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Vegetable grafting: An emerging approach in vegetable production: A brief review

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Abstract
Vegetable grafting entails cutting the stem (scion) of a seedling vegetable plant and combining it to the rootstock of a seedling vegetable plant. Vegetable grafting is a method that increases production under biotic and abiotic challenges such as sub-optimal and supra-optimal temperature, salt, drought, pest damage, diseases, and so on. Commercial vegetable grafting has been practised for a few decades, and the area under vegetable grafting is steadily expanding. Vegetable grafting has the ability to boost production per unit land available by expanding the area under cultivation of vegetables under non-traditional conditions and unstable agro-ecosystems. Nowadays, most watermelons, cucumbers, and other solanaceous crops are grafted before being planted in the field. In many other nations, grafting is an effective technology for use in conjunction with more sustainable crop production practises, such as lower rates and overall use of soil fumigants. Vegetable grafting is a low-cost alternative to long and sluggish breeding techniques for developing resistant cultivars.

Keywords: Vegetable grafting, root stock, scion, biotic and abiotic stress

Introduction

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. 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) [47].

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) [28, 7, 6]. However, commercial grafting of vegetables only originated in the early 20th century with the aim of managing soil borne pathogens (Leonardi, 2016) [32]. 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. Similarly, grafting of tomato (*Solanum lycopersicum* L.) was started in the 1960 (Lee and Oda, 2003) [28].

Though, the benefits of using grafted plants are profuse, not all vegetable species are capable of being grafted, because genetic background, growth characteristics, anatomy, and physiological and biochemical factors of the species influence the success percent of grafted plants (Martinez *et al*., 2010; Goldschmidt, 2014; Fan *et al*., 2015; Gratao *et al*., 2015) [33, 17, 12, 18]. Among vegetable crops, grafting is commonly and economically practiced in solanaceous and cucurbitaceous vegetables *viz*., Tomato (*Solanum lycopersicum* L.), Eggplant (*S. melongena* L.), Sweet pepper, Watermelon [*Citrullus lanatus* (Thunb.) Matsum. and Nakai], Melon (*Cucumis melo* L.), Bitter gourd (*Momordica charantia*), and Cucumber (*C. sativus* L.). By 1990, the percentage of grafted Solanaceae and Cucurbitaceae vegetables had increased to 59% in Japan and 81% in Korea (Lee, 1994) [30]. Currently, the cultivation of all the cucurbits under greenhouse conditions in Japan and Korea is based on grafting techniques (Sanjeev Kumar *et al*., 2018) [50].

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.

Purpose of cultivation of grafted vegetables

A variety of biotic and abiotic stressors are to blame for decreased yield and poor vegetable quality. Furthermore, in order to control biotic challenges, farmers apply pesticides indiscriminately, which is a big source of concern among health-conscious people. Soil-borne illnesses are a major source of biotic stress in the vegetable firm.

The development of disease-resistant varieties is the best solution for cultivation in disease-prone locations. Grafting, which swiftly and directly combines the features of two plants, one supplying a root system (rootstock) and the other providing a shoot (scion), can bypass some of these restrictions and make superior genetic stocks available to farmers.

Although the primary goal of grafting is to avoid soil-borne diseases such as fusarium wilt in Cucurbitaceae (cucumber, melon, etc.) and bacterial wilt in Solanaceae (tomato, pepper, etc.), it is used for a variety of purposes and has several advantages (Lee *et al*., 2010) [31] such as yield increase, shoot growth promotion, disease tolerance, nematode tolerance/resistance enhanced nutrient uptake, enhanced water uptake, high salt tolerance, wet soil tolerance, heavy metal and organic pollutant tolerance, quality changes, extended harvest period, multiple and/or successive cropping allowed, convenient production of organic wastes and ornamental values for exhibition and education.

