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Review Article

GRAFTING OF VEGETABLE CROPS AS A TOOL TO IMPROVE YIELD AND TOLERANCE AGAINST DISEASES- A REVIEW

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Abstract- Now a day's Grafting is regarded as a rapid alternative tool to the relatively slow breeding methodology. To increase domestic and sustainable vegetable production grafting is a new technology by using resistant rootstock to improve yield and quality of produce. It was first started in Japan & Korea and Efforts are being made in AVRDC to improve production in the Asian lowland tropics. Currently most watermelon, cucumber and various solanaceae crops are grafted before being transplanted in the green house or in the field. The purpose of grafting also has been greatly expanded to various type of stress tolerance, increasing plant vigor, yield and duration of crop. Vegetable grafting has potential to promote cultivation of the vegetables under non-traditional conditions and frazile agro-eco-systems. Focus on enhancing the capacity of vegetable production and consumption to reduce malnutrition by adopting some innovations.

Keywords- Grafting, Vigor, Stress, Frazile and Tolerance.

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Introduction

India is the world's second largest producer of vegetable crops after China, accounting for about 14 percent of the world production. In 2013-14, India acreage of vegetable cultivation is around 9.396 million ha area with the annual production of 162.89 million mt, and productivity is 17.3 mt/ha [6]. With increasing population, there is need to boost the production of vegetable crops. The grafting is one of the tools for sustainable vegetable production by using resistant rootstock. It reduces dependence on agrochemicals [71] for the organic production. Grafting has been utilized in horticulture ever since the first millennium. The process involves union of two parts (a rootstock and scion) together from two different plant parts to form a single, living plant [51]. The first attempt in vegetable grafting was done by grafting watermelon (*Citrullus lanatus*) onto pumpkin (*Cucurbita moschata*) rootstock in Japan and Korea in the late 1920s [53]. Production and demand for grafted vegetable plants continues to increase across Asia and Europe, and has begun to expand to North America [50]. Watermelon is one of the vegetables in which grafting is performed intensively in the world [13].

A variety of problems are normally linked with grafting and producing grafted seedlings. Most important problems are the labour and techniques essential for the grafting process and after graft handling of seedlings for quick healing for 7 to 10 days. An expert can graft 1200 seedlings per day [150 seedlings per hour), but the numbers vary with the grafting method. Similarly, the post graft handling method depends mostly on the grafting methods. Vegetables susceptible to various diseases, generally Fusarium wilt, Verticellium wilt, Bacterial wilt, nematodes and several insect pests [24]. Now a day's, grafting of vegetable crops is used to induce vigour, precocity, better yield and quality, survival rate, reduce infection by soil-borne pathogens and to enhance the tolerance against abiotic stresses by using desired rootstocks. In global, this method of propagation has gained much fame in grafting of cucurbits, tomato, eggplant and pepper onto vigorous and disease-resistant rootstocks to ensure adequate yields where salinity, biotic stresses, and environmental stresses/or unfavorable growing temperatures limit productivity [52,19,17]. Further inventions are mechanized and robotic grafting has given a fillip to this novel eco-friendly approach [62].

Survey conducted in North America showed that the total number of grafted seedlings used in there was over 40 million seedlings with the bulk of these used as hydroponic tomato in green houses [50]. In Japan use of grafted plants exceeding 90% for watermelon and cucumber, 79% for eggplant and 58% for tomato as per the survey reported by the Japanese government in 2011 [56]. In Greece, it is very much popular, where the ratio of production area of grafted plants, amounts to 90-100% for early cropping of watermelon, 2-3% for tomato and egg plants, and 5-10% for cucumbers [44]. As shown in [Table-1], Europe and Spain are top in grafted seedlings production with 129 million grafted seedlings followed by Italy (47 million grafted seedlings) and France (28 million grafted seedlings) [8]. A survey of 16 Italian nurseries having just about 80% of transplant production, in 1999 less than 10 million grafted plants were produced that is increased to more than 60 million plants in 2011 [53].

