Review Article

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

ABSTRACT

Grafted vegetable seedlings are an unparalleled horticultural technology practiced for a long time. This technique was introduced into Europe and other countries in the late 20th century along with improved grafting methods suitable for commercial production and productivity of grafted vegetable seedlings. Mostly related to disease incidences, and abiotic stress tolerance including the soil and water pollution stress. Considering various research works on grafting it can be assumed that it is one of the best methods to be included in organic farming practices. Grafting improves quality of the plant and is used to induce resistance against low and high temperatures. Growth, yield and fruit quality of the scionsolanaceous crops is greatly influenced by the type of rootstock used. Commercial grafting of vegetables has started for several decades and the area under vegetable grafting is gradually increasing. This review discusses recent literature on vegetable grafting with a focus on the genetics and breeding of the rootstock, and delves into current issues affecting the grafting industry. Fruit quality of solanaceous crops plants grafted on *S. sisymbriifolium*, *S. torvum* and *S. toxicarium* (all resistant to soil-borne diseases) rootstocks was compared with that of plants on their own roots.

Key words: rootstock, solanaceouscrops, tomato, brinjal, chilliand grafting

INTRODUCTION

In vegetable production, India comes as a second largest producer in the world after China and mostly areas covered under vegetables is 10.29 million ha and total production 176.17 million Tonnes (NHB, 2018). Grafting is a method of growing together two plant parts (a rootstock and a scion) by the process of tissue regeneration and finally grows as a one plant. Grafting of fruit trees has been practiced for many years, but in Olericulture(…) , grafting of vegetable is a new technique. Vegetable grafting reduces the agrochemicals dependence on organic production (Rivard*et al.*, 2008). The advantages of vegetable grafting have been noticed by many workers. Grafts were used to induce resistance against low and high temperatures, enhance nutrient uptake, increase synthesis of endogenous hormones,improve water use efficiency,reduce uptake of persistent organic pollutants from agricultural soils, improve alkalinity tolerance, raise salt tolerance,and limit the negative effect of heavy metal toxicityRivero*et al.*, (2003), Venema*et al.*, (2008),Pulgar*et al.*, (2000), Colla*et al.*, (2010a), Rouphael*et al.*, (2008), Otani and Seike (2007) Colla*et al.*, (2010), Martinez-Rodriguez *et al.*, (2008), Savvas*et al.*, (2010).The scion variety affects size, yield, and quality of fruit in grafted plants, but rootstock effects can drastically alter these quality characteristics Davis *et al.*, (2008). The quality characteristics might be affected by grafting as a result of the translocation of metabolites associated with fruit quality to the scion through the xylem and/or modification of physiological processes of the scion Rouphael*et al.*, (2008).A report

Comment [A1]: This is a broad introduction. It is better to make other sub-headings related to Table 1-3

Comment [A2]: Explain the meaning

Comment [A3]: Use “, “ in a parallel sentence from India reveals that bacterial wilt can cause 27% losses eggplant Peddy P (1986).To causal organism resistant rootstock is an effective technology to prevent the bacterial wilt. A report from Bangladesh indicated that grafting of eggplant on resistant rootstocks to present bacterial wilt.Grafting tomato was introduced commercially in the 1960's (Lee and Oda, 2003). Along with the rapid development of intensive protected cultivation technologies which prevented farmers from continuing traditional crop rotation, vegetable grafting became a crucial tool to overcome soil borne diseases and other pests.In the Mediterranean, where land use is very intensive and continuous cropping is a common practice, vegetable grafting is considered an innovative technique and is in increasing demand by farmers (Khah*et al*. 2006).Vegetable grafting, primarily for tomatoes, recently increased (Atasayar 2006) and Khah*et al*. (2006) showed that tomato grafting on suitable rootstocks has positive effects on cultivation performance, especially in greenhouse conditions. Grafting of chili peppers (*C. annuum* L.) is a recent practice where *C. annuum* scions are grafted onto *C. annuum* rootstocks that have soilborne disease resistance to fungi and nematodes (Morra and Bilotto, (2006), in Rodriquez and Bosland, 2010). To promote grafttake, foliar applications of the phytohormoneabscisic acid, to reduce defoliation, and the vitamin ascorbic acid, to accelerate callus formation at the cut stem surfaces, were suggested for grafting sweet peppers (C. annuum L.) (Johkan*et al*., 2008, 2009). Pepper grafting may have positive (Colla*et al*., 2008; Palada and Wu, 2008; López-Marín*et al*., 2009; Gisbert*et al*., 2010) or negative (M'hamdi*et al*., 2010; GarcíaRodríguez*et al*., 2010) influences on plant growth or yield traits.