Basic requirement for vegetable grafting

1. Choosing the right rootstock/scion: Grafting is usually done at the 2-3 true leaf stage, and the rootstock and scion are chosen based on the similar stem diameters.
2. Graft compatibility: Graft compatibility aids in lowering mortality rates even at later stages of growth. Callus development between scion and rootstock causes the production of vascular bundles.
3. Grafting aids: Grafting clips, tubes, pins, and grafting blades are used.
4. Screening house: a 60-mesh nylon net structure used for nurturing seedlings prior to grafting.
5. Healing of grafts: For the growth of callus formation in seedlings during 5-7 days, the temperature range and relative humidity in the healing chamber should be 28-29o C and 95%, respectively. This also aids in scion and rootstock adhesion by lowering light intensity and transpiration with the help of controlled temperature and humidity.
6. Acclimatisation of grafted plants: Acclimatisation occurs once callus formation is complete. Once the damaged surface has healed sufficiently, the grafted plants are moved to the greenhouse's mist chamber or placed under clean plastic to prevent leaf burning and wilting.

Grafting methods

The method of grafting is determined by the crop, the farmers' experience, the person chosen, the quantity of grafts required, the aim of the grafting, access to labour, and the availability of machinery and infrastructure (Lee *et al*., 2010) [31]. Those methods as the following.

1. **Splicing grafting:** This technique is often referred to as tube grafting or one cotyledon splice grafting. Producers and commercial vegetable transplant firms prefer and use this procedure the most. In most vegetables, it can be done by hand or by machine. This approach is popular for cucurbits and other solanaceous crops.
2. **Pin grafting:** is comparable to splice grafting. To hold the grafted position, customised pins are utilised instead of grafting clips.
3. **Top insertion grafting:** Because watermelon seedlings are smaller in size than bottle gourd or squash rootstock, this approach is recommended for producing grafted watermelon transplants. This approach necessitates a temperature range of 21-36 °C till transplantation occurs. This method is often used in China because it results in a strong union and vascular connection when combined with the language grafting strategy. (Oda, 1999) [40].
4. **Apical grafting:** In this instance, scion plants are cut with one to three true leaves, the lower stem is cut at a slanting angle to form a tapered wedge, and the clip is inserted to make contact between the scion and rootstock after splitting (Johnson *et al*., 2011) [23]. This method is most widely utilised in the cultivation of sunflowers. Cleft grafting is another name for it.
5. **Tongue grafting:** For grafting, the same size rootstock and scion material are used. To achieve consistent size, seeds are placed 5 - 7 days before rootstock seeds. This approach is labour intensive and takes up more room, but the survival rate of seedlings is high, thus farmers and small nurseries like it. This approach does not work with hollow hypocotyl rootstocks.

Post-graft healing environment

Proper management of newly grafted transplants is required to provide a better grafting success rate. Water loss from the scion during the first two days may result in wilting of the scion and, eventually, failure of the grafting process; consequently, humidity should be maintained to prevent (95%) water loss.

Grafted grafts should be covered with black plastic sheeting for 5-7 days after grafting to improve humidity, reduce light intensity, and promote healing.

As healing chambers, plastic tunnels are employed. On a commercial scale, healing rooms can achieve 95% grafting success (Dong *et al*., 2015). During the healing phase, keep the grafted plantlets away from direct sunlight.

Physiology of graft union formation

A successful graft union must meet the five parameters listed below:

1. Rootstock and scion must be compatible.
2. Appropriate cambial contact of the scion and rootstock

3. Sufficient pressure to keep the cut surfaces firmly together.
4. Desiccation can be avoided by keeping a high humidity level surrounding the cut surface.
5. Grafting can only take place when both plants are at the right physiological stage (Hartmann and Kester, 2010) [19].

Cucurbitaceous vegetables

Grafting is used to control Fusarium wilt and make plants more drought and flood resistant. Watermelon is one of the crops in this family that is currently grafted (Yetisir *et al.*, 2003) [59]. The many grafting procedures utilised in cucurbits are mentioned in Table 1 below.

Solanaceous vegetables

Tomato, aubergine and sweet pepper are among the solanaceous vegetables that can be grafted. Grafting is common in nearly all greenhouse-grown tomatoes and eggplants. Grafting is widely used to manage illnesses such as bacterial wilt in tomatoes, which can entirely kill the crop. Grafting became a commercial practise in the tomato crop in the 1960s (Lee *et al*. 2010) [31]. Grafting is a strategy used in tomato to solve difficulties caused by insect pests, weeds, and diseases such as late blight and Fusarium wilt, as a result of which yield is lowered (Pogonyi *et al*., 2005) [42].

