International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(2): 1664-1672

Received: 21-01-2019
Accepted: 23-02-2019

Grafting techniques in vegetable crops: A review

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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. Vegetable grafting involves cutting the stem of a vegetable plant at the seedling stage and attaching it to the rootstock of the seedling of a vegetable plant like wild brinjal or pumpkin. Once the attachment is made, the grafted seedling is grown in controlled climatic conditions, after which it can be planted in the field. Grafting onto specific rootstocks generally provides resistance to biotic and abiotic stress tolerance, growth, yield and quality of crops, soil borne diseases and nematodes. Grafting is an effective technology for use in combination with more sustainable crop production practices, including reduced rates and overall use of soil fumigants in many other countries. The first interspecific, herbaceous grafting was recorded in 1920 for watermelon (*Citrullus lanatus*) in Japan and Solanaceous vegetables it took 30 more years (1960's) to commercialize grafting in their production and the first record of eggplant (*Solanum melongena* L.) grafted on scarlet eggplant *(Solanum integrifolium* Poir.) was reported in the 1950s, one another example is that muskmelons grafted to interspecific hybrid squash (*Cucurbita maxima* × *Cucurbita moschata*) had resistance against vine decline caused by *Monosporascus spp.* and it is tolerant to charcoal rot (*Macrophomina phaselina*). If these scientists are to be confidence, vegetable grafting would result in plants that are more tolerant to bacterial wilt, thereby increasing its longevity as well as yield and reducing losses for vegetable farmers and increasing their revenue. Vegetable grafting research at ICRISAT is focused on tomato and Chilli plants but is also being tested upon capsicum, brinjal, bitter gourd, snake gourd, and even the exotic vegetable zucchini.

Keywords: Vegetable grafting, rootstock, cucumber, eggplant, muskmelon

Introduction
India is second largest producer of vegetables in the world followed by China. Area under vegetables 10.29 million ha and total production 176.17 million tonnes (NHB data 2017-18). These are the products of herbaceous plants which are annual, biennial and perennial whose plant parts such as leaves, fruits, roots, stems, petiole and flower etc. are used for culinary as well as consumed as raw. The researchers are now being directed for improvement in quality of horticultural produces. Many dieticians support to take 300g of vegetables every day to make our balanced diet along with other diets. There are 125 g leafy vegetables, 75 g other vegetables and 100 g root and tuber vegetables. (ICMR, New Delhi). With the projected inhabitants of 133 Crores in 2020 and 165 Crores in 2050, we have to produce at least 190 and 240 million tonnes respectively. Vegetables are productive foods are carbohydrates, protein, roughages and rich source of vitamins and mineral i.e. called protective food. The grafting is one of the tools for sustainable vegetable production by using resistant rootstock. Grafting is an art of joining together two plant parts such as different species of same genera (a rootstock and a scion) by means of tissue regeneration, in which the resulting combination of plant parts achieves physical reunion and grow as a single plant (Janick, 1986). In Olericulture, vegetable grafting is a relatively new one technique but in Pomology, grafting of fruit trees has been practiced for thousands of years, which is centuries-old technique. Commercial vegetable grafting using resistant roots stocks is one of the best tools for sustainable vegetable production. Vegetable grafting reduces the agrochemicals dependence on organic production (Rivard *et al.*, 2008) [55]. Vegetable grafting also induce vigour, precocity, better yield and quality, survival rate, reduce infection by soil-borne pathogens and tolerance against abiotic stresses by using desired rootstocks. In world, vegetable grafting is gain more popularity in case of cucurbits, tomato, eggplant and pepper using vigorous and disease -resistant rootstocks

to ensure adequate yields, whereas biotic and abiotic stresses causes limits the productivity (Lee and Oda, 2003; Chang *et al.,* 2008; Buller *et al.,* 2013) [42, 16, 13].

