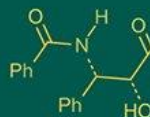


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Omesh Thakur
College of Agriculture &
Research Station, IGKV,
Gariaband, Chhattisgarh,
India

Padmakshi Thakur
S. G. College of Agriculture &
Research Station, IGKV,
Jagdalpur, Chhattisgarh, India

Kuntal Satkar
College of Agriculture &
Research Station, IGKV,
Gariaband, Chhattisgarh,
India

Corresponding Author:
Omesh Thakur
College of Agriculture &
Research Station, IGKV,
Gariaband, Chhattisgarh,
India

Advances in grafting techniques of vegetable crops: A comprehensive review

Omesh Thakur, Padmakshi Thakur and Kuntal Satkar

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Abstract

Vegetable grafting has emerged as an extremely valuable horticultural practice for increasing crop productivity, adaptability, and sustainability under intensive crop structure. This method involves mixing an exquisite scion with a sturdy and strain-resistant one that allows the flora to cope better under harsh environmental and soil conditions. Grafted flora often show additional resistance to soil-borne diseases, salinity, drought stress, and extreme temperatures. Additionally, grafting will increase water and nutrient uptake, promote energetic plant growth, stabilize yields, and promote longer production cycles while reducing dependence on chemical pesticides and fertilizers. The method is considerably used in solanaceous crops consisting of tomato, eggplant, and pepper, as well as cucurbit crops including of cucumber, watermelon, and melon, where it helps in the discounting of the effects of diseases along with Fusarium wilt, roto nematode wilt, and bacterial wilt. Recent developments in rootstock development, mechanized grafting structures, and nursery production techniques have additionally expanded the performance and industrial software of grafting. Therefore, vegetable grafting is taken into consideration as a green and eco-friendly way to overcome every biotic and abiotic irritating scenario within the cutting edge vegetable cultivation.

Keywords: Vegetable grafting, rootstock and environmentally

Introduction

Grafting is a method of plant propagation in which single crops are layered together to maintain their growth as a single plant and used explicitly in woody flowers. Commercial vegetable grafting originated in Japan and Korea and was practiced for about 30 years. Initially, the cultivation of grafted plant in green began to specify the extreme crop losses caused by the infection of soil-borne diseases, which worsened through successive and deep cultivations. Even though grafting has been a minor common practice in fruit trees due to the fact that vegetable grafting is of latest popularization in a commercial scale (Sakata *et al.*, 2007) [38]. It changed to introduced to western international locations inside the early nineties and is currently globally practiced use of adjacent scion varieties and introduced rootstocks. Vegetable grafting is a horticultural technique in which a preferred vegetable variety (scion) is hybridized with a well-suited rootstock, usually belonging to the equivalent botanical own family, to ensure a successful aggregation and emergence. The rootstock is usually determined for its full life root system, strong enhancement and ability to face dangerous soil and environmental conditions. It has a vital function of absorbing and transporting water and essential nutrients to the aerial parts of the plant, thereby increasing its resistance to abiotic stresses and pathogens present in the soil. Thus, grafted plants often suggest good growth, better yield potential, superior fruit too first-class, and higher conventional plant overall performance.

In modern vegetable production, grafting has emerged as an untested and practical alternative to long traditional breeding applications and other crop development techniques. This method promotes advanced productivity, fruit best, and set-up-harvest shelf presence while increasing nutrient uptake and plant vigor. It will also increase tolerance to salinity, temperature fluctuations, and many soil-borne diseases, especially in crops belonging to the Solanaceae and Cucurbitaceae families grown under intensive cultivation structures. In addition, grafting is quite useful in inclusive cultivation and hydroponic production systems, where repeated cultivation often affects in elevated disease pressure. Despite its advantages, the adoption of vegetable grafting in India is frankly limited due to dismal conditions

associated with high mortality of grafted seedlings after grafting, highlights the importance of expertise improvement, advanced nursery monitoring and standardized grafting protocols.

