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Impact of Biotic and Abiotic Stresses and their Management Prospects on Vegetative Growth, Fruit Yield and Quality of Grafted Solanaceous Vegetables for Hi-valued Horticultural Production

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Grafted veggie seedlings are an exceptional horticultural technique that has been used for a very long time. This approach, along with improved grafting techniques appropriate for commercial production and productivity of grafted vegetable seedlings, was introduced into Europe and other nations in the late 20th century. mainly connected to illness prevalence and abiotic stress tolerance, such as stress from soil and water pollution. Grafting is one of the best techniques to use in organic

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farming practises, according to a number of study studies on the subject. In order to increase a plant's quality and resilience to both high and low temperatures, grafting is used. The variety of rootstock used has a significant impact on the growth, yield, and fruit quality of scion solanaceous crops. With a focus on the genetics and breeding of the rootstock, this review examines recent literature on vegetable grafting and explores current problems affecting the grafting industry. Fruit quality of solanaceous agricultural plants grafted on *S. sisymbriifolium*, *S. torvum*, and *S. toxicarium* rootstocks—all of which are immune to soil-borne diseases—was compared to that of plants on their own roots.

Keywords: Rootstock; solanaceous crops; tomato; brinjal; chilliand grafting.

1. INTRODUCTION

“Grafting is a technique for combining two plant components (a rootstock and a scion) through the process of tissue regeneration, which eventually results in the growth of a single plant. Grafting of vegetables is a novel method in olericulture, a field of horticulture that deals with the cultivation, preservation, processing, and marketing of vegetables. Grafting of fruit trees has been done for many years. Vegetable grafting lessens the reliance on agrochemicals in organic agriculture” [1]. Many employees have become aware of the benefits of vegetable grafting. Grafts were used to "improve nutrient uptake, boost endogenous hormone synthesis, and promote resistance against low and high temperatures." increase water usage effectiveness decrease the uptake of persistent organic contaminants from farming soils, increase salt and alkalinity tolerance, and lessen the toxic effects of heavy metals Rivero et al. [2], Venema et al. [3], Pulgar et al. [4], Colla et al. [5], Rouphael et al. [6], Otani and Seike [7] Colla et al., [8], Martinez-Rodriguez et al. [9], Savvas et al. [10]. Size, yield, and fruit quality are influenced by scion variety in grafted plants, but rootstock impacts have a significant impact on these quality traits as well. Davis et al. [11]. Grafting may alter the quality traits by transferring metabolites linked to fruit quality to the scion through the xylem and/or altering the physiological functions of the scion. Rouphael et al. [6]. By promoting improved nutrient uptake and supplying essential resistance against pests and diseases, rootstocks play a significant part in increasing fruit output. The genetic diversity of rootstocks led to interactions with the soil's quality, replanting circumstances, and pH that resulted in varying nutrient concentrations in the scions' fruits and foliage, which allowed for the observation of the differences between rootstocks. Dowarah et al. [12]. According to a study from India, bacterial wilt can result in a 27% loss of eggplant. P. Peddy [13]. An efficient technique to stop the bacterial wilt is to use rootstock that is resistant to the causative organism. According to a study from Bangladesh, grafting eggplant on rootstocks that are resistant to bacterial wilt can cause the disease. In the 1960s, grafting tomatoes were made available for purchase [14]. Vegetable grafting evolved into a critical tool to combat soil-borne diseases and other pests along with the quick development of intensive protected cultivation technologies that prohibited farmers from continuing traditional crop rotation. Vegetable grafting is regarded as an innovative method and is in growing demand by farmers in the Mediterranean, where continuous cropping is a prevalent practise and land use is very intensive [15]. Tomato grafting on suitable rootstocks has been shown to improve cultivation performance, particularly in greenhouse conditions, according to Khah et et al. [15]. Vegetable grafting, mainly for tomatoes, has recently increased [16]. Recently, chilli peppers (*C. annuum* L.) have been grafted onto rootstocks that have resilience to nematodes and fungi that cause soilborne diseases (Morra and Bilotto, [17], in Rodriquez and Bosland, 2010). For sweet peppers (*C. annuum* L.) grafting, foliar applications of the phytohormone abscisic acid, to lessen defoliation, and the vitamin ascorbic acid, to hasten callus development at the cut stem surfaces, were recommended [18,19]. Colla et al. [20], Palada and Wu [21], López-Marn et al. [22], Gisbert et al. [23], and others have shown that pepper grafting can affect plant growth or yield traits positively or negatively [24,25].