In India, grafting work has been started in IIHR Bangalore to select best rootstocks for water logged conditions by Dr RM Bhatt and his associates. The first ever initial short course on vegetable grafting was started in 2013 by IIHR, Bangalore. The *Momordica cochinchinensis*, a dioecious vegetable crop is utilizing for grafting with male as rootstock and female plant as scion in the NBPGR regional station, Trissur, Kerala. The female plants were grafted on to the male plants to achieve higher production. Graft success was 98%. CSKHPKV, Palampur initiated work on grafting and identified more than 22 rootstocks of brinjal, chilli, tomato and cucurbits for importing resistance to bacterial wilt and nematodes. Some private players are also involved in grafting. One of them is 'VNR Private Seed Limited' in Chhattisgarh which is supplying grafted brinjal seedlings resistant to bacterial wilt to farmers. The other seed company is 'Takii Seed India Private Limited'.

Table-1 *Countries position of vegetable grafting in world*

Country	Watermelon	Cucumber	Melon	Tomato	Brinjal	Pepper
Israel	70%		5%	15%	5%	-
Japan	93%	72%	30%	48%	65%	5%
Korea	98%	95%	95%	15%	2%	25%
Greece	100%	5-10%	40-50%	2-3%	-	-
Spain	98%	-	3%	4500 ha	-	-
Morocco		-	-	75%	-	-
Cyprea	80%	-	-	170 ha	-	-
Italy	30%	-	5-6 million	1200 ha	-	-
France	-	3%	1000 ha	2800 ha	-	-
Netherland	-	5%		50%	-	-
Turkey	30%	5%		25%	10%	-

Source: Histil South Africa (PTY), 2007 cited by Yassin and Hussen [94]

Basic pre-requisites for vegetable grafting

1. Selecting the right rootstock/scion: Select the desirable rootstock and scion having the same stem size (diameter). Grafting should be done at 2-3 true leaf stage.

2. Graft compatibility: Compatible rootstock and scion minimizes the Mortality rate even in later stage of growth. Rapid Callus formation takes place between scion and rootstock and leads the formation of vascular bundles.

3. Grafting aids: Commonly used aids to perform grafting i.e., Grafting clips, Tubes, Pins, and Grafting Blade**.**

4. Screening house: Used for growing seedlings prior to grafting. It should be constructed with 60-mesh nylon net. Arrange double door, the upper half of the structure should be covered with a separate UV resistant polyethylene to prevent UV light penetration.

5. Healing of grafts: Healing is most critical to provide favourable conditions to promote callus formation of grafted seedlings. In healing chamber, temperature should be 28-29 ^{0}C with 95% relative humidity for 5-7days in partially shaded place (darkness for 1-2 days) to promotes callus formation at union. It helps in formation of better graft union by reducing transpiration, maintains high humidity, maintains optimum temperature and reduces light intensity. The main aim is to initiate environment by controlling temperature and humidity [91].

6. Acclimatization of the grafted plants: After the callus has formed and the wounded surfaces are healed, plants may be put under a mist system, greenhouse or placed under a clear plastic cover for acclimatization to prevent leaf burning and wilting.

Methods of grafting: The familiar methods used for vegetable grafting were listed in [Table-2] and a few methods were explained as per the commercial use.

1. Cleft grafting: This is widely used method of grafting in solanaceous crops. Here scion plants are pruned to have 1-3 true leaves and the lower stem is cut to slant angle to make a tapered wedge and clip is placed to make contact between scion and rootstock after placing scion into the split made [41].

2. Tongue approach/Approach grafting: This method most widely used by farmers and small nurseries. This method requires more space and labor compared to other methods but high seedling survival rate can be attained even by beginners. Grafted seedlings have a uniform growth rate but it is not suitable for rootstocks with hollow hypocotyls.

3. Hole insertion/Top insertion grafting: This is most popular method in cucurbits scion and rootstock should have hollow hypocotyls are preferred in this method [76]. To achieve a high rate of success, relative humidity should be maintained at 95%. The optimum temperature should maintain at 21-36◦C up to transplanting. One person can produce 1,500 or more grafts/day.

4. One cotyledon/Slant/Splice grafting

It has recently been adopted by commercial seedling nurseries and applicable to most vegetables [74]. The grafted plants should be maintained in the dark at 25 ◦C and 100% humidity for three days for graft union formation. This method has been developed for robotic grafting of cucurbits.

5. Tube grafting: It is similar to slant grafting except that in this method root stock & scion joined are held with an elastic tube instead of clips [50]. It is more popular in tomato, brinjal.

6. Pin grafting: Pin grafting is basically the same as the splice grafting. Instead of placing grafting clips, especially designed pins are used to hold the grafted position. The pins are made of natural ceramic so it can be left on the plant without any problem.

