). *Agriculture*, 9(7): 157.

Negi, V., Kumar, P., Sharma, P., Raj, D., Singh, A. and Vats, B. 2016. Graft compatibility studies in interspecific tomato-potato grafts. *Himachal Journal of Agricultural Research.* 42(1): 29-31.

Nicoletto, C., Tosini, F. and Sambo, P. 2013. Effect of grafting and ripening conditions on some qualitative traits of 'cuore di bue' tomato fruits. *J. Sci. Food Agr*. 93: 1397-1403.

Penella, C., Landi, M., Guidi, L., Nebauer, S. G., Pellegrini, E., San Bautista, A. and Calatayud, A. 2016. Salt-tolerant rootstock increases yield of pepper under salinity through maintenance of photosynthetic performance and sinks strength. *Journal of Plant Physiology*. 193: 1-11.

Peres, L. E., Carvalho, R. F., Zsögön, A., Bermúdez-Zambrano, O. D., Robles, W. G. and Tavares, S. 2005. Grafting of tomato mutants onto potato rootstocks: an approach to study leaf-derived signaling on tuberization. *Plant Science*. 169(4): 680-688.

Petran, A. J. 2013. Interspecific grafting of tomato (*Solanum lycopersicum*) onto wild eggplant (*Solanum torvum*) for increased environmental tolerances (Doctoral dissertation, University of Minnesota).

Petran, A. and Hoover, E. 2014.*Solanum torvum* as a compatible rootstock in interspecific tomato grafting. *Journal of Horticulture*. 103(1): 2376-0354.

Priyanka, A., Sujatha, K. B., Sivakumar, T. and Rajasree, V. 2019. Morphological changes in the compatible grafts of tomato cv. PKM 1 with different solanaceous rootstocks. *Journal of Pharmacognosy and Phytochemistry*. 8(3): 2416-2419.

Pugalendhi, L., Bharathi, S., Priya, R. S. and Velmurugan, M. 2021. Biochemical and quality attributes of grafted tomato (*Solanum lycopesicum* L.). *The Pharma Innovation Journal*. 10(8): 333-338.

Pugalendhi, L., Tamilselvi, N. A. and Thangamani, C. 2019. Vegetable grafting-a boon for soil-borne pest and disease management-a review. *Madras Agricultural Journal*. 106(10/12): 561-570.

Rahman, M.A., Rashid, M.A., Hossain, M.M., Salam, M.A. and Masum, A.S.M.H. 2002. Grafting compatibility of cultivated eggplant varieties with wild Solanum species. *Pakistan J. Biol. Sci*. 5: 755-757.

Ramesh, R., Achari, G., Asolkar, T., Dsouza, M. and Singh, N. P. 2016. Management of bacterial wilt of brinjal using wild brinjal (*Solanum torvum*) as root stock. *Indian Phytopathol*. 69: 260-265.

Ramesh, R., D'Souza, M., Asolkar, T., Achari, G. and Gupta, M. J. 2022. Rootstocks for the Management of Bacterial Wilt in Eggplant (*Solanum melongena* L.) and Tomato (*Solanum lycopersicum* L.) in the Coastal Regions of India. Advances in Agriculture, 2022.

Rana, S., Kumar, P., Sharma, P., Singh, A. and Upadhyay, S. K. 2015. Evaluation of different rootstocks for bacterial wilt tolerance in bell pepper [*Capsicum annuum* (L.) var. *grossum* (Sendt.)] under protected conditions. *Himachal Journal of Agricultural Research*. 41(1): 100-103.

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

Rivard, C. L., O'Connell, S., Peet, M. M. and Louws, F. J. 2010. Grafting tomato with interspecific rootstock to manage diseases caused by *Sclerotium rolfsii* and southern root-knot nematode. *Plant Disease*. 94(8), 1015-1021.

Rivard, C. L., O'connell, S., Peet, M. M., Welker, R. M. and Louws, F. J. 2012. Grafting tomato to manage bacterial wilt caused by *Ralstonia solanacearum* in the Southeastern United States. *Plant Disease*. 96(7): 973-978.

Rivero, R. M., Ruiz, J. M., Sánchez, E. and Romero, L. 2003. Does grafting provide tomato plants an advantage against H_2O_2 production under conditions of thermal shock?. *Physiologia Plantarum*. 117(1): 44-50.

Sabatino, L., Iapichino, G., Maggio, A., D'anna, E., Bruno, M., and D'Anna, F. 2016. Grafting affects yield and phenolic profile of *Solanum melongena* L. landraces. *Journal of Integrative Agriculture.* 15(5): 1017-1024.

Sanwal, S. K., Mann, A., Kumar, A., Kesh, H., Kaur, G., Rai, A. K. and Kumar, P. 2022. Salt tolerant eggplant rootstocks modulate sodium partitioning in tomato scion and improve performance under saline conditions. *Agriculture*. 12(2): 183.

Schwarz, D., Rouphael, Y., Colla, G. and Venema, J. H. 2010. Grafting as a tool to improve tolerance of vegetables to abiotic stresses: Thermal stress, water stress and organic pollutants. *Scientia Horticulturae*. 127(2): 162-171.

Sen, A., Chatterjee, R., Bhaisare, P. and Subba, S. 2018. Grafting as an alternate tool for biotic and abiotic tolerance with improved growth and production of Solanaceous vegetables: challenges and scopes in India. *International Journal of Current Microbiology and Applied Sciences*. 7(1): 121-35.

Sharma,V., Kumar, P., Sharma, P., Singh, A., Sharma, P. K. and Negi, N. D. 2018. Performance of grafted tomato for horticultural and quality traits under polyhouse conditions. *Himachal Journal of Agricultural Research*. 44(1&2): 54-59.

Sherly, J. 2010. Studies on grafting of brinjal accessions (*Solanum melongena* L.) with wild solanum rootstocks. *PhD (Hort) Thesis, TNAU, Coimbatore*.

Singh, H., Kumar, P., Chaudhari, S. and Edelstein, M. 2017. Tomato grafting: a global perspective. *HortScience*, 52(10): 1328-1336.

Singh, H., Kumar, P., Kumar, A., Kyriacou, M. C., Colla, G. and Rouphael, Y. 2020. Grafting tomato as a tool to improve salt tolerance. *Agronomy*. 10(2): 263.

Subba, S. K., Thapa, U., Dukpa, P. and Tamang, A. 2021. Characterization of *Solanum* spp for Grafting and its Interpretation on Morphological, Production and Nutritional Quality of Fruit Under Polyhouse. *Int. J. Curr. Microbiol. App. Sci*. 10(10): 77-89.

Venema, J. H., Dijk, B. E., Bax, J. M., van Hasselt, P. R. and Elzenga, J. T. M. 2008. Grafting tomato (*Solanum lycopersicum*) onto the rootstock of a high-altitude accession of *Solanum habrochaites* improves suboptimal-temperature tolerance. *Environmental and Experimental Botany*. 63(1-3): 359-367.