History & Current status of vegetable grafting

The first vegetable grafting experiment was completed using watermelon (*Citrullus lanatus*) grafting on pumpkin (*Cucurbita moschata*) rootstock in Japan and Korea inside the late 1920s. Self-grafting was used as a technique to produce large-sized chicken end results, as stated in a Chinese e-book written within the fifth century and Korean e-book written in the 17th century (Lee and Oda, 2003) [27]. In India, grafting of paintings in IIHR, Bangalore by Dr. TNAU, Coimbatore has done work on grafting brinjal using *Solanum nigrum* as rootstock. NBPGR nearby locations, Thrissur, Kerala have accomplished paintings on chickpea grafts using taking *Momordica cochinchinensis* as rootstock with performance fee of ninety eight%. CSKHPKV, Palampur started work on grafting in cucurbits and solanaceous vegetables and identified additional than 22 rhizomes of these greens to provide resistance against bacterial wilt and nematodes.

East Asia is the largest market for vegetable grafts due to high attention to cucurbits and other grafted greens. In Korea, Japan, and China, ninety-nine%, ninety-four%, and forty% of watermelon are produced through grafting, respectively. In the case of Solanaceous vegetables, approximately 60-65% of tomatoes and eggplants and 10-14% of peppers are produced via grafting. In the Netherlands, all tomatoes under soilless subcultures make use of grafted tomato seedlings (Bie *et al.*, 2017) [7]. Currently, vegetable imports are growing internationally especially in Eastern Europe, North and South America, India and the Philippines. Canada exports grafted transplants to Mexico, thus the global purchase and sale of grafted vegetable transplants is rapidly increasing.

Importance and advantages of grafting

Vegetable grafting provides several, sometimes concurrent advantages:

1. **Control of biotic stress:** efficient inhibition of soilborne diseases (Fusarium, Verticillium, nematodes, bacterial wilt) through resistant rootstocks.
2. **Tolerance to abiotic stress:** increased tolerance to salinity, waterlogging and temperature extremes by virtue of rootstock characteristics enhancing water uptake, ion exclusion, and hormonal signalling (Alqardaei *et al.*, 2025) [3].
3. **Yield stability and vigor:** more root mass and root activity usually result in increased vegetative vigor and greater yield under optimal as well as stress environments (Hashem *et al.*, 2024) [19].
4. **Shelf life and quality:** the quality of fruit characteristics (sugars, acidity, firmness) and postharvest life can be affected by the rootstock selection (Saka *et al.*, 2025) [37].
5. **Cropping system adaptability:** enables off-season/soilless production and enhances cropping of poor soils (Singathiya *et al.*, 2025) [39].
6. **Extending the harvesting period:** Helps in extending the harvesting period by maintaining plant health for longer durations.

7. **Nutrient and water uptake:** Improves nutrient and water uptake efficiency due to a stronger root system.
8. **Sustainable and intensive cultivation:** Supports sustainable and intensive cultivation, especially in protected and high-value crops.
9. **Reduced Chemical Use:** Decreases reliance on synthetic pesticides, fungicides, and fumigants, supporting eco-friendly and organic farming practices.
10. **Extended Cropping:** Allows for multiple or successive cropping in the same field by overcoming soil-borne issues that would otherwise limit planting.

Importance of scion-rootstock compatibility and selection criteria

- Compatibility is crop-and genotype-specific: many successful grafts are intraspecific (e.g., tomato onto tomato) or interspecific within the same genus (tomato onto *Solanum* relatives), and some intergeneric combinations (e.g., eggplant onto tomato rootstock) are used where compatible. Selection criteria are:
- Disease-resistance profile (target pathogens/nematodes)
- Abiotic tolerance (salinity, drought, low temperature)
- Root system architecture and vigor
- Influence on scion phenology, fruit quality and yield
- Seed availability, cost and legal/regulatory status
- Field and nursery performance in the target environment
- Wild or semi-wild rootstocks remain a major source of tolerance factors (e.g., *S. torvum*, semi-wild accessions of tomato), and local evaluation is now highlighted due to rootstock performance being environment-specific (Latifah *et al.*, 2023) [26].

Major Grafting Methods

1. Hole Insertion Grafting

Popular for cucurbits (Melon, cucumber). The rootstock (usually squash or bottle gourd) has a hole at the cotyledon junction. Scion (cucumber/melon) is inserted into the hole.