Table-2 *Grafting methods and rootstocks used in vegetable crops*

Scion Plant	Rootstock	Method
Eggplant	*Solanum torvum*	Tongue and cleft method.
	S. sissymbrifolium	Cleft method
	Solanum khasianum	Both tongue and cleft methods
Tomato	*L. pimpinellifolium*	Only Cleft method
	S. nigrum	Tongue and cleft methods
Cucumber	*C. moschata*	Hole insertion and tongue method
	Cucurbita maxima	tongue method
Water melon	*Benincasa hispida*	Hole insertion and cleft method
	C. moschata	Hole insertion and cleft method
	C. melo	Cleft method
	C. moschata × C. maxima	Hole insertion method
	Lagenaria siceraria	Splice Grafting
Bitter gourd	*C. moschata*	Hole insertion and tongue method
	Lagenaria siceraria	Hole insertion
Bottle gourd	*C. moschata, Luffa sp.*	Hole insertion and tongue method

Grafting of cucurbitaceous vegetable crops

Grafting can be used with a variety of cucurbits to provide control of Fusarium wilt, drought tolerance, and flooding tolerance. Currently, watermelon is one of the vegetables in which grafting is performed intensively in the world [96]. The success of grafting includes survival rate, compatibility, and effect on quantity and quality traits tolerance / resistance to biotic and abiotic stresses. There are various methods of grafting of cucurbits listed in [Table-2]

Graft compatibility and survival rate

Graft compatibility is defined as an adequately close genetic relationship between stock and scion to form successful graft union, assuming that all other factors (technique, timing, temperature, etc.) are satisfactory. The Inter-generic grafting of highly nematode-susceptible watermelon (*Citrullus lanatus*) cultivars 'Congo' and 'Charleston Gray' onto highly nematode-resistant wild watermelon (*Cucumisa fricanus*) and wild cucumber (*C. myriocarpus*) seedling rootstocks resulted in 36 % survival of the intergrafts reported by Pofu and Mashela [66]. Various rootstocks of cucurbits that are using for different quality, quantity, biotic and abiotic stresses elaborated under subheadings.

Effect of grafting on quantitative characters

The effect of different cucurbit rootstock on growth and yield of cucumber under the impact of root-knot nematode shown that, rootstock affected the fruit yield, where Strongtosa and Shintosa produced higher marketable yield ranging from 260% to 280% of that ungrafted plants [2]. Grafting increases the yield of watermelons due to an increase in mean fruit size [3]. As shown by Yetisir, et al. [95], Huitron-Ramirez, et al. [38], watermelon grafted onto interspecific squash rootstock (*C. maxima* × *C. moschata* Duchesne) found to increase fruit size by 52% and yield were significantly higher with firm flesh than fruit from non-grafted plants. The Khankahdani, et al. [45] observed maximum fruit yield in grafted watermelons on 'Bottle gourd' rootstock by splice grafting technique (13.60 kg/plant) and the least recorded in seedy watermelons (4.37 kg/plant. Grafting mini-watermelons onto a commercial root-stock (PS 1313 *Cucurbita maxima* × *Cucurbita moschata*) revealed more than 60% higher marketable yield when grown under conditions of deficit irrigation compared with un-grafted melons [73]. A study on growth and yield of grafted cucumber on different soilless substrates showed that, grafted plants formed a significantly larger stems and longer root systems which led to 24% increased yield by Marsic and Jakse [55]. Reid and Klotzbach [70] also proved that grafting in cucumber increases yield.