Challenges in grafting Small amounts of alkaloids to the fruits from the rootstock may occur as observed when tomatoes were grafted onto jimson weed (Lowman and Kelly, 1946). The improved resistance and better yield with grafted plants was inconsistent in some cases. Proper knowledge rootstock-scion compatibility is required which may not be available and understood properly by the rural farmers.

Grafting method

Selection of grafting is done on crop with the help of the farmers experience, the number ofgrafts required, the motive of grafting and available facilities required for machinery andinfrastructure (Lee *et al*.,2010). Manual grafting is better and mostly practices as comparedof using machines and grafting robots (Lee *et al*.,2010).

1.Tongue / approach grafting

Equal size of rootstock and scion are used for grafting. This method requires more labor andspace but percentage of seedling survival is high and most commonly practice by smallnurseries farmers. This method is not used in rootstocks with hollow hypocotyls Thakur and Savita (2020).

2. Cleft grafting

It is also called apical or wedge grafting. In this method slant angle is made in lower stem andscion is pruned with 1-3 true leaves and scion is placed into split and clip is attach in betweenscion and rootstock (Johnson *et al*.,2011). This is done in mainly Solanaceous crops.

3.Slant grafting:

This is also known as onecotyledon grafting. It has recently been adoptedby commercial seedling nurseries. It is applicableto most vegetables. It has been developed forrobotic grafting. Rootstock should be sown 7 –10 days before scion sowing to ensure uniformdiameter of hypocotyls and to hold the scion onrootstock perfectly Lakshmi *et al*., (2019).

4.Hole insertion grafting:

This is also called astop insertion grafting. This is most popular incucurbits. When scion and rootstock have hollowhypocotyls, this method is preferred. In thismethod grafting can be performed by makinghole on the top of the root stock and by insertingthe scion in that hole which should be preparedin such a way to similar diameter as math withhole measurements of stockLakshmi*et al*., (2019).

5.Splice grafting

This method is mostly used by growers. It can be practice byhand or machines in most Solanaceousvegetable crops Thakur and Savita (2020). One cotyledon spliced grafting. This method is most widely used and preferred by producers and commercial grated transplant companies. It can be carried out by hand or machines in most vegetables. This method is popular for vegetable solanaceous crops Ahmed Hashim (2019).

6.Pin grafting

In this method designed pins are used to hold the graftedposition instead of placing grafting clips. It is similar methodas splice grafting Thakur and Savita (2020). The ceramic pin is nearly about 15 mmlong and 0.5 mm in diagonal width of thehexagonal cross-section. The pins are made ofnatural ceramic so it can be left on the plantwithout any problem Lakshmi *et al*., (2019). Experimental results revealed thatbamboo pins, rectangular in cross-sectional shape, could successfully replace the expensiveceramic pins at much lower price.