Table 1: Different Rootstocks & Scions used in cucurbitaceous & solanaceous vegetables and its method of grafting

Rootstock	Scion	Method of grafting
Cucurbitaceous vegetable		
Benincasa hispida, Cucurbita moschata Cucurbita melo, Cucurbita moschata × Cucurbita maxima Lagenaria siceraria	Watermelon	slice grafting, top insertion and cleft method
Cucurbita moschata, Cucurbita maxima	Cucumber	Tongue and top insertion method
Cucurbita moschata, Luffa sp.	Bottle gourd	Top insertion and tongue method.
Cucurbita moschata, Lagenaria siceraria	Bitter gourd	Top insertion and tongue method
Solanaceous vegetable		
Lycopersicum pimpinellifolium	Tomato	Cleft grafting
Solanum nigrum		Tongue and cleft grafting
Solanum torvum	Brinjal	Tongue and cleft grafting
Solanum sissymbrifolium		Cleft method
Solanum khasianum		Tongue and cleft method

Table 2: Brief review of vegetable grafting

Crop	Rootstock	Scion	Impact of grafting	Reference
Tomato	*S. torvum, S. sisymbriifolium*	Tomato	Early flowering	Rashid *et al.* (2004) [46].
	Heman and Primavera	Tomato cv. 'Big Red'	Early flowering	Khah *et al.* (2006) [24].
	S. sisymbriifolium	Tomato	Early flowering	Romana (2006) [48].
	Beaufort and Arnold	Tomato cultivars Beril, Swanson and Yeni Talya	Highest fruit yield/plant	Turhan *et al.* (2011) [56].
	Tomato cv. 'Beaufort'	Tomato genotype 'Catalena'	More fruit /plant	Mohamed *et al.* (2012) [34].
	African eggplant cultivars 'Aworoworo' and 'Green'	Tomato varieties 'Tropimech' and 'Roma	Early flowering, early harvest and total soluble solids highest average fruit weight	Nkansah *et al.* (2013) [38].
	Tomato cv. 'Unifort'	Tomato cv. 'Faridah'	Early fruiting, highest average fruit weight	Ibrahim *et al.* (2014) [22].
	Brinjal rootstock VI034845	Tomato cv. Avatar	More fruits per plant, maximum pericarp thickness, highest yield per plant	Kumar *et al.* (2017b) [26].
	Solanum pimpinellifolium	Tomato cv. 'Ramellet'	More fruits per plant, highest average fruit weight	Fullana-Pericas *et al.* (2018) [13].
	Tomato rootstock LS-89	Tomato	Early harvesting, highest fruit weight, maximum pericarp thickness, highest TSS	Sharma (2019) [51].
	Solanum sisymbrifolium	'BARI Tomato-4	More fruits per plant	Hossain *et al.* (2019) [20].
	Brinjal var. Navkiran	Tomato var. Sona NTH 2829	Highest number of fruit/plant, low titratable acidity	Singh *et al.* (2019) [53].
Brinjal	*S. torvum*	Eggplant cultivar Faselis	Increased protection against pathogen infestations (*M. incognita*) with less loss of quality and yield	Curuk *et al.* (2009) [8].
	Solanum incanum × S. melongena	Black Beauty	Highest yield	Gisbert *et al.* (2011a) [16].
	Solanum torvum	Longo	Highest marketable yield	Moncanda *et al.* (2013) [35].
	Solanum xanthocarpum	Pusa Shyamala	Highest solasodine conten	Kumar *et al.* (2017) [25].
	Solanum torvum	Pusa Shyamala	Lowest infection of bacterial wilt	Kumar *et al.* (2017) [25].
	L23B	cv. Classic F1	Highest marketable production/hectare	Hoza *et al.* (2017) [21].
	Torpedo	Classic F1	Highest average fruit weight	Hoza *et al.* (2017) [21].
	BARI Hybrid Begun-4	BARI Begun-8	Highest average fruit weight, highest yield/plant	Quamruzzaman *et al.* (2018) [44].
	Solanum torvum	Scarlatti	Lowest glycoalkaloid	Sabatino *et al.* (2019) [49].
	Solanum torvum	Surati Ravaiya Purple	Maximum fruit set, highest marketable fruit yield/plant, highest marketable yield/hectare, minimum infestation of fruit and shoot borer	Kumar *et al.* (2019) [27].
	Solanum grandiflorum x *Solanum melongena*	Madonna	Highest average fruit weight	Mozafarian *et al*. (2020) [36].