Effect of grafting on qualitative characters

According to Ali [4] made observations on fruit quality and showed that fruit quality varies with both cultivar and rootstock and more vigorous plants tended to have better quality fruit. With regard to watermelon fruit, grafting on to different rootstocks has been known to increase fruit firmness and thus increase shelf life. Bruton, et al. [16] evaluated fruit quality of grafted plants and found that when watermelon plants grafted onto *C. maxima* × *C. moschata* and *C. ficifolia* rootstocks, fruits had higher firmness. Fruit soluble solid content (SSC) and lycopene also varied with the cultivar and rootstock [25]. Irregular fruit quality issues reported for watermelon comprise of reduced soluble solids, improved number of yellowish bands in the flesh, dull taste, poor texture and decreased firmness [52,21]. However, others report have optimistic effects on grafting watermelon, including an increase in fruit firmness, soluble solids and lycopene content by Salam, et al. [75]. Yetisir, et al. [96] reported that quality (Brix, firmness, rind thickness, and fruit shape) of watermelon was greatly affected by grafting, but the results were dependent on the rootstock used. Zhu, et al. [99] found an enhanced content of ascorbic acid with grafting. Proietti, et al. [68] reported vitamin-C content increased by 7% grafted mini watermelon plants and 40% increased lycopene content if mini watermelon grafted onto hybrid rootstock 'PS1313' *C. maxima* × *C. Moschata*. A report of grafted watermelon, mentioned a 20% increased percentage of lycopene and total carotenoids by Davis, et al. [27]. Huang, et al. [37] evaluated an increased vitamin-C in case of cucumber. A watermelon var. F-90 was grafted onto the rootstock of *Cucubirta maxima* var. Dulce Maravilla, found an improved iron uptake as well as the consequent translocation of this micronutrient towards the shoot than un-grafted watermelon plants [72].

Effect of grafting on biotic stresses

Grafting plays an important role in controlling disease by using various rootstocks. Grafting of watermelon onto other cucurbitaceous rootstocks to provide soil-borne disease resistance has been highly successful [4]. The rootstocks for cucurbits include bottle gourd and *Cucurbita moschata* × *C. maxima* hybrids both are highly resistant to the *Fusarium oxysporum* which affecting and causing severe losses to crop [46]. The study conducted in AVRDC [9] shows that disease susceptible lines of bottle gourd can be grafted onto Luffa (sponge gourd) or pumpkin to improve crop performance. Grafting is a speedy technique in melon for controlling race 1 and 2 of *Fusarium oxysporum f. melonis* [58]. The plants of 'Crimson Sweet' grafted onto 'Shintoza' *Verticillium* colonization was checked, possibly due to the grafting defence mechanism identified by King, et al. [46]. It has been shown that by using Verticillium wilt tolerant rootstocks; commencement of symptoms can be postponed for three weeks, consequently the watermelon fruits can reach to maturity [63]. Thies and Levi [85] reported that watermelon plants grafted onto wild watermelon rootstocks (*C. Lanatus* var. *citroides*), were screening resistant or moderately resistant to the nematode, *M. incognita***.** 'Crimson Sweet' watermelon grafted onto 'Emphasis' and 'Strong Tosa' two rootstocks had a elevated rate of growth and improved tolerance to V. dahliae than non grafted/ self-grafted plants [17]. According to Pavlou, et al. [64] grafting of susceptible cucumber *cv.* Brunex F1, and other Dutch type cucumber hybrids, onto *C. ficifolia, C. moschata,* and *C. maxima* × *C. moschata*isan effective control measure against root and stem rot (reduced by 75-100%). Siguenza, et al. [83] also reported that *C. moschata* rootstock, used for cucurbits, having a high intensity of tolerance to root knot nematode.

Effect of grafting on abiotic stresses

Grafting used as a tool for reducing the effect of abiotic stresses. Grafted watermelon has potential to survive under abiotic stress. The watermelon grafted onto bottle gourd rootstock in heavy or loam soils, it enhances flooding tolerance. Cucurbits may be grafted onto pumpkin will provide some drought tolerance in sandy soil (9]. Mini watermelons grafted on to a commercial rootstock PS1313 (*Cucurbita maxima* Duchesne × *Cucurbita moschata* Duchesne) shown that an increase of over 60 % higher yield when grown under scarcity of irrigation conditions in contrast to ungrafted melon plants [73]. The higher marketable yield recorded with grafting was mainly due to an improvement in water and nutrient uptake [80]. Rouphael, et al. [73] found that accumulation of cu in leaf and fruits were considerably lower in cucumber plants if it is grafted on Shintoza-type rootstock (*Cucurbita maxima* Duchesne X *Cucurbita moschata* Duchesne).It is also resistant to low temperatures, if shock of grafting has been passed and grow more vigorously than non- grafted plants [3]. In watermelons, the quantity of chemical fertilizers can also be reduced to about one-half to two-third in grafted plants as compared to the standard recommendation for the non-grafted ones [77]. An increased levels of heavy metals such as cadmium, mercury, lead, arsenic etc., in farming constitute an rising hazard to plant growth, development, and yield, even also for human health and environment [20,35] that are integrated from various sources either industry, waste water or by soil amendments [34]. Some heavy metals are poisonous even in low concentrations while others present in plant tissues devoid of losing yield and observable symptoms [87]. A report on melon plants, cv. Arava grafted on the cucurbita rootstock i.e. TZ-48 found that B, Zn, Sr, Mn, Cu, Ti, Cr, Ni and Cd were lesser in fruits from grafted plants [29]. Cadmium restricts the photosynthesis, nitrogen metabolism, water transport, phosphorylation in mitochondria and chlorophyll content [30]. The watermelons grafted onto saline-tolerant rootstocks increases around 81% yields under greenhouse production [23]. The effect of grafting on cucumber under NaCl stress condition showed the increased flavour, taste and nutrient contents in grafted cucumber comparable to non-grafted plants [98]. Goreta, et al. [33] reported watermelon cv. Fantasy was grafted onto Strongtosa rootstock (C. maxima Duch × C. moschata Duch) increases the shoot weight and leaf area even under saline conditions. Huang, et al. [37] reported reduced shoot dry weight of cucumber *cv.* Jinchun no. 2 can be alleviated by grafting onto bottle gourd rootstock Chaofeng 8848. The attention also made to extend abiotic stress by proving [Table-3] of content.