Table 1: Grafting methods and rootstocks used in Solanaceous crops

Comment [A4]: Table 1-2 shloudbe referred to in the paragraph text

Scion Plant	Rootstock	Method
Tomato	*Lycopersicumpimpinellifolium*	Cleft grafting (Ahmed Hashim (2019)
	Solanumnigrum	Tongue and cleft grafting (Ahmed Hashim (2019)
Brinjal	*Solanumtorvum*	Tongue and cleft grafting (Ahmed Hashim (2019)
	Solanumsissymbrifolium	Cleft method (Ahmed Hashim (2019)
	Solanumkhasianum	Tongue and cleft method (Ahmed Hashim (2019)

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

Crop	Biotic stress	Potential root stocks
Tomato	Fusarium wilts	Efialto (Bolandnazar*et al*.,2014)
	Bacterial wilt	Dai Honmei, RST-04-105-T, VI046103 (EG195), VI045276 (EG203), Shincheong gang F1, and Nordox (Rivard*et al*., 2012)
	Fusarium crown and root rot	Natalia, Cuore di Bue F1 and He-Man F1(Keatinge*et al*., 2014)
	Southern blight	Beaufort, and Maxifort (Onduso, 2014)
	Verticillium wilt	Beaufort (Vitale *et al*., 2014)
	Root knot nematode	Big Power, VI046103(EG195) and VI045276 (EG203) (Hiba*ret al*., 2006)

Pepper	Phytophthora blight	PR 920', 'PR 921', and 'PR 922 (Kaskavalci*et al*., 2009)
	Corky root	Eldorado, Beaufort, Snooker (Jang *et al*., 2012)
Brinjal	Bacterial Wilt	*Solanumtoxicarium, S. torvum*and *S.integrifolium (*Rivard*et al*., 2010)
	Nematode	Beaufort (Al- Chaabi*et al*., 2009)

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

Crop	**Abiotic stress**	**Potential root stocks**
Egg plant	High temperature tolerance	*Solanumintegrifolium*× *Solanummelongena (*Lee *et al*., (2010)
	Tolerant to drought	*Solanummacrocarpum, Solanumgilo,* PKM-1 (Lee *et al*., (2010)
	Higher yield even at low temperature	*S. integrifolium x S. melongena (*Pandey and Rai (2003)
Tomato	Resistant to water-logging	*Solanumlaciniatum (*Pandey and Rai (2003)
	Low and high temperature tolerance	*Solanummelongena (*Lee *et al*., (2010)
	Resistant to drought	*Solanumchilense (*Pandey and Rai (2003)
	Tolerant to drought	*Solanumpennelli*(Penella*et al*., 2014)
	Tolerance to cold and chilling	*Solanumhabrochaites*(Penella*et al*., 2014)
	Tolerant to humidity	*Solanumcerasiforme* (Penella*et al*., 2014)
	Resistant to salt	*Solanumcheesmanii*(Penella*et al*., 2014)
	Tolerance to salt	*Solanumgalapagense*(Penella*et al*., 2014)
	Flood- and drought-tolerances	*Solanum torvum,* 'EG195' o'EG203, 'PP0237-7502, PP0242-62(Penella*et al*., 2014)
Chilli	High temperature tolerant	*C. annuumcv*. Toom-1 and 9852-54 (AVRDC 2003 & 2009)
Pepper	Flooding tolerance	Chili accessions 'PP0237-7502', 'PP0242-62' and 'Lee B' (Pandey and Rai (2003)
	Water stress tolerent	Atlante, C-40, Serrano, PI-152225, ECU-973, BOL-58 and NuMex Conquistador (Penella*et al*., 2014)

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

Comment [A5]: You are creating paragraphs that are too long.One paragraph should focus on one idea.