1.1 Challenges in Grafting

As was seen when tomatoes were grafted onto jimson weed, a small quantity of alkaloids from the rootstock may transfer to the fruits (Lowman and Kelly, 1946). There were varying degrees of improvement in resistance and production with grafted plants. Rootstock-scion compatibility requires knowledge that may not be accessible to or correctly understood by rural farmers.

1.2 Grafting Method

Crops are chosen for grafting with the aid of the farmer's experience, the number of grafts needed, the purpose of the graft, and the availability of the facilities needed for the machinery and infrastructure [26]. As opposed to using machinery or grafting robots, manual grafting is preferable and more common [26].

1. Tongue / approach grafting

For grafting, equal-sized stem and scion are used. Small-scale farmers most frequently use this technique, which requires more work and room but has a high percentage of seedling survival. In rootstocks with empty hypocotyls, this technique is not applied both Thakur and Savita [27].

2. Cleft grafting

Another name for it is wedge or apical anastomosis. This technique involves making a slant angle in the lower stalk, pruning the scion with 1-3 true leaves, splitting the scion, and attaching a clip between the scion and the rootstock [28]. Primarily solanaceous products are used for this.

3. Slant grafting

One cotyledon anastomosis is another name for this. Commercial seedling nurseries have just lately started using it. It applies to the majority of veggies. It was made specifically for autonomous grafting. To guarantee uniform hypocotyl diameter and securely retain the scion on the rootstock, rootstock should be sown 7–10 days before scion sowing Lakshmi and co. [29].

4. Hole insertion grafting

Another name for this is top insertion grafting. This is the most well-liked in cucurbit. This approach is favored when both the rootstock and the scion have hollow hypocotyls. According to this technique, grafting can be done by creating a hole on top of the root stock and inserting the scion into that hole, which should be prepared to have a comparable diameter to the measurements of the stock hole (Lakshmi et al., 2016).

Table 1. Grafting methods and rootstocks used in Solanaceous crops

Scion Plant	Rootstock	Method
Tomato	*Lycopersicumpimpinellifolium*	Cleft grafting [30]
	Solanum nigrum	Tongue and cleft grafting [30]
Brinjal	*Solanum torvum*	Tongue and cleft grafting [30]
	Solanum sissymbrifolium	Cleft method [30]
	Solanum khasianum	Tongue and cleft method [30]

Table.2. Potential rootstocks of solanaceous vegetable for biotic stress tolerance

Crop	Biotic stress	Potential root stocks
Tomato	Fusarium wilts	Efialto [31]
	Bacterial wilt	Dai Honmei, RST-04-105-T, VI046103 (EG195), VI045276 (EG203), Shin cheong gang F1, and Nordox (Rivard et al. 2012)
	Fusarium crown and root rot	Natalia, Cuore di Bue F1 and He-Man F1 [32]
	Southern blight	Beaufort, and Maxifort [33]
	Verticillium wilt	Beaufort [34]
	Root knot nematode	Big Power, VI046103(EG195) and VI045276 (EG203) (Hibar et al. 2006)
Pepper	Phytophthora blight	PR 920', 'PR 921', and 'PR 922 (Kaskavalci et al. 2009)
	Corky root	Eldorado, Beaufort, Snooker [35]
Brinjal	Bacterial Wilt	*Solanum toxicarium, S. torvum*and *S.integrifolium (*Rivard et al. 2010)
	Nematode	Beaufort [36]

Table 3. Potential rootstocks of solanaceous vegetable for abiotic stress tolerance

Crop	Abiotic stress	Potential root stocks
Egg plant	High temperature tolerance	*Solanum integrifolium*× *Solanum melongena* [26]
	Tolerant to drought	*Solanum macrocarpum, Solanum gilo,* PKM-1 [26]
	Higher yield even at low temperature	*S. integrifolium x S. melongena* [37]
Tomato	Resistant to water-logging	*Solanum laciniatum* [37]
	Low and high temperature tolerance	*Solanum melongena* [26]
	Resistant to drought	*Solanum chilense* [37]
	Tolerant to drought	*Solanum pennelli* [38]
	Tolerance to cold and chilling	*Solanum habrochaites* [38]
	Tolerant to humidity	*Solanum cerasiforme* (Penellaet al., 2014)
	Resistant to salt	*Solanum cheesmanii* [38]
	Tolerance to salt	*Solanum galapagense* [38]
	Flood- and drought-tolerances	*Solanum torvum,* 'EG195' o'EG203, 'PP0237-7502, PP0242-62 [38]
Chilli	High temperature tolerant	*C. annuumcv*. Toom-1 and 9852-54 [39,40]
Pepper	Flooding tolerance	Chili accessions 'PP0237-7502', 'PP0242-62' and 'Lee B' [37]
	Water stress tolerant	Atlante, C-40, Serrano, PI-152225, ECU-973, BOL-58 and NuMex Conquistador [38]