Period of flowering and harvest

The rootstock and scion join together may adjust amounts of hormones produced and their influence on grafted plants parts. Flowering is delayed in grafted pumpkin, bottle gourd, wax gourd, and watermelon, especially in plants with 'Shintosa'-type rootstocks [93]. Sakata, et al. [74] stated that compared with other rootstocks, watermelon grafted onto bottle gourd causes early formation of female flowers. Flowering date affects fruit harvest time, which can have a direct impact on quality. No much report found that could provide more information about grafting effects on flowering and earliness.

Grafting of Solanaceous vegetable crops:

Grafting technology has been adopted on a large scale in Vietnam to control bacterial wilt in tomatoes that could otherwise completely destroy crops. Grafting in tomato was introduced commercially in 1960s [52]. While it can be expensive, grafting onto resistant rootstocks can provide an effective solution to some soil borne diseases where breeding has not yet produced varieties with effective levels of disease [9]. However, there are production problems like weeds, insect pests and diseases including late blight and Fusarium wilt with high rainfall, flooding, and high temperatures can significantly reducing the yield. Grafting is one of the techniques to solve abovementioned problems exist in tomato [67]. Grafting sweet pepper onto selected rootstocks of sweet pepper and chilli (hot) pepper can minimize problems caused by flooding and tolerance to bacterial wilt, Phytophthora blight and root knot nematodes [7].

Table-3 *Reports on grafting of cucurbits against abiotic stresses*

Low Temperature				
S. No	**Scion plant**	**Rootstock**	**Effect**	**Reference**
2.	Cucumber	*C. ficifolia,* Sicos angulatus L.	Improved vegetative growth and early yield	Zhou, et al. [98]
		Cucumber scion grafted onto squash rootstock (*C. moschata*Duch	Tolerate sub optimal temperature	Shibuya, et al. [82]
3.	Watermelon	Interspecific squash hybrid *C. maxima* × *C. moschata*	To advance the planting date during cool period	Davis, et al.[26]
Flooding				
1.	Cucumber	Squash rootstocks	Increase in chlorophyll content	Kato, et al. [43]
2.	Watermelon cv. 'Crimson Tide	*Lagenaria siceraria* SKP (Landrace)	Decrease in chlorophyll content - less pronounced	Yetisir, et al. [96]
Stress due to organic pollutants				
1.	Cucumber	3 rootstock Yuyuikki-black' , Schintosa-1gou and Hikari power-gold on dieldrin concentration	50-70% and 30-50% decreased dieldrin concentration in fruits grafted on Yuyuikki-black' with those of grafted on Schintosa-1gou *C. maxima* ×*C. moschata* and Hikaripower-gold (*C. moschata*), respectively.	Otani and Seike [60]

Brinjal is widely cultivated in tropical and temperate regions around the world and is open to grafting. It is prone to numerous diseases and parasites, in particular to *Ralstonia solanacearum*, Fusarium and Verticillum wilts, nematodes and insects [24]. It has been reported that brinjal grafted onto wild *Solanum* species and other resistant rootstocks is an efficient technique to control various pathogens [47].