According to Tuberosa, 2012 drought responsive traitaffects the crop quality and yield when grafted under waterstressedconditions. Altunlu and Gul, 2012 observed thatwhen tomato hybrid "Beaufort" (*Solanumlycopersicum*L. ×*Solanumhabrochaites*S.) grafted onto rootstock ("Resistar")reduced the plant growth due to occurrence of water stresscondition. Petran, 2013 reported that when tomato scions("Celebrity" and "3212") onto turkey berry rootstock(*Solanumtorvum*S.) under water-stressed conditions helps indelayed wilting of plant. According to Nilsen *et al*. (2014) when tomato cv. “BHN602” grafted onto the tomato rootstock“JjakKkung under well-water condition leads to reduction inthe leaf area and growth of plant. Penella*et al.* (2014)concluded that when (*Capsicum annuum*L.cv. Verset) graftedonto the rootstocks “Atlante,” “PI-15225,” and “ECU-973under water-stresses conditions helps in improving themarketable yield of crop by maintaining the photosyntheticrate. Ibrahim *et al.* (2014) and Al-Harbi*et al.* (2016) stated this when grown under full or deficit irrigation reigntomato cv. Faridah grafted onto the tomato hybrid “Unifort”(*Solanumlycopersicum*L. × *Solanumpimpinellifolium*L.)results in the expanding of yield. López-Marín*et al.* (2017)stated when rootstock “Atlante” used as the scion actsdifferently when the grafting combination of Atlante/VersetandAtlante/Herminio .Similarly, it is important to test it fordrought tolerance because it influence yield and growthcomponent. In grafted plants the movement of endogenous flowering substances across the graft union is easy. The early flowering in grafted plants may be due to better and improved root system of the rootstocks used, which has resulted in increased water and nutrient uptake. These results are in conformity with the findings of Ibrahim *et al*. (2014). The early harvest in grafted plants may be due to the compatibility of various physiological traits such as photosynthetic rate, nutrient use efficiency, proper water flow and hormonal response which also influenced plant growth and biomass production. The results are in line with the findings of Khah*et al*. (2006), Gisbert*et al*. (2010) and Ibrahim *et al*. (2014).

Higher root weight of tomato plants grafted on rootstocks are expected, since, according to Bletsos and Olympios (2008), most of the rootstocks used are breeding products with well-developed root system that result in to higher biomass in scion. In pathogen-free fields, ‘He-man’ has been reported previously to have no effects on stem length in greenhouse grown tomato cv. ‘Big Red’, whereas it increased this characteristic in open field crops (Khah*et al*., 2006). In addition, this rootstock, in another study, increased dry weight of the above-ground parts in tomato cv. ‘Rita’ (Romano and Paratore, 2001). Grafting of tomato cv. ‘Cherokee Purple’ on ‘Beaufort’ also increased growth in open field crops (Buller *et al*., 2013). These results are in agreement with those reported by Pogonyi*et al*. (2005) who found increased productivity, expressed as a higher average fruit weight in tomato cv. ‘Lemance’ grafted on ‘Beaufort’. Also, increase of fruit size and weight as well as of total yield per plant of tomato cultivars ‘Yeni Talia’, ‘Swanson’, and ‘Beril’ grafted on ‘Beaufort’ rootstock were reported by Turhan*et al*. (2011). On the contraryBuller*et al*. (2013), reported no increase in yield of tomato cv. ‘Cherokee Purple’ grafted on ‘Beaufort’, whereas ‘He-man’ was found to increase productivity of tomato cv. ‘Big Red’ grown in greenhouse (Khah*et al*., 2006). The strong effect of rootstock-scion combination could be the reason for these differences. The increased yield produced by plants infected with V. dahliae and grafted on ‘Nova’, ‘Beaufort’, and ‘Vigomax’ is in accordance with earlier reports, where the effect of rootstocks on tomato yield was independent of the disease pressure, in case of another soil-borne pathogen, such as *Pyrenochaetalycopersici* R.W. Schneid&Gerlach (Michel and Lazzeri, 2010). In addition, yield is strongly affected by factors like pathogen identity and virulence, soil and weather conditions, and the crop cultivar used as scion (Michel and Lazzeri, 2010). Grafting on rootstocks variably affects fruit characteristics of tomato and other vegetables, which are of a major concern for consumers (Rouphael*et al*., 2010). Among the quality characteristics affecting consumers' preferences are the total soluble solids (TSS) and pH that are connected to palatability of fruit, flesh firmness and size that define fruit appearance, and the pericarp thickness that is connected to postharvest injuries and storage. TSS is an important quality criterion reflecting concentration of sugars in fruit (Flores *et al*., 2010). Lower TSS content recorded in tomatoes grafted on rootstocks could be attributed to cytokinins produced in rootstock, as reported in grafted watermelon by Lopez-Galarza *et al*. (2004). More specifically, these researchers provided evidence that cytokinins, after transporting to the scion, reduce sugar content. In addition, Bari and Jones (2009) reported that production of cytokinins can be increased as part of the plant's responses to the presence of pathogens (Bari and Jones, 2009). However, the slightly lower TSS content (o Brix) and dry matter, found in fruit of tomatoes grafted on certain rootstocks, in the present study, fell within the normal range for tomato, and, therefore, are considered as not important (Flores *et al*., 2010) and Buller *et al*. (2013) also reported that grafting on 'Beaufort' had no influence on fruit TSS of tomato cv. 'Cuore di Bue', cv. 'oxheart', and cv. 'Cherokee Purple'. Furthermore, differences were not recorded in TSS content between tomato un-grafted tomato cv. 'Big Red' and grafted on 'Heman' and 'Primavera' rootstocks grown under open-field and greenhouse conditions (Khah*et al*., 2006). In contrast to these findings, Pogonyi*et al*. (2005) reported that soluble solid content in fruit of tomato cv. 'Lemance' was lower in plants grafted on 'Beaufort'. Turhan*et al*. (2011) also reported that grafting tomato on 'Beaufort' increased TSS content depending on cultivars used as a scion but it did not have any effect on pH.