Background of vegetable grafting

The first time of vegetable grafting was done along with rootstock of watermelon (*Citrullus lanatus*) and pumpkin (*Cucurbita moschata*) in Japan and Korea in the late 1920s (Leonardi, 2016) [43]. Self-grafting was used as a technique to produce large-sized gourds fruits, as reported in a Chinese book written in the 5th century and Korean book written in the 17th century (Lee and Oda, 2003) [42]. However, commercial grafting of vegetables only originated in the early 20th century with the aim of managing soil borne pathogens (Louws *et al.,* 2010) [55]. Among the Solanaceous crops, aubergine (*Solanum melongena* L.) was first grafted on to scarlet onto scarlet aubergine (*Solanum integrifolium* Lam.) was started in the 1950 (Oda, 1999) [46]. Similarly, grafting of tomato (*Solanum lycopersicum* L.) was started in the 1960 (Lee and Oda, 2003) [42]. By 1990, the percentage of grafted Solanaceae and Cucurbitaceae vegetables had increased to 59 % in Japan and 81 % in Korea (Lee, 1994) [41]. In India, grafting work has been started in IIHR, Banglore by Dr. R M Bhatt and his associates. TNAU, Coimbatore has done work on brinjal grafting using *Solanum nigrum* as rootstock. NBPGR regional station, Thrissur, Kerala have done work on cucurbit grafting by taking *Momordica cochinchinensis* as rootstock with success rate of 98%. CSKHPKV, Palampur initiated work on grafting in cucurbits and solanaceous vegetables and have identified more than 22 rootstocks of these vegetables to impart resistance to bacterial wilt- and nematodes. Grafting tomato onto hardy tomato or eggplant rootstocks can minimize problems caused by flooding, soil-borne diseases, and root-knot nematode. Watch as staff from AVRDC - The World Vegetable Center demonstrate this simple, effective technique. Private companies like „VNR Seed Private Limited" and "TAKII SEED INDIA PRIVATE LIMITED" is also involved in vegetable grafting and supplying grafted quality seedlings.

Importance and use of vegetable grafting

Resistance to biotic and abiotic factors

Grafting used as tool for reducing the effect of biotic and abiotic stresses. The watermelon grafted onto bottle gourd rootstock in heavy or loamy soils enhances flooding tolerance. Cucurbits grafted on pumpkin provide drought tolerance in sandy soil (Anonyms, 2018) [7]. Mini watermelons grafted onto a commercial rootstock PS1313 (*Cucurbita maxima* Duchesne × *Cucurbita moschata* Duchesne) have shown 60 % increase in yield when grown under irrigation stress conditions in contrast to ungrafted melon plants. (Rouphael *et al.,* 2008) [56] found that cucumber grafted on Shintoza-type rootstock (*Cucurbita maxima* Duchense × *Cucurbita moschata*) has shown low temperature resistance and copper toxicity resistance. The watermelon grafted onto saline-tolerant rootstocks increases around 81% yield under greenhouse production (Colla *et al.,* 2010). Goreta *et al.,* (2008) reported that watermelon cv. Fantasy grafted onto Strong Tosa rootstock (*C. maxima* Duch × *C. moschata* Duch) increases the shoot weight and leaf area even under saline conditions. Soil bore diseases like verticilium wilt, bacterial wilt, fusarium wilt, corky root etc. and nematodes area some of the biotic stresses cause damage in vegetable production especially in continuous cropping of greenhouses (Lee *et al.,* 2003; Pogonyi *et al.,* 2005). Pepper scion (Nokk wang) grafting onto breeding lines (PR 920, PR 991 and PR 922) resistant to *Phytophthora* blight and bacterial wilt showed greater rate of survival when they were inoculated with *Phytophthora capsici* and *Ralstonia solanacearum* (Jang *et al.,* 2012).

Effect of grafting on qualitative and quantitative characters

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). A study 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 (Nicoletto *et al.,* 2012). In contrast, grafting eggplant on *Solanum torvum* and *Solanum sisymbrifolium* 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.

Flowering and harvesting time

Flowering is delayed in grafting pumpkin, bottle gourd, wax gourd and watermelon, especially in plants with "Shintosa"-type rootstocks (Yamasaki *et al.,* 1994). (Sakata *et al.,* 2007) stated that when compared with other gourd, it 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. The late flowering in grafted plants may be due to the growth of scion plants.