2. Tongue (Whip & Tongue) Grafting

Rootstock and scion materials of equal duration are used in this method of grafting. Scion seeds are sown 5 to seven days earlier from rootstock seed which allows you to achieve this normal duration. Farmers and small nurseries prefer this process because it has an immense seed survival peak even which requires several hard paintings and fields. It is incompatible with rootstocks, which have hollow hypocotyls, but. Small incisions or cuts are meticulously made with the scion and rootstock all through step one of the grafting method. These are the 2 main elements that go into the grafting method. After those notches are produced, a clip is used to align and stabilize them together. To allow the scion and rootstock to merge grade by grade, this clipping acts as a stabilizing agent. This is a critical step due to the fact that graft cannot take area until the alignment is maintained. The very last stage is then completed as the scion and rootstock have healed their marriage and are essentially a plant. The sample and the original root machine are carefully separated. This is to ensure that the plant that is now grafted can use the power and strength of the rootstock to develop on its own. This type of grafting is commonly used for tomatoes, eggplants, and peppers

3. Splice (Slant/Whip) Grafting

A simple and common method where both the rootstock and scion are cut on a slant and joined, then held by a clip. This type of graft is commonly used for tomatoes and peppers.

4. Cleft Grafting

This type of graft may also be called wedge grafting. Cut the rootstock horizontally below the cotyledons making a slit about one cm in the center of the rootstock stem. Cut the scion stem into a wedge shape about a centimetre in length, insert the scion wedge into the slit in the rootstock. Use a grafting clip to hold securely in place. Mostly used when scion is smaller than rootstock. This method is used in solanaceous crops like tomato, eggplant

5. Pin grafting

In this type of grafting technique where ceramic pins secure the union of a scion (desired plant) onto a rootstock, similar to splice grafting but using pins instead of clips, often involving horizontal cuts on cotyledons for alignment, ideal for linking plants of different sizes or when a perfect rootstock isn't available, but expensive ceramic pins limit its widespread use compared to clips.

6. Side Grafting

This type of graft may also be called approach grafting. To begin, cut a forty-five-degree downward angle slit about

halfway through the rootstock stem below the cotyledons. Make an upward angled slit in the scion at the same height as the rootstock. Bring the stems together so they overlap making full contact between the two cuts. Wrap with paraffin film or use a grafting clip to secure the union. Begin to remove the scion stem below the union after five days, slicing through the stem a little each day, removing entirely within eight days. Similar to cleft grafting but done on the side. This grafting is common in Tomatoes in protected cultivation.

7. Hole Insertion Grafting

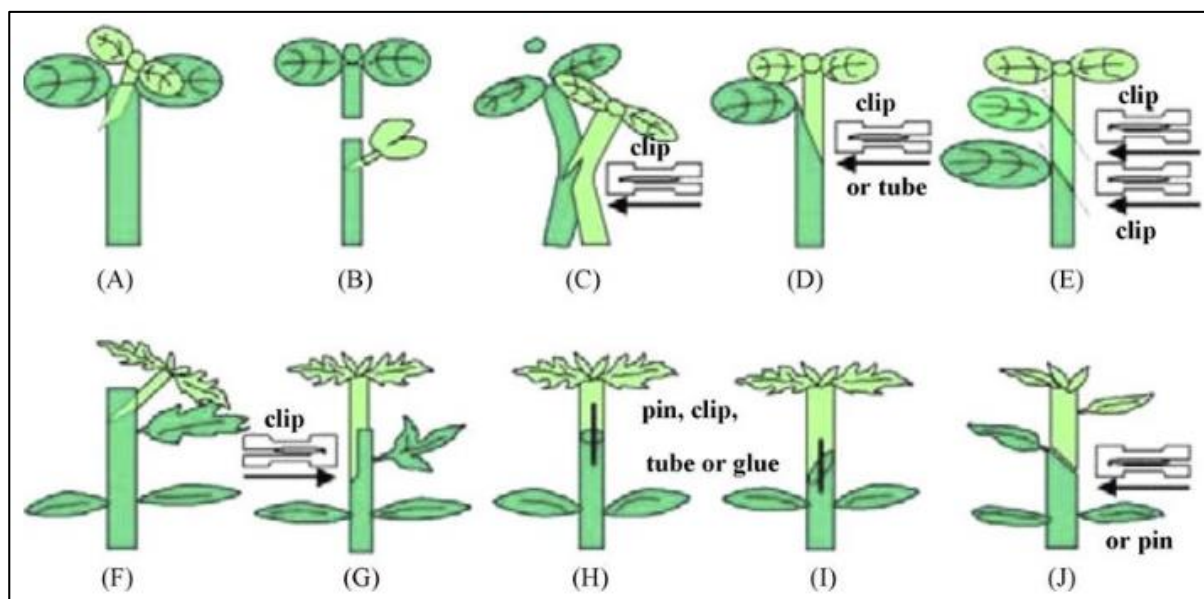
Popular for cucurbits (Melon, cucumber). The rootstock (usually squash or bottle gourd) has a hole at the cotyledon junction. Scion (cucumber/melon) is inserted into the hole.