In an experiment conducted by Khah (2005) it was reported that grafted plants have higher plant height, leaf area index, as well as the fresh and dry weights of stems and leaves and yield was comparatively higher than the nongrafted plants. Harvesting of fruits was also 7 days earlier for the grafted tomato plants. Similar observation was also recorded by Gisbert*et al*., 2011 and Rahman *et al*., 2002 when they grafted eggplant cultivars onto perennial and wild Solanaceous species. Augmented water and nutrient uptake improved stomatal conductance in tomato when grafted onto vigorous rootstock (Fernandez- Garcia *et al*., 2004a). Improved photosynthesis rates of grafted plants increase the crop productivity (Matsuzoe*et al*., 1993). According to Besri, (2003) 15-20% of yield increase was reported for the grafted tomatoes even when only half of the plants were planted. Grafting resulted in bigger fruit size in tomatoes, and thus increased the yield (Pogonyi*et al*., 2005). Grafting is an effective approach to improve fruit quality under both optimum growth conditions and salinity. The fruit quality of shoot, at least partially, depends on the root system (Flores *et al*., 2010). In soil less tomato cultivation, grafted plants had higher marketable yield, fruit quality (Gebologlu*et al*., 2011). Grafting of eggplants onto S. torvum increased the fruit size without any effect on quality and yield. Sugar, flavor, colour, carotene content and texture can be affected by grafting and the type of rootstock used (Davis *et al*., 2008). In contrast, grafting eggplant on Solanumtorvum and Solanumsisymbrifolium negatively affected vitamin C content, firmness and some sensory attributes but overall impression was not influenced (Arvanitoyannis *et al*., 2005).Di-Gioia*et al*., 2010 recorded no significant differences in total soluble solids by tomato "Oxheart" grafted onto 2 inter-specific S. lycopersicum × S. habrochiates and also found that vitamin C content was decreased by 14-20 % if tomato plants grafted onto Beaufort F1 and Maxifort F1. So, there is need of further research regarding improvement of qualitative traits via grafting techniques. In domesticated tomato, variability for abiotic stresses especially salt tolerance is limited. But, wild species such as *S. pimpinellifolium, S. peruvianum, S. cheesmaniae, S. habrochaites, S. chmielewskii and S. pennellii* in the genus Solanum possessed sources of tolerance and the same have been exploited as rootstock to enhance productivity under wide environmental stress conditions, whereas, introgression with commercial tomato is difficult due to the problem of crossibility. To sum up, grafting in vegetable crops especially in solanaceous vegetables is highly useful to eliminate various challenging biotic and abiotic stressors globally. Proper selection of scion and rootstock is the key factor for higher fruit yield and quality. Under changing climate, this technique could play significant role to improve vegetable productivity. Thus, there is a need to identify more resistant sources by exploiting wild and elite germplasm.