5. Splice grafting

The majority of producers use this technique. In the majority of Solanaceous Vegetable Crops, it can be done manually or mechanically Savita and Thakur [27]. One cotyledon was grafted together. The majority of producers and commercial grated transplant businesses use and favour this technique. In most veggies, it can be done manually or mechanically. This approach is common for solanaceous vegetable products Hashim Ahmed [30].

6. Pin grafting

Instead of using grafting clips, specially designed pins are used in this technique to hold the grafted position. It is a technique akin to the patch grafting Thakur and Savita used [27]. The ceramic pin has a hexagonal cross-section with a diagonal diameter of 0.5 mm and is almost 15 mm long. Because the pins are natural ceramic, they can be kept on the plant without any issues. Lakshmi and co. [29]. Experimental findings showed that bamboo pins with a rectangular cross-section could effectively substitute costly ceramic pins for a much lower cost.

2. EFFECT OF ROOTSTOCK ON GROWTH, YIELD AND QUALITY OF SOLANACEOUS VEGETABLE CROPS

2.1 Growth

When grafted under water-stressed circumstances, the 2012 drought responsive trait, according to Tuberosa, affects the crop quality and yield. The tomato hybrid "Beaufort" (*Solanum lycopersicum* L. *Solanum habrochaites* S.) grafted onto rootstock ("Resistar"), according to Altunlu and Gul [41], inhibited plant development when water stress conditions were present. According to Petran [42], tomato scions ("Celebrity" and "3212") planted on turkey berry rootstock (*Solanum torvum* S.) in drought-stressed circumstances help delay plant wilting. Nilsen et al. [43] found that when tomato cv. "BHN602" was grafted onto the tomato rootstock "JjakKkung" under well-water conditions, the plant's development and leaf area were reduced. Open field harvests grew more quickly after being grafted with the tomato variety "Cherokee Purple" on "Beaufort" [44]. These outcomes are consistent with those observed by Pogonyi et al. [45] who discovered increased productivity in tomato cv. "Lemance" grafted on "Beaufort," as indicated by a higher average fruit weight. According to an experiment done by Khah [46], grafted plants have greater plant heights, leaf area indices, fresh and dry weights of stems and leaves, and yields that are comparable to those of nongrafted plants.

2.2 Yield

According to Penella et al. [38], the rootstocks "Atlante," "PI-15225," and "ECU-973" when grafted onto (*Capsicum annuum* L.cv. Verset) under water-stressed conditions aid in improving the marketable yield of crop by keeping the photosynthetic rate. This was mentioned by Ibrahim et al. [47] and Al-Harbi et al. [48] for the reigntomato cv when grown under full or deficit irrigation. The output increases when Faridah is grafted onto the tomato hybrid "Unifort" (*Solanum lycopersicum* L. *Solanum pimpinellifolium* L.). According to Lopez-Marn et al. [49], the stem "Atlante" used as the scion behaves differently depending on whether it is grafted onto Atlante/Verset or Atlante/Herminio. Similarly, since it affects yield and growth components, it is crucial to evaluate it for drought tolerance. Endogenous flowering compounds easily penetrate the graft union in grafted plants.

On the other hand, no increase in tomato cv yield was recorded by Buller et al. in 2013. The yield of the greenhouse-grown tomato variety "Big Red" was found to be increased by "He-man," but not by "Cherokee Purple," which was grafted on "Beaufort" [15]. These variations may be brought about by the potent effects of rootstock-scion combinations. The higher yield produced by plants grafted on "Nova," "Beaufort," and "Vigomax" and infected with V. dahliae is consistent with earlier reports that found the influence of rootstocks on tomato yield to be independent of disease pressure in the case of another soil-borne pathogen, such as Pyrenochaeta lycopersici R.W. Schneid & Gerlach [50]. Additionally, elements like pathogen identity and virulence, soil and weather conditions, and the crop cultivar used as a scion all have a significant impact on output [50]. Even when only half of the seedlings were planted, Besri (2003) reports that the grafted tomatoes' yield increased by 15-20%. Grafting improved tomato yield by resulting in larger fruit size [45]. Under ideal growth circumstances and salinity, grafting is a successful method to enhance fruit quality. The root structure, at least in part, determines the fruit quality of the shoot [51]. Grafted plants had better marketable yield and fruit quality in soil-free tomato farming [52].