8. Top Grafting (Decapitation Grafting)

The rootstock top is removed, and the scion is placed directly on the cut surface. This grafting method is used for mass propagation in greenhouses for tomatoes and eggplants.

9. Apical grafting

In this case, scion plants are cut with 1-3 true leaves and the lower stem is cut to a slanting angle to form a tapered wedge and the clip is placed to make contact between scion and rootstock after splitting (Johnson *et al.*, 2011) ^[21].



Major grafting methods in cucurbits and solanaceous vegetables: (A and B) hole insertion grafting; (C) tongue approach grafting; (D, E and J) splice grafting; (F, G) cleft grafting; (H and I) pin grafting.

Impact of grafting in vegetable crops

- A. Effect of grafting on qualitative & quantitative characters
- B. Effect of grafting on abiotic stresses
- C. Effect of grafting on biotic stresses

A. Effect of grafting on qualitative & quantitative characters

The quality of vegetables is commonly described as the 'set of characteristics of a product capable of satisfying the consumer's wants and determining its cost' (Peri, 2004) ^[35]. Grafting is an effective method to improve first-class fruit under any most reliable growing conditions and salinity. The fruit quality of shoot, which at least in part, relies on the

root machinery (Flores *et al.*, 2010) ^[16]. In soil less tomato cultivation, grafted flowers had higher marketable yield, fruit high quality.

Maurya *et al* (2019) ^[29] reported that grafting is the possibility of elevated fruit length in watermelon when grafted on rootstock with strong root structure. This has led many farmers to adopt transplanting as a standard practice. Additionally, the rootstock has been shown to persuade a variety of delicious qualities along with fruit shape, skin color, rind thickness, and soluble solids concentrations.

Fita *et al.* (2007) mentioned fruit mass as control however higher number of fruit in accordance with plant. An increase in fruit mass of 10% was also reported with the help of Verzera *et al.* (2014) ^[44] when 'RS841' became used as the

rootstock. Vanitha and Ravi (2024) ^[43] highlighted that development of excessively priced vegetables in controlled climatic environments such as NVPH, shed internet, etc. Are more competitive and profitable over daily cultivation. The growing conditions, the grafted varieties performed higher in terms of yield attributing traits such as chlorophyll content material and leaf area, which in turn led to a higher yield increase through 42% towards open field conditions. This has actually shown that the grafting and favorable environmental conditions help in increasing the crop cycle and thus the variety of pickings over non-grafted tomatoes. Grafting in tomato resulted in a more marketable yield because of the robust rootstocks with higher uptake of water and nutrients, which ended up with higher culmination in line with planting and longer harvest times listed with the help of Sharma *et al* (2018).

In cucumber, Goreta Ban *et al.* (2014) obtained more fruit mass while the plantlets were grafted onto interspecies hybrid (*Cucurbita maxima* Duch. × *Cucurbita moschata* Duch.) rootstocks 'RS841' and 'Strong Tosa' than when grafted onto zucchini (*Cucurbita rophatsidecks* 'Fla. non-viorant plants *et al.* (2013) obtained improved marketable yields in cucumber (*C. sativus*) 'Akito' and 'Ekron' grafted onto three commercial rootstocks, 'PS1313', 'P360' (*C. maxima* × *C. moschata*) and 'Affyne' (*C. sativus* The highest marketable yield). due to larger fruit size, not due to a better number of fruits in line with plant. Flesh firmness became negatively affected by grafting aubergine ('Tsakoniki') on to *S. torvum* and *Solanum sisymbriifolium* Lam. (Arvanitoyannis *et al.*, 2005) ^[5]. A reduction in firmness (-13%) was reported in the fruit of aubergine 'Black Bell' grafted on to *S. torvum* reported by Cassaniti *et al* (2011) ^[9].