Role of grafting on abiotic stress tolerance:

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Environmental stress is the most important limiting factor in the current climatic situation for plant growth and horticultural productivity worldwide. Extreme temperature, draught and salinity are the major ones which have influenced crop productivity the most (Schwarz et al., 2010). Increasing global warming, expansion of the saline affected area and lack of availability quality water storage in arid lands are becoming a limiting factor for crop production and climatologists believe that the combined environmental stress in the tropics will only get worse over time. Though several stress tolerant cultivars have been produced through breeding but the complex nature of the genetic tolerance of environmental factors makes it difficult and time consuming (Ashraf and Foolad, 2007) and grafting can be a rapid alternative to develop environmental stress tolerant planting material.

IMPACT & SUSTENANCE ROLE OF BIOTIC STRESS TOLERANCEON GRAFTED SOLANACEOUS VEGETABLES:

Disease tolerance

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Soil borne diseases like Fusarium (Fusariumoxysporum f. sp. lycopersici, race 1 and race 2) and verticillium wilts (Verticilliumdahliae, races 1 and races 2), bacterial speck (Pseudomonas syringaep.v. tomato), root knot nematodes (Melodogyne spp.) and corky root (Pyrenocheatalycopersici) have been reported to be among the most destructive for protected tomato crops (Besri, 2002; Poffley, 2003). These used to be controlled by fumigants from which methyl bromide but after the Copenhagen Amendment to the Montreal Protocol in 1992, most of the countries around the globe phases out methyl bromide by 1 January 2005 as it was added to the list of substances that deplete the ozone layer (Anon, 2014). With rapid development in intensive protected cultivation grafting has become a crucial tool. Root stocks of certain species have excellent tolerance to various soil-borne diseases like Fusarium, Verticillium, Phytophthora, nematodes, and other pests, this kind of resistance developed in the grafted plants may be resulted from limited colonization of bacteria or pathogen in the lower stem and preventing them from invading xylem tissues (Grimault and Prior, 1994). One more reason could be the inherent resistance of the rootstocks and improved plant nutrient uptake which improves disease control in grafted vegetable plants. Few experiments have also reported to provide some protection from viruses when the susceptible scions were grafted on specific root socks. Mahmoud, (2014) found that grafting increased TYLCV tolerance in susceptible plants, delayed the appearance of TYLCV symptoms and increase of yield components compared to non-grafted plants in tomato. Iouannou (2001) observed grafted eggplants showed lower disease incidences with higher yield and fruit size. Similar type of observations were obtained when tomato was grafted onto Beaufort' rootstocks (S. lycopersicum and S. habrochaites (Hasna et al., 2009). Tomatoes (Solanumlycopersicum L.) when grafted onto commercial rootstockand subjected to infection with Verticilliumdahliae, the grafted plant exhibited resistance to the verticillium wilt disease (Paplomatas et al., 2002). Grafting of chilli peppers (Capsicum annuum L.) is a recent practice where C. annuum scions are grafted onto C. annuum rootstocks that have soilborne disease and nematode resistance (Morra and Biloto 2006). Rivard and Louws (2008) found that 'German Johnson' heirloom tomatoes had 0% fusarium wilt incidence in infested soils when grafted onto resistant CRA 66 or Hawaii 7996 tomato rootstock, compared to a 79% incidence on non-grafted controls.

CONCLUSION:

Vegetable grafting is also developing around the globe as a means to overcome a-biotic and biotic stresses which are responsible for 70% and 30% of the yield gap, respectively. Among the major a-biotic stresses, salinity and drought are the ones forecasted to rise due to global climate change. Notwithstanding, the enormous significance of grafting as a means for securing yield stability and quality in vegetables crops, commercial its practice has heavily centered on the production of high-valued solanaceous and cucurbitaceous vegetable crops. Among future perspectives is the extension of grafting practice to other seasonal crops including combinations where both rootstock and scion deliver 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.

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Comment [A8]: Use Reference Manager, such as EndNote, Mendeley, danZotero

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