2.3 Quality

The root systems of the used rootstocks, which have led to greater water and nutrient uptake, may be the cause of the early flowering in grafted plants. These outcomes are consistent with the conclusions reached by Ibrahim et al. [47]. The compatibility of various physiological traits, such as photosynthetic rate, nutrient use efficiency, appropriate water flow, and hormonal response, which also affected plant growth and biomass production, may be the cause of the early harvest in grafted plants. The results are in line with the findings of Khah et al. [15], Gisbert et al. [23] and Ibrahim et al. [47]. According to Bletsos and Olympios [53], most of the rootstocks used are breeding products with well-developed root systems that result in higher biomass in scion, so higher root weight of tomato plants grafted on rootstocks is anticipated. He-man was earlier reported to have no effects on stem length in greenhouse-grown tomato cv. "Big Red" in pathogen-free fields, but to increase this characteristic in open field crops [15]. Additionally, in another research, this rootstock increased the dry weight of the above-ground parts in tomato cv [54]. Additionally, 'Yeni Talia,' 'Swanson,' and 'Beril' tomato cultivars grafted on 'Beaufort' rootstock reported increases in fruit size and weight as well as overall yield per plant. Turhan et al. [55]. Consumers are very concerned about how tomato and other vegetable fruit traits are affected by grafting on rootstocks, which can vary [56]. Total soluble solids (TSS) and pH, which are related to fruit palatability, flesh firmness and size, which characterise fruit appearance, and pericarp thickness, which is related to postharvest injuries and storage, are among the quality traits influencing consumers' tastes. TSS is a crucial quality measure that reflects the amount of sugar in fruit [51]. According to Lopez-Galarza et alstudy .'s on grafted watermelon, the lower TSS content observed in tomatoes grown on rootstocks may be due to cytokinins produced by the rootstock (2004). More precisely, these researchers offered proof that, after travelling to the scion, cytokinins lower sugar content. Additionally, according to Bari and Jones [57], the plant can respond by producing more cytokinins when diseases are present [57]. However, the current research found that tomatoes grafted on specific rootstocks had slightly reduced TSS content (o Brix) and dry matter in their fruit, but these values fell within the normal range for tomatoes and are therefore not regarded as particularly significant [51]

Additionally, according to Buller et al. [44], grafting on "Beaufort" had no effect on the fruit TSS of the tomato cultivars "Cuore di Bue," "oxheart," and "Cherokee Purple." Additionally, there were no variations in TSS content between tomato plants grown in open fields and greenhouses that were ungrafted and grafted on the 'Heman' and 'Primavera' rootstocks, respectively [15]. In contrast to these results, Pogonyi et al. [45] found that tomato plants grafted on the 'Beaufort' variety had lower levels of soluble solids in their fruit. According to Turhan et al. [55], tomato grafting on 'Beaufort' increased TSS content based on the cultivars used as a scion but had no impact on pH. Harvesting of fruits was also 7 days early for the grafted tomato plants. When they grafted eggplant cultivars onto perennial and wild Solanaceous species, Gisbert et al. [58] and Rahman et al. [59] also noted a similar finding. When grafted onto robust rootstock, tomatoes' stomatal conductance increased, enhancing water and nutrient absorption (Fernandez-Garcia et al., 2004a). Crop yield is raised by grafted plants' increased photosynthesis rates [60]. When eggplants were grafted onto *S. torvum*, the fruit size grew without affecting the quality or yield. The variety of rootstock used and grafting can have an impact on the amount of sugar, flavour, colour, and carotene as well as on the texture [11]. Contrarily, grafting eggplant on Solanum torvum and Solanum sisymbrifolium had a detrimental impact on the amount of vitamin C, the firmness, and some sensory characteristics, but the general impression was unaffected [61]. By grafting tomato "Oxheart" onto two inter-specific S. lycopersicum S. habrochiates, Di-Gioia et al. [62] found no significant differences in total soluble solids. They also discovered that the vitamin C content of tomato plants grafted onto Beaufort F1 and Maxifort F1 dropped by 14–20%. In order to enhance qualitative traits using grafting techniques, more study is required. In domesticated tomatoes, there is little variation for abiotic stresses, particularly salt tolerance. However, wild species of the genus Solanum, including S. pimpinellifolium, S. peruvianum, S. cheesmaniae, S. habrochaites, S. chmielewskii, and S. pennellii, had sources of tolerance that were used as rootstocks to increase productivity under a variety of environmental stress conditions. However, introgression with commercial tomato is challenging because of the issue of crossibility. In conclusion, grafting is a very effective method for removing various difficult biotic and abiotic stressors worldwide, particularly in solanaceous vegetable crops. For greater fruit production and quality, proper scion and rootstock selection is essential. This method could be extremely helpful in increasing vegetable productivity in a changing environment. Therefore, it is necessary to find more resistant sources by utilising wild and exceptional germplasm.