Graft compatibility and survival rate

There are many reasons why rootstocks affect scion fruit quality. The most obvious is rootstock/scion incompatibility, which induces undergrowth and/or overgrowth of the scion, leading to decreased water and nutrient flow through the grafted union, ultimately causing wilting [27]. Nevertheless, to get positive effect of grafting on vegetable quality, rootstock/scion combinations should be carefully selected for specific climatic and geographic conditions [26]. Highest survival rate of grafted plants using *Solanum torvum* rootstock is in agreement with the observations of Petron and Hoover [65].

Effect of grafting on quantitative characters

Grafting in solanaceous vegetable crops increase in yield as mentioned in several reportsIn tomato, grafting resulted in the formation of more number of internodes and flowers in outdoor cultivation and number and total weight of fruits in indoor cultivation [88]. An increase in yield of tomato due to grafting reported by Khah, et al. [44]; Kleinhenz, et al. [48] and Gebologlu, et al. [32]. A report of grafted brinjal plants on S. *torvum* were significantly more vigorous, as measured by plant height, stem diameter and root biomass than the control plants by Bletsos, et al. (2003). Ioannou, et al. [39] found that grafted plants were taller and more vigorous than self-rooted ones and had a larger central stem diameter. According to Reid and klotzbach [70], grafted brinjal plants yielded more than ungrafted ones. Though, the economic feasibility has to be studied more before application of the techniques.

Effect of grafting on qualitative characters

A study showed that fruit quality varies with both cultivar and rootstock and more vigorous plants tend to be better quality fruit and reported that the solutes associated with fruit quality are translocated in the scion through the xylem, whereas quality traits, e.g. fruit shape, skin colour, skin or rind smoothness, flesh texture and colour and soluble solids concentration are influenced by the rootstock [57]. In soilless tomato cultivation, grafted plants had higher marketable yield, fruit quality and pH content of fruits depending on rootstocks [32]. The vigour of the scion predominated over the foliar control in terms of the nutritional state of Fe in the tomato plants [72]. In contrast grafting of eggplant on *Solunum torvum* and *Solunum Sisymbriifolium* negatively affected vitamin C content, firmness and some sensory attributes but overall impression was not influenced [11]. Flores, et al. [31] found that fruit from 'Kyndia', an indeterminate commercial cultivar, grafted onto 'UC82B', a determinate processing cultivar had elevated TSS compared to self-grafted tomato plants. Khah, et al. [44] also stated difference in total soluble solids and fruit juice pH on grafted tomato as compared to non grafted plants. However, Di-Gioia, et al. [28] recorded no significant differences in total soluble solids by tomato 'Oxheart' grafted onto 2 interspecific *S. lycopersicum*x *S. habrochaites* and also found that vitamin C content also decreased by 14-20%, if tomato plants grafted onto Beaufort F1 and Maxifort F1. Colla, et al. [22] reported no significant difference in titrable acidity and pH, when 2 pepper hybrids were grafted on 5 commercial rootstocks Snooker, Tresor, RX360, DRO8801 and 97.9001. So, there is necessitating to further studies for application of grafting techniques in qualitative traits.

Effect of grafting on biotic stresses

The primary purpose of grafting vegetables worldwide has to provide resistance to diseases**.** Soil borne diseases (corky root, fusarium wilt, verticillum wilt, bacterial wilt) and nematodes, are some of the biotic stress cause damages in vegetable production especially in continuous cropping of greenhouses [52], [67]. AVRDC [7], recommends *eggplant* accessions EG195 and EG203. They are resistant to damage caused by bacterial wilt, root-knot nematode, and tomato fusarium wilt. Grafted brinjal which was planted on infected soil with wilt disease produced better yield over the non-grafted plants [14]. The use of *Solanum torvum*as rootstock was reported to provide resistance to *Verticillium* wilt, *Fusarium* wilt, bacterial wilt and root knot nematode [81] though generally grafting controls the common disease like fusarium wilt in tomato plants [46]. Grafting of tomato on beaufort significantly reduced root galling due to root-knot nematodes, and this was the best treatment among all other treatments [42]. According to AVRDC [7], chili accessions PP0237- 7502, 0242-62 and Lee B for grafting which are resistant to damage caused by bacterial wilt and Phytophthora blight. Pepper scion ('Nokkwang') grafting onto lines ('PR 920', and 'PR 921', and 'PR 922') resistant to both *Phytophthora* blight and bacterial wilt showed greater rate of survival [40]. When the susceptible commercial pepper variety (cv. Gedon) grafted onto rootstocks resistant to *Rhizoctonia* root rot and *Fusarium* wilt grown in the infested soil was less attacked with wilt disease, while un-grafted plants were severely infected [12]. Few other reports were given in Table. So far, it has been need to more research and develops resistant lines for disease resistance.