Huang *et al.* (2009) showed that under saline conditions (60 Mm NaCl), TSS and TA have been much improved in cucumber culmination of plants grafted directly to 'Fig leaf green' (*C. ficifolia*) and 'Chaofeng Kangshengwang' (*L. siceraria*), compared to a self-grafted one.

Zhou *et al.* (2014) ^[46] mentioned that the use of pumpkin hybrid rootstock led to a development of the qualitative and quantitative carotenoid profile. An increase in lutein (5.5-13.7 mg kg⁻¹ fresh mass) was produced in fruit samples from flora grafted on 'Elsi', 'P360', 'RS841' and 'AS10', and approximately eightfold additional β-carotene than the manage%acarogen noted in fruits grafted on 'Elsi', 'P360', 'RS841' and 'AS10' 'P360'. Khah *et al.* (2006) ^[22] found no variations within the lycopene content content between non-grafted tomato 'Big Red' and a graft on 'Heman' and 'Primavera' rootstocks under open field and greenhouse conditions. Graft achieved on *C. maxima* × *C. The Moschata* rootstock advanced watermelon fruit post-harvest overall performance especially by maintaining better flesh lycopene levels, extra intense chroma and higher flesh firmness (Kyriacou and Soteriou, 2015) ^[25].

Abdul-Razzaq and Hanchal (2014) reported the germination reaction for grafting, using two types of germ, namely Charleston (A) and Crimson (B) and the mixture Shahd (C), to inoculate 3 chicken mixtures, especially ES113 F1 (1), Ulmpic (1). 2), RS841 (three), the treatment, the inoculation of Charleston over the individual Ulmpic, was drastically better in increasing the wide range of fruits and total yield, while the treatment of inoculation of Charleston on the original RS841 was drastically superior to the treatment, dissolution and dissolution inoculation of Kremson over

genuine Ulmpic in Ziad. The total yield amounted to 76.6 tons per hectare, while the treatment of vaccination witnessed the original Ulmpic exceeded the remaining treatments in increasing the percentage of total soluble solids to 11.25%.

Davis *et al.*, (2008) ^[13] reported that when *Solanum torvum* grafted with eggplant make the fruit size bigger but not changing their yield and quality. With the help of grafting the content of Sugar carotene, flavor, colour, texture can be affected. Kyriacou *et al.* (2015) ^[25] concluded that use of grafting lead to creating the variation on sweetness, acidity and fruit ripening time.

Nicoletto *et al* (2012) ^[31] obtained 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 Di-Gioia *et al.*, (2010) ^[14] 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.

According to Ofori (2015) ^[33], tomatoes grafted on 'Black Beauty' have been shown to result in elevated plant growth, yield and best compared to non-grafted plant life. Kumar *et al.* (2015) ^[23] concluded that fruit quality processes such as titratable acidity, soluble solids content, pore and skin shade, fruit shape index, and dry count content content can be encouraged via the selection of rootstock in vegetable grafting. Successful transplant operations, with a 95% success rate on an industrial scale, often utilize recycling beds and plastic tunnels.

Dong *et al.* (2015) ^[15]. *Solanum incanum* L. Is the wild ancestor of common brinjal (*S. melongena* L.) and is naturally found in South and Southeast Asia, Madagascar and Mauritius. Despite the potential of brinjal breeding, *Solanum incanum* has not been extensively studied.

Kumari *et al.* (2021) ^[24] determined that cultivation of pepper in polyhouse and open discipline conditions, improved the average general chlorophyll content of all hybrid species under NVPH conditions (13.79 mg g⁻¹ FW), compared to an open field (eleven.32 mg g⁻¹ FW). As for the species, the grafted PHS-448 located the most chlorophyll-containing material within the top, middle, and dorsal leaves. As the temperature increased with the crop level, the loss in chlorophyll content material changed to detected in each growth condition. There have also been reviews of tomatoes and other crops releasing chlorophyll due to excessive temperatures (Vijayakumar and Beena, 2020) ^[40]. The warmer environment inside the polyhouse facilitates the improvement of the morphological development of the crop, which includes plant height, the wide variety of branches, and the price of expansion of leaf location Parvej *et al.*, (2010) ^[34] and the same had been determined.