Essential 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 0C 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 (Wilson *et al*., 2012)

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

Selection of grafting method depends on the crop, the farmers experience, personal choice, the number of grafts required, the purpose of grafting, access to labour and the availability of machinery and infrastructure facilities (Lee *et al.,* 2010). Although many machines and grafting robots have been developed but manual grafting is the most popular and widely used method (Lee *et al.*, 2010)

a) Cleft grafting

It is also called apical or wedge grafting. Here scion plants are pruned with 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 split made (Johnson *et al.,* 2011). This method is most widely used in solanaceous crops.

b) Tongue / approach grafting

Equal sized rootstock and scion material used for this grafting. Therefore, to attain uniform size, scion seeds are sown 5-7 days earlier than rootstock seeds. This method is labour intensive and requires more space but seedling survival rate is high, hence, most widely used by farmers and small nurseries. This method is not suitable for rootstocks with hollow hypocotyls.

c) Hole insertion / Top insertion grafting

This is most popular method in cucurbits scion and rootstock should have hollow hypocotyls are preferred in this method. This method is preferred for grafted watermelon transplant production because the size of watermelon seedlings is relatively small than rootstock of bottle gourd or squash. This method require optimum temperature of 21-36˚c up to transplanting. This method is very popular in china because it results in a strong union and vascular connection compared with the tongue grafting approach (Oda, 1994).

d) Splice grafting/ tube grafting / one cotyledon splice grafting

This method is most widely used and preferred by growers and commercial grated transplant producers. It can be performed in most vegetables by hand or machines. This method is popular in Cucurbits and Solanaceous vegetable crops.

e) Pin grafting

Pin grafting is similar to splice grafting. Instead of placing grafting clips, especially designed pins are used to hold the grafted position.

f) Post-graft healing environment

Proper care of newly grafted transplants is necessary to secure a higher success rate for the grafting process. Loss of water from the scion during the first 2 days may lead to wilting of scion and ultimately failure of the grafting process; therefore, humidity should be maintained to prevent (95%) water loss. Grafted transplants should be covered for 5-7 days after grafting with black plastic sheeting to increase humidity, reduce light intensity and to promote healing process.

Plastic tunnels are used as healing chambers 95% grafting success can be obtained on commercial scale using healing room (Dong *et al.,* 2015). Avoid the grafted plantlets to direct sunlight during the healing process.

Table 1: Grafting methods and rootstocks used in vegetable crops

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

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 (Yetisir *et al*., 2003). 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 1.

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. Various rootstocks of cucurbits that are using for different quality, quantity, biotic and abiotic stresses elaborated under subheadings.