Effect of grafting on abiotic stresses:

Abiotic stress significantly affects tomato production both in open field and greenhouse condition. These include, too cold, wet or dry, hypoxia, salinity, heavy metal contaminations, excessive and insufficient nutrient availability, and soil pH stress. These conditions cause various physiological and pathological disorders leading to severe crop loss [79]. To induce resistance against low and high temperatures, grafts were generally used. Grafting influences absorption and translocation of phosphorus, nitrogen, magnesium, and calcium [69]. The Improved nutrient uptake in grafted seedlings increases photosynthesis rate of plants, which is particularly noticeable under less than optimal growing conditions such as weak sunlight and low CO_2 content in solar greenhouses during winter months [36]. It has been suggested that these conditions allow grafted plants to produce higher yields, sometimes with improved fruit quality [92,99]. Grafting minimizes the negative effect of boron, copper, cadmium, and manganese toxicity [79]. Venema, et al. [86] studied the impact of grafting of tomato (*Solanum lycopersicum* Mill.) onto the rootstock of a cold-tolerant high altitude accession of a related wild species (*Solanum habrochaites* LA 1777) with respect to higher root mass ratios and relative growth rate, found that *S. habrochaites* LA 1777 appeared to be a valuable germplasm pool to improve the low-temperature tolerance. Grafting tomato plants for increased salinity tolerance is a promising practice to improve the crop performances in saline soil conditions [23]. Observations that root elongation rate of *Solanum habrochaites* is less inhibited by low temperature [86]. Chilli gave highest yield under high-temperature conditions when grafted on sweet pepper rootstocks [61]. Brinjal roots can survive for days under water, as a result most of brinjal lines may graft successfully with tomato lines that will maintain high yields and fruit quality of the scion variety. A survey conducted in Japan showed that, approximately 7% of brinjal fruit contain cadmium at concentrations exceeding the internationally acceptable limit for fruiting vegetables [10]. According to Arao, et al. [10], grafting reduce cadmium concentrations in brinjal fruit by grafting onto *Solanum torvum*. In particular, grafting *Solanum melongena* plants onto *Solanum torvum* reduced the leaf and stems cadmium concentrations by 67–73% in comparison to self-grafting. Growth and vigorof brinjal cv.Suqiqie improved when grafted on rootstock *Solanum torvum* under saline conditions [54,90]. The various other reports also mentioned below in [Table-4].

Table-4 *Abiotic stress tolerance through grafting*

S. No	Scion plant	Rootstock	Effect	Reference
Low Temperature				
1.	Tomato	*S. lycopersicon x S. habrochaites*	Higher yields even at 10^{0}C to 13^{0}C	Okimura, et al. [59]
		Tomato cv. Big Red grafted onto cv. Heman [*S. lycopersicum* L. x *S. hirsutum* (Vahl)Dunal] and cv Primavera (S. lycopersicum L.)	Produce more fruits than control	Khah, et al. [44]
		Accession LA 1777 of S. habrochaites backcross seed progeny of *S. habrochaites* LA 1778 x *S. lycopersicum* cv. T5	Able to alleviate low root temperature stress for different scions	Bloom, et al. [15]; Venema, et al. [86].
4.	Brinjal	*S. integrifolium* x *S. melongena*	Higher yield even at 18^{0}C to 21^{0}C	Okimura, et al. [59]
High Temperature				
1.	Tomato	Brinjals	Enhanced vegetative growth at 28^{0}C decreased total fruit dry weight	Abadelmageed and Gruda [1]
2.	Brinjal	Heat-tolerant rootstock (cv. Nianmaoquie)	Prolonged growth stage and yield increase up to 10%	Wang, et al. [89]
3.	Chilli	*C. annuum*cv.Toom-1 and 9852-54(AVRDC)	Highest yields	Palada and Wu [61]
Flooding				
4.	Tomato	Brinjal accessions EG195 and E203	Flooding tolerance	AVRDC [5], [7]
5.	Pepper	Chili accessions 'PP0237-7502', 'PP0242-62' and 'Lee B'	Flooding tolerance	AVRDC [5], [7]

Period of flowering and harvest

It was observed that non-grafted plants bloomed earlier than grafted plants. The late flowering in grafted plants might be due to the growth of scion plants was interrupted for a week nearly due to grafting and prolonged vegetative growth which has been also reported by Suthar, et al. [84] in brinjal for delayed flowering in grafted plants. It increases the plant vigour and extending the duration of economical harvest time. Grafting is also conducted to study the movement of some endogenous flowering substances across the graft union, proven that the flower-inducing stimuli controlled by photoperiod moved easily through the graft union, while the stimuli induced by vernalization did not [18].