Nicoletto *et al.* (2013) ^[30] mentioned that solutes responsible for high quality of fruits are transported through xylem and rootstock directly inspired high quality parameters such as fruit shape, color, smoothness, texture, shade (flesh) and TSS of culmination. Maurya *et al.*, (2019) ^[29] stated that grafting delayed flowering in pumpkin, bottle green, wax green and watermelon while Shintosa used as rootstock. The delay in flowering in grafted vegetable inflorescences may be due to the age and emergence of the scion taken for

grafting. Interspecific hybrids used as rootstocks can decorate fruit pleasantly by increasing the accumulation of macro-and micronutrients, phenolic compounds, nutrition C, lycopene, and flavonoids inside the fruit of grafted plants. Rivero *et al.* [2008] stated that tomato cv. RX-335 showed extended PAL preferences and improved levels of total phenols and o-diphenols, however decreased in addition to PPO and GPX activities, and reduced dry weight.

B. Effect of grafting on Abiotic stress

Grafting helps in reducing the effect caused by abiotic stresses. (Rouphael *et al.*, 2008) [36] 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) [12]. Albacete *et al.* (2010) [2] found under salt stress condition the tomato cultivars grafted onto *Solanum lycopersicum* L. × *Solanum cheesmaniae* L. shows relationships to leaf xylem concentration, indole-3-acetic acid and ABA. According to Tuberosa (2012) [42] drought responsive trait affects the crop quality and yield when grafted under water stressed conditions. Nilsen *et al.* (2014) [32] found when tomato cv. “BHN602” grafted onto the tomato rootstock “JakkKung under well-water condition leads to reduction in the leaf area and growth of plant.

According to Lopez-Marin *et al.* (2017) stated when the rootstock “Atlante” was used because the genus works differently while the grafting combination of Atlante/Verset and Atlante/Herminio. Similarly, millet is crucial to check it for drought tolerance as it affects the yield and increases the goal. Penella *et al.* (2006) found the water flow responses of different pepper cultivars, especially *Capsicum annum* L. Cv. Verse and *Capsicum annuum* L. Cv. Atlante, PI-15225 and ECU973. Their gaze showed that those species validated effective osmotic adjustment under water flow conditions. This model allowed the peppers to maintain the most reliable capabilities of their photosynthetic machinery no matter the water shortage. The ability to effectively regulate osmotic flow allows those species to maintain photosynthesis and normal plant health, highlighting their potential resilience and flexibility to difficult environmental conditions.

Grafting greatly improves vegetable tolerance to temperature extremes (both heat and cold) with the help of the use of a pressure-tolerant rootstock, canopy for better water/nutrient absorption, stronger antioxidant activity, and reduced cell damage, ultimately stabilizing the boom, yield resistant to temperature and yield. vegetation. This protective effect stabilizes plant physiology, allowing for higher overall performance under harsh temperatures that would normally stunt growth or reduce fruit set in non-grafted opposite digits.

Grafting watermelon, melon, cucumber, even summer squash onto low temperature tolerant rootstocks such as interspecific hybrid between *Cucurbita maxima* Duch. × *C. moschata* Duch. or fig leaf gourd can greatly reduce the risk of severe growth inhibition caused by low soil temperatures in winter greenhouses. Cucumber grafted onto fig leaf gourd (*Cucurbita ficifolia* Bouché), an excellent rootstock even at low soil temperature, grows much faster than own-rooted cucumber or even summer squash because of the rootstock's

ability to absorb water and nutrient more efficiently at low temperatures (Tachibana, 1982) [41].

C. Effect of grafting on biotic stress

The effect of grafting on biotic stress is mainly due to the inherent resistance or tolerance of determinants on rootstocks. Resistant rootstocks can restrict access to pathogens, reduce disease spread, and enhance plant defense responses through advanced nutrient uptake, hormone signaling, and activation of systemic resistance mechanisms. Furthermore, grafting can reduce biotic stress by promoting stronger root systems and collective plant vigour, allowing flora to withstand more resistance to pollution.