	MWR rootstock	MCV2	Highest average fruit weight	Musa *et al.* (2020) [37].
Cucurbits	Xiuli, Nanzhen No-3, Nanzhen No-4	melon	Higher plant height, diameter of stem, and number of leaves per vine	Bie *et al.* (2010) [4].
	Cucumis and *Cucurbita*	Tainan No 1	Parallel grafting survival rate and best vegetative growth, significant effect on fruit quality was observed	Chao and Yen (2013)
	Squash	*Cucumis sativus* L.	Increased plant height, physical characters, early and total yield of cucumber fruits in both summer and winter seasons	El-Sayed *et al.* (2014) [11].
	Pumpkin	Bitter gourd	Recorded with highest protein content	Selvi (2014)
	Pumpkin	Palee F1 hybrid	Highest ascorbic acid content	Selvi (2014)
	RS-17 and RS-8	Sardes	Increased yield	Bekar *et al.* (2017) [25].
	Lagenaria siceraria	cucumber cv. Kalaam	High plant survival rates (95%), better vegetative growth and maximum fruit yield	Noor *et al.* (2019) [39].
	Lagenaria siceraria	cucumber cv. Kalam F1	Highest fruit weigh, Total soluble solids, fruit dry matter, fruit yield	Aslam *et al.* (2020) [2].

Table 3: Rootstock tolerance/resistance to biotic and abiotic factors

Crop	Rootstock	Resistance to	Reference
Tomato	*Solanum pimpinellifolium*	Nematode resistance	Rai *et al.* (2010) [45].
	S. integrifolium x *S. melongena*	High temperature tolerance	Okimura *et al.* (1986) [41].
	Solanum sisymbriifolium	Nematode resistance	Baidya *et al.* (2017) [3].
	Solanum torvum	Nematode tolerance	Dhivya *et al.* (2016)
	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.* (2004) [10], Venema *et al.* (2008) [57].
Brinjal	*Solanum khasianum*	Nematode tolerance	Ali *et al.* (1992) [1].
	Solanum integrifolium	Nematode tolerance	Gisbert *et al.* (2011) [15].
	cv. Nianmaoquie	Heat-tolerant rootstock	Wang, *et al.* (2007) [58].
Cucumber	*Cucumis metuliferus*	Nematode tolerance	Sigüenza *et al.* (2005) [52].
	Citrullus colocynthis	Nematode tolerance	Punithaveni *et al.* (2015) [43].
	C. ficifolia	Low temperature tolerance	Zhou, *et al.* (2007) [60].
Bitter gourd	*Cucumis metuliferus*	Nematode tolerance	Tamilselvi *et al.* (2015) [54].
	Cucurbita moschata	Nematode tolerance	Tamilselvi, 2014 [55].

Conclusion

Solanaceous and cucurbitaceous vegetables are now grown all over the world using grafting technology, which has become an essential aspect of production practises due to its usage in nematode resistance, disease management, and crop yield increase. Grafting has emerged as an efficient surgical technique for minimising biotic and abiotic stresses in vegetable production systems now that effective grafting procedures have been established and disease-resistant rootstocks are also accessible. The favourable impacts of dynamic interspecific rootstocks on scion concert are frequently reflected on fruit size, particularly in crops such as watermelon, cucumber, and tomato, although fruit shape is primarily governed by the scion genotype. Similarly, grafting has a limited and inferior effect on exocarp and mesocarp thickness compared to the scion genotype, and it interacts with fruit maturity. Variation in the epidermal and pulp coloration of annual fruits, as determined by changes in pigment concentrations, can be influenced directly and indirectly by grafting through its interaction with fruit ripening behaviour; such an interaction is common for watermelon, whereas coloration effects on tomato, melon, and pepper appear strongly rootstock-specific. Given the numerous applications of vegetable grafting around the world, this technique has the potential to solve the problems of India's vegetable industry and boost farmers' income by increasing crop yield and lowering the cost of purchasing massive amounts of fertiliser and pest and disease control products.

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