Recent innovations of Vegetable Grafting:

Now a day's many new innovations developed to perform grafting in vegetables, few are summarised below:

i) Grafting Robots: A full automation model developed in the Netherlands can graft 1,000 tomato or eggplant seedlings per hour and has more functions such as automatically selecting matching rootstock and scion seedlings, which is a crucial process to increase the success rate. According to Kobayashi [49], the first commercial model of a grafting robot (GR800 series; Iseki & Co. Ltd., Matsuyama, Japan) became available for cucurbits in 1993 and there were various semi- and fully automated grafting robots. The reports also noted of grafting robots developed in other countries [Table-5].

ii) Micro-grafting: In vitro grafting using very small or micro explants (< 1/1000th mm^3) from meristematic tissues to eliminate the viruses from infected plants. Micro grafting has been used in herbaceous plants to evaluate the physiology of grafting and determine the chemical basis of cell to cell contacts. This method provides rapid propagation of virus free plants although, it is expensive.

Table-5 *Some robots developed for grafting vegetables*

Robots	Model	Developed by	Vegetable crops
AG1000 robot	fully automated	Yanmar Agricultural Equipment Co. (Osaka, Japan) 1994,	Solanaceous
Arnabat S.A.	Semi-automated	Barcelona, (Spain) 2000.	cucurbits, Solanaceous
Iseki's GR800 & GR-600	Semi-automated	Helper Robotech Co., Gimhae, Korea (2004)	Cucurbits

iii) Double grafted and single grafted tomato: Pomato is a plant resultant of vegetable grafting. In this tomato scions were grafted onto potato rootstocks by cleft grafting. Above the ground harvest over 500 cherry tomatoes with 10^0 Brix TSS. There are single tomato grafts like Indigo Rose, Brandywine and Sun Sugar. Log House is introduced the technique of producing double grafted tomato plants, red and yellow pear tomato as scions by using on Big Beef or Geronimo rootstock in U.S. and marketed in 2010.

Future knowledge necessary to grafting

Limitation of available rootstock information: There is inadequate information concerning use of other rootstocks, compatibility to open-field cultivars, and field performance of grafted seedlings in various climatic conditions.

Automation technology: Grafting in herbaceous plants need automation to produce grafted seedlings for large-scale commercial purpose. Semi- or fully-automated grafting robots were invented by several agricultural industries and some models are accessible in East Asia, Europe, and newly in the United States. The new attentiveness need to be developing for commercial use.

High production costs: The high cost of grafted seedlings is the result of intensive labour input for propagation, a longer production phase, and the added costs of the rootstock. Those expenses often discourage potential users of grafted seedlings.

Controlled environment: The controlled conditions contributed the ability to manipulate production arrangement and survival rate.

Conclusion

Grafting is a method of plant propagation, done by utilising selective rootstock and scion combinations for tolerance against soil borne diseases that directly influences the production of vegetable crops. As a result, increased net returns achieved in wide range of soil and environmental stress conditions even in off season. It is a rapid alternative means to the moderately slow breeding methodology. In recent days, grafting application leads the limit use of harmful soil disinfectants which minimizes the toxic residues in vegetables and environmental pollution. Hence, it is suggested that, by adopting modern innovations and indigenous wild relatives, we can realize commercial use of grafting to attain the low input sustainable horticulture in future.

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B. Ashok Kumar and Sanket Kumar contributed equally to the concept, outline and tables including writing manuscript.

Abbreviations:

TSS- total soluble solids, mt- Metric tonnes, NBPGR- National bureau of plant genetic resources, IIHR- Indian institute of horticultural research, AVRDC- Asian vegetable research and development centre, Var. - Variety, Cv. - Cultivar, Co. ltd- Company limited, and < - less than.

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