According to Jang *et al.* (2012) [20], Nokkwang pepper candy potatoes grafted on PR 920, PR 921 and PR 922 traces have mounted resistance against Phytophthora disease and bacterial wilt with the highest performance rate while Phytophthoracapsicant and Ralstonia organisms have been used or new.

Attia *et al.* (2003) [6] suggested that once susceptible pepper scion (cv. Gedon) grafted on inventory flowers resistant to Rhizoctonia root rot and Fusarium wilt grown in undisturbed infested soil showed less disorder infested while in case of non-grafted plants higher infection. Grafting melons and watermelons on hybrid *Cucurbita* rootstocks has been shown to reduce the incidence of Fusarium wilt and increase yield.

Eubergine is grafted on *Solanum sisymbriifolium* proof against Verticilium wilt (Bletsos FA, 2003) [8]. Watermelon grafted on bottle gourd improves immunity against fusarium wilt which has been pronounced with the help of Lee JM, (2010) [27]. Eggplant grafting on shintosa rootstocks improves vegetative growth at low temperature has been reported by (Gao, 2008) [17].

D. Flowering and harvest period

Flowering dates are specifically inspired with the help of fruit size and harvest time. Only a few reviews are available offering specific information on the effect of grafting on flowering and harvest time. However, research on grafted crops of chickpea has shown that grafting leads to a multiplicity of female plants and promotes earlier onset of female flowering, thus contributing to advanced fruit set and harvest. Maurya *et al.* (2019) [29] explained that Shintosa was used because the rootstock, grafted behind the schedule flowered into pumpkin, bottle green, wax green and watermelon. Vegetable crops with grafting may additionally take longer to flower due to the age and maturity of the scion.

Sakata *et al.* (2007) [38] found that compared to different rootstocks, watermelon grafted onto bottle gourd induces early formation of daughter plant life. Flowering date affects fruit harvest time, which can have an instantaneous effect on sufficiency. No much record determined that would provide more information on grafting results on flowering and early. It was determined that non-grafted flowers flowered earlier than grafted plants. Suthar *et al.* (2005) [40] in brinjal the delayed flowering in grafted flowers could be due to the growth of the scion plant life being interrupted for a week almost due to grafting and prolonged vegetative growth for after flowering in grafted plants. It increases plant vigor and increases the period of low-price harvest.

Table 1: Grafting methods and rootstocks used in vegetable crops

Crop (Scion)	Common Rootstocks	Grafting Method
Brinjal	<i>Solanum torvum</i>	Tongue and cleft method
Tomato	<i>S. pimpinellifolium</i>	Tongue and cleft method
	<i>S. nigrum</i>	Tongue and cleft method
Bottle gourd	<i>C. moschata</i> , <i>luffasp</i>	Hole insertion method
Bitter gourd	<i>C. moschata</i>	Hole insertion and tongue method
	<i>Lagenaria siceraria</i>	Hole insertion method
Watermelon	<i>Benincasahispida</i>	Hole insertion and cleft method
	<i>C. melo</i>	Cleft method
	<i>Lagenaria siceraria</i>	Splice grafting
Cucumber	<i>Cucurbita moschata</i>	Hole insertion and tongue method
	<i>C. maxima</i>	Tongue method
Pak-Choi	<i>R. sativus</i> var. <i>longipinnatus</i>	Splice grafting

Table 2: Rootstocks used in vegetable crops for Biotic& abiotic stress

Crop	Common Rootstock	Purpose
Tomato	Disease-resistant hybrids, wild <i>Solanum</i> <i>S. habrochaetes</i> , <i>S. torvum</i> ,	Fusarium, bacterial wilt, vigor salinity tolerance; vigor and yield stability
Eggplant	Wild <i>Solanum</i> species	Wilt resistance
Cucumber	Squash, pumpkin, bottle gourd Shintoza (<i>C. maxima</i> × <i>C. moschata</i>)	Fusarium, cold tolerance, High temperature
Melon	Squash, figleaf gourd TZ 148 (<i>C. maxima</i> × <i>C. moschata</i>) Shintoza (<i>C. maxima</i> × <i>C. moschata</i>)	Soil-borne diseases Salinity, Mineral and water uptake
Watermelon	Bottle gourd, squash	Fusarium wilt control
Sweet pepper	<i>Capsicum annum</i>	Root-knot nematode, Phytophthora capsica

Recent innovations of Vegetable Grafting

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

- The first semiautomatic cucumber grafting system was commercialized in 1993.
- A simple semiautomatic grafting machine can produce 350-600 grafts/hour with 2 operators, whereas manual grafting techniques produce about 1,000 grafts/person/day
- A fully automated grafting robot performing 750

grafts/hour with a 90-93% success rate

1. 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.