3. ROLE OF GRAFTING ON BIOTIC STRESS TOLERANCE

For protected tomato products, soil-borne diseases such as Fusarium (*Fusarium oxysporum* f. sp. lycopersici, races 1 and 2) and verticillium wilts (*Verticillium dahliae*, races 1 and 2), bacterial speck (*Pseudomonas syringaep*.v. tomato), root knot nematodes (Melodogyne spp) [63,64]. After the Copenhagen Amendment to the Montreal Protocol in 1992, most nations around the world phased out methyl bromide by 1 January 2005 because it was added to the list of substances that deplete the ozone layer. Previously, these were regulated by fumigants, primarily methyl bromide [65]. Grafting has become an essential instrument with the rapid growth of intensive protected cultivation. This type of resistance developed in the grafted plants may be the result of limited colonisation of bacteria or pathogen in the lower stem and preventing them from invading xylem tissues. Root stocks of certain species have excellent tolerance to various soil-borne diseases like Fusarium, Verticillium, Phytophthora, nematodes, and other pests [66]. The inherent resistance of the rootstocks and better nutrient uptake, which improve disease control in grafted vegetable plants, could be another factor. When susceptible scions were grafted on particular root socks, a few trials also claimed to offer some protection from viruses. Mahmoud, [67] discovered that grafting increased tomato yield components compared to non-grafted plants, delayed the onset of TYLCV symptoms, and raised TYLCV tolerance in susceptible plants. Iouannou (2001) noted that grafted eggplants had higher yields and larger fruits, as well as reduced disease incidences. Similar findings were made when tomatoes (*S. lycopersicum* and *S. habrochaites*) were transplanted onto Beaufort's rootstocks [68]. After being grafted onto commercial rootstock and infected with Verticillium dahliae, tomato plants (*Solanum lycopersicum* L.) showed resilience to the verticillium wilt disease [69]. *Capsicum annuum* L. scions are grafted onto *C. annuum* rootstocks that have resistance to nematodes and soilborne disease in a recent technique known as chilli pepper grafting [17]. When grafted onto resistant CRA 66 or Hawaii 7996 tomato rootstocks, 'German Johnson' heritage tomatoes had 0% fusarium wilt incidence in infested soils, as opposed to a 79% incidence on non-grafted controls, according to research by Rivard and Louws [1].

4. ROLE OF GRAFTING ON ABIOTIC STRESS TOLERANCE

"In the present climatic conditions, the most significant limiting factor for plant growth and horticultural productivity globally is environmental stress. The three main factors that have had the greatest effects on crop yield are extreme temperatures, drought, and salinity" (Schwarz et al., 2010). "Climate scientists predict that the combined environmental stress in the tropics will only get worse over time as a result of rising global warming, the expansion of the saline affected area, and the absence of quality water storage in arid lands. Although many stress-tolerant cultivars have been developed through breeding, the complicated genetic makeup of environmental tolerance makes this process difficult and time-consuming" (Ashraf and Foolad, 2007). Developing planting material that is resistant to environmental stress can be accomplished more quickly through grafting [70-77].

5. CONCLUSION

Vegetable grafting is also becoming more popular all over the world as a way to combat biotic and abiotic stresses, which account for 30% and 70%, respectively, of the yield difference. Salinity and drought are two of the main abiotic stressors that are expected to worsen as a result of climate change. Despite the enormous importance of grafting for ensuring quality and yield stability in vegetable crops, its industrial application has largely focused on the cultivation of highly valuable solanaceous and cucurbitaceous vegetable crops. Among future possibilities is the extension of grafting practice to other seasonal crops including combinations where both rootstock and scion produce harvestable products. The various innovative pilot research studies nevertheless demonstrated the potential of creating harvestable rootstock–scion combinations as a means of saving growth space and minimizing waste. Such unique grafting model systems may assist in elucidating scion–rootstock synergy and sink competition in production of high-valued horticultural crops.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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