Table 2: Rootstocks for cucurbitaceous crops and some related characteristics

Rootstock	Cultivar	Major characteristics	Possible disadvantage
Watermelon			
Bottle gourd (*Lagenaria siceraria* L.)	Dongjanggoon, Bulrojangsaeng, Sinhwachangjo (Korea), FR Dantos, Renshi, Friend, Super FR Power (Japan)	VRS, FT, LTT	New fusarium race, susceptible to Anthracnose
Squash (*Cucurbita moschata* Duch.)	Chinkyo, No. 8, Keumkang (Korea)	VRS, FT, LTT	Inferior fruit shape and quality
Interspecific hybrid squash (*Cucurbita maxima* Duch.× C. *moschata* Duch.)	Shintozwa, Shintozwa #1, Shintozwa #2, Chulgap, (Japan, China, Taiwan, Korea)	VRS, FT, LTT, HTT, SV	Reduced fertilizers required. Some quality reduction may result.Pumpkins (Cucurbita pepo L.)
Pumpkins (*Cucurbita pepo* L.)	Keumsakwa, Unyong, Super Unyong	VRS, FT, LTT	Mostly for cucumbers
Wintermelon (*Benincasa hispida* Thunb.)	Lion, Best, Donga	GDR	Incompatibility
Watermelon [*Citrullus lanatus* (Thunb.) Matsum. *et al*.Nakai]	Kanggang, Res. #1, Tuffnes (Japan), Ojakkyo(Syngenta)	FT	Not enough vigor and disease Resistance
African horned (AH) cucumber *(Cucumis metuliferus* E. Mey. ex	NHRI-1	FT, NMT	Medium to poor graft Compatibility
Cucumber			
Figleaf gourd (*Cucurbita ficifolia* Bouché)	Heukjong (black seeded figleaf gourd)	LTT, GDT	Narrow graft compatibility
Squash (*Cucurbita moschata* Duch.)	Butternut, Unyong #1, Super Unyong	FT, FQ	Affected by Phytophthora
Interspecific hybrid squash (*Cucurbita maxima* Duch.× *C. moschata* Duch.)	Shintozwa, Keumtozwa, Ferro RZ, 64-05 RZ, Gangryuk Shinwha	FT, LTT	Slight quality reduction expected
Bur cucumber (Sicyos angulatus L.)	Andong	FT, LTT, SMT, NMT	Reduced yield
AH cucumber (*Cucumis metuliferus* E. Mey. ex Naud)	NHRI-1	FT, NMT	Weak temperature tolerances
Melon			
Squash (*Cucurbita moschata* Duch.)	Baekkukzwa, No. 8, Keumkang, Hongtozwa	Baekkukzwa, No. 8, Keumkang, Hongtozwa	Phytophthora infection
Interspecific hybrid squash (*Cucurbita maxima* Duch.× *C. moschata* Duch.)	Shintozwa, Shintozwa #1, Shintozwa #2	FT, LTT, HTT, SMT	Phytophthora infection, poor fruit quality Pumpkin (Cucurbita pepo L.)
Pumpkin (*Cucurbita pepo* L.)	Keumsakwa, Unyong, Super Unyong	FT, LTT and HTT, SMT	Phytophthora infection
Melon (*Cucumis melo* L.)	Rootstock #1, Kangyoung, Keonkak, Keumgang	FT, FQ	Phytophthora problem
AH cucumber(E. Mey. ex Naud)	NHRI-1	FT, LTT, SMT, NMT	Weak temperature tolerance

Cultivars vary greatly depending upon countries, growing types, years, and grafting methods.
VRS: vigorous root systems; FT: Fusarium tolerance; LTT: low temperature tolerance; ST: strong vigor; HTT: high temperature tolerance; GDT: good disease tolerance;
GDR: good disease resistance; NMT: nematode tolerance; SMT: high soil moisture tolerance; FQ: fruit quality modification
Source: Scientia Horticulturae: December 2010

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 (Ali A.D.H., 2012). 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 (King *et al*.). The study conducted in AVRDC (Anonymous.2013) 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.* (Nisini *et al*.) The plants of 'Crimson Sweet' grafted onto 'Shintoza' *Verticillium* colonization was checked, possibly due to the grafting defence mechanism identified by King, *et al*. 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 (Paplomatas *et al*.). Thies and Levis 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 (Buller *et al*.) [13]. According to Pavlou, *et al*. 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*. 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 (Anonymous 2013). 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 (Rouphael *et al.*) [56]. The higher marketable yield recorded with grafting was mainly due to an improvement in water and nutrient uptake (Schwarz *et al.*). Rouphael, *et al.* [56] 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 (Alexopoulos *et al.*). 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 (Salehi *et al.*). 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 that are integrated from various sources either industry, waste water or by soil amendments (Gupta *et al.*). Some heavy metals are poisonous even in low concentrations while others present in plant tissues devoid of losing yield and observable symptoms (Verkleij *et al.*). 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 (Edelstein *et al.*). Cadmium restricts the photosynthesis, nitrogen metabolism, water transport, phosphorylation in mitochondria and chlorophyll content (Feng *et al.*). The watermelons grafted onto saline-tolerant rootstocks increases around 81% yields under greenhouse production (Colla *et al.*) [19]. 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 (Zhou *et al.*) [73]. Goreta, *et al*. 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*. 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 (Yamasaki *et al.*). Sakata, *et al*. 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.