Some robots developed for grafting vegetables Sinha *et al.* (2018)

Robots	Model	Developed by	Vegetable crops
AG1000robot	Fullyautomated	Yanmar Agricultural EquipmentCo. (Osaka, Japan) 1994	Solanaceous
ArnabatS.A	Semiautomated	Barcelona, (Spain) 2000.	Cucurbits, Solanaceous
seki'sGR800 &GR-600	Semiautomated	Helper Robotech Co., Gimhae, Korea (2004)	Solanaceous

2. Micro-grafting

In this technique of grafting, use of small part of a plant i.e. explant (< 1/1000th mm³) from meristematic tissues to eliminates the infected plants from different virus. It is used in herbaceous plants. This method is expensive that is why not used as commercial means.

3. Double grafted in tomato

In the pomato is an example of vegetable grafting. With the help of cleft grafting, tomato scion were grafted onto potato rootstock.

Points to remember during vegetable grafting

1. **Selection of rootstock and scion:** Selection of desirable and uniform size of rootstock and scion and grafting method should be practised at 2-3 true leaf stage.
2. **Compatibility:** Use of compatible rootstock and scion can increase survival percentage with low mortality of

seedlings also causes rapid callus formation which influence success and survival of grafts.

3. **Tools:** Use of grafting tools like clips, tubes, grafting blade
4. **Screening chamber:** Used for growing healthy seedlings. 60 mesh nylon net is used for covering side wall of the structure and UV resistant polythene is used for cladding of upper half.
5. **Healing of grafted plants:** It is the most critical prerequisite for vegetable grafting. Under healing chamber favourable conditions like temperature (28-29°C).RH(95%) should be maintained for around one week under partial shade condition for formation of callus at the grafting joint point.
6. **Hardening:** After callus formation at graft union point and successful union of stock and scion it's important to expose grafted plants to outside condition temporarily to harden then plants against adverse field conditions so that mortality of the grafts in field can be minimized.

Problems Associated With Vegetable Grafting:

Various problems are commonly associated with grafting and cultivation of grafted seedlings. Major problems are the efforts and technology required for the grafting operation and submit graft management of grafted seedlings for rapid recovery in 7 to 10 days. A professional can graft 1200 seedlings in steps per day (one hundred and fifty seedlings per hour), but the numbers vary with the grafting method. Similarly, the submit graft management method mostly relies on the grafting technique. Also improper management of submit grafting environment (excessive heat, excessive humidity, direct water overhead, too mild and inadequate mild). Too much light within the publish grafting environment, pushing newly transplanted plant to perform activities, including photosynthesis, that can be hard to cure and increase. Uneven aging, in adequate sanitation at all stages from seed sowing through graft plant regeneration, can promote and transmission of the disease. Expensive rootstock seeds and transplanting equipment, etc., are a major problem.

Conclusion

The importance of grafting in vegetable crops lies in its ability to improve plant adaptability, increase productivity, and sell sustainable crop production. It provides a green answer to controlling soil-borne diseases and allows farmers to address unfavorable environmental and soil conditions without over-reliance on chemical treatments. In recent years, vegetable grafting has become a crucial horticultural practice to strengthen and enhance male production. By combining high-yielding scion cultivars with viable and drought-tolerant rootstocks, grafting allows overcoming key production constraints that include salinity, drought, soil-borne pathogens, and the effects of continuous cultivation. This technique increases the use of water and nutrients, reduces the need for chemical insecticides and soil disinfectants and helps in regular yields under harsh growing environments. It is a successful application in solanaceous and cucurbit plants, highlighting its vast position in increasing vegetable production while encouraging environmentally responsible and economically feasible farming systems. Therefore, grafting is confirmed as a modern and sustainable method for assembly increasing the demand of amazing vegetable crops globally.

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