Table 3: Reports on grafting of cucurbits against abiotic stresses

Low temperature			
Scion plant	**Rootstock**	**Effect**	**Refrence**
Cucumber	*C. ficifolia,* Sicos angulatus L. Cucumber scion grafted onto squash rootstock (*C. moschata* Duch	Improved vegetative growth and early yield Tolerate sub optimal temperature	Zhou, *et al.* Shibuya, *et al.*
Watermelon	Interspecific squash hybrid *C. maxima* × *C. moschata*	To advance the planting date during cool period	Davis, *et al.*
Flooding			
Cucumber	Squash rootstocks	Increase in chlorophyll content	Kato, *et al.*
Watermelon cv. ‘Crimson Tide	*Lagenaria siceraria* SKP (Landrace	Decrease in chlorophyll content - less pronounced	Yetisir, *et al.*
Stress due to organic pollutants			
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

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 (Lee, *et al.*). 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 (Anonymous 2013). 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 (Pogonyi, *et al.*). 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 (Anonymous 2009). 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 (Collonier, *et al.*). It has been reported that brinjal grafted onto wild *Solanum* species and other resistant rootstocks is an efficient technique to control various pathogens (King *et al.*).

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 (Davis *et al*.). Nevertheless, to get positive effect of grafting on vegetable quality, rootstock/scion combinations should be carefully selected for specific climatic and geographic conditions (Davis *et al*.). Highest survival rate of grafted plants using

Solanum torvum rootstock is in agreement with the observations of Petron and Hoover.

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 (Pogonyi *et al.*). AVRDC, 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 (Bletsos *et al.*). The use of *Solanum torvum*as rootstock was reported to provide resistance to *Verticillium* wilt, *Fusarium* wilt, bacterial wilt and root knot nematode though generally grafting controls the common disease like fusarium wilt in tomato plants (Sebahattin *et al.*). Grafting of tomato on beaufort significantly reduced root galling due to root-knot nematodes, and this was the best treatment among all other treatments (Kaskavalci *et al.*). According to AVRDC, 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 (Jang, *et al.*). 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 (Attia *et al*.).

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 (Savvas *et al.*). To induce resistance against low and high temperatures, grafts were generally used. Grafting influences absorption and translocation of phosphorus, nitrogen, magnesium, and calcium (Pulgar *et al.*). 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 CO2 content in solar greenhouses during winter months (Hu *et al.*). It has been suggested that these conditions allow grafted plants to produce higher yields, sometimes with improved fruit quality (Xu *et al.*). Grafting minimizes the negative effect of boron, copper, cadmium, and manganese toxicity (Savvas *et al.*). Venema, *et al.* 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 (Colla *et al.*) [19]. Observations that root elongation rate of *Solanum habrochaites* is less inhibited by low temperature (Venema *et al.*). Chilli gave highest yield under high-temperature conditions when grafted on sweet pepper rootstocks (Palada and Wu). 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 (Arao, *et al.*) According to Arao, *et al.* 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 vigor of brinjal cv. *Suqiqie* improved when grafted on rootstock *Solanum torvum* under saline conditions (Wei *et al.*). The various other reports also mentioned below in [Table-4].

Table 4: Abiotic stress tolerance through grafting.

Scion plant	Rootstock	Effect	Reference
Low temperature			
Tomato	*S.lycopersicon x S. habrochaites* Tomato cv. Big Red grafted onto cv. Heman [*S. lycopersicum* L. x *S. hirsutum* (Vahl) Dunal] and cv Primavera (S. lycopersicum L.) Accession LA 1777 of S. habrochaites backcross seed progeny of *S. habrochaites* LA 1778 x *S. lycopersicum* cv. T5	Higher yields even at 100C to 130C Produce more fruits than control Able to alleviate low root temperature stress for different scions Able to alleviate low root temperature stress for different scions	Okimura, *et al.* Khah, *et al.* Bloom, *et al.* Venema, *et al.*
Brinjal	*S. integrifolium* x *S. melongena*	Higher yield even at 180C to 210C	Okimura, *et al.*
High temperature			
Tomato	Brinjals	Enhance vegetative growth at 280C decreased total fruit dry weight	Abadelmageed and Gruda

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.* 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 (Chailakhyan and Khrianin).

Problems faced during vegetable grafting
Various problems associated with the production and management of grafted transplants is as following:
a) This technique is labour intensive and required specialized trained workers.
b) Requires time management for rootstock and scion seeds sowing.
c) Require a controlled environment for graft healing.
d) Grafting can increase the risk of pathogen spread, especially for seed borne pathogens in the nursery. Workers performing grafting within a greenhouse and growth chamber face the problems of heat stress and discomfort, especially during April-June, September and October (Marucci *et al.,* 2012)

Current status of vegetable grafting
East Asia is the largest market for vegetable grafting because of high concentration of cucurbits and other grafted vegetables. In Korea, Japan and China, 99 %, 94 % and 40 % of watermelon respectively are produced through grafted transplants (Bie *et al.,* 2017). In case of Solanaceous vegetables, about 60-65 % tomatoes and eggplants and 10-14 % of peppers are produced through grafted transplants. In the Netherlands all the tomato under soilless culture conditions utilize grafted tomato transplants (Bie *et al.,* 2017). Currently, vegetable grafting is expanding worldwide particularly in Eastern Europe, North and South America, India and Philippines. In china, over 1500 commercial nurseries are producing grafted transplants. Canada exporting grafted transplants to Mexico, thus the international trading of grafted vegetable transplants is rapidly increasing (Bie *et al.,* 2017).

Recent innovations of Vegetable Grafting
Now a day's many new innovations developed to perform grafting in vegetables, few are summarized below:

i) 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 100 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.

ii) Micro-grafting: *In vitro* grafting using very small or micro explants (< 1/1000th mm3) 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.

iii) 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 (Kobayashi *et al.*), 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-4].

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

Conclusion and future perspectives
Vegetable grafting technique is the positive effects of dynamic interspecific rootstocks on scion concert are often reflected on fruit size, particularly in crops such as watermelon, cucumber, and tomato, whereas fruit shape constitutes a trait predominantly governed by the scion genotype. Similarly, grafting effect on exocarp and mesocarp thickness is limited and inferior to that of the scion genotype, moreover it interacts with fruit maturity. Variation in the epidermal and pulp colouration of annual fruits, determined by changes in pigment concentrations, can be influenced by grafting directly and indirectly through its interaction with fruit ripening behavior; such an interaction is common for watermelon while colouration effects on tomato, melon and pepper appear strongly rootstock-specific. Considering the diverse applications of vegetable grafting worldwide, this technique has the potential to solve the problems of vegetable industry of India and can boost farmers income by improving the crop yield and reducing the cost incurred on purchasing of huge amount of fertilizers and pest and disease control products. Grafting is an eco-friendly technology which promotes organic vegetable production. Fruit texture can be highly affected by grafting as manifested most consistently in the case of watermelon grafted on interspecific cucurbit rootstocks which generally increase pulp firmness; whereas loss of firmness in melon can reflect latent rootstock–scion incompatibility. Arguably the most important sensorial attribute is fruit sweetness, elicited by soluble carbohydrates whose concentration is liable to the effects of grafting. Rootstock-mediated changes in sweetness may also encompass changes in melon starch content and in the relative proportions of hexoses to sucrose. Nursery production and management is labour intensive. To solve this problem, scientists must focus on developing and popularizing facilities, equipment and grafting robots to increase the efficiency of grafting and reduce labour cost. Storage technology for grafted transplants demands the consideration of researchers the developments of databases, software, mobile applications and crop models related to grafted vegetables will assist nursery managers and farming communities in the selection of suitable scion and rootstock cultivars, in the international market the trading of grafted transplants is increasing rapidly, with the development of

grafted vegetable industry in India this option can be availed to earn foreign exchange.

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