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# Exploitation of Grafting for Abiotic and Biotic Stress Management in Vegetable Crops: A Review

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

Growing vegetables is often impacted by various abiotic and biotic stresses that can hinder growth and yield. Abiotic stresses, such as salinity, water stress, and temperature fluctuations, and biotic stresses, including diseases, pests, and nematodes, pose significant threats to agriculture. Grafting, a horticultural technique, offers a promising solution to overcome these challenges. In cases of salinity stress, grafting with salt-tolerant rootstocks can limit the transport of harmful ions to the shoot and help store them in the roots, mitigating ion toxicity. Water stress, including drought and water logging, can be addressed by grafting with drought-tolerant rootstocks, which can reduce yield losses and enhance photosynthesis under adverse water conditions. Grafting can also

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improve nutrient uptake, translocation of water, and osmoregulation, thereby assisting plants in surviving under water stress. High and low-temperature stresses, which can disrupt plant metabolism, membrane stability, and growth, can also be addressed through grafting. Grafted plants with temperature-tolerant rootstocks may indirectly enhance tolerance to extreme temperatures. Additionally, grafted plants can adapt to varying temperature conditions by promoting root growth, nutrient absorption, and the production of specific compounds that protect against temperature-related damage. Heavy metal stress, which can contaminate crops and impact human health, can be alleviated by using rootstocks that control the uptake and transport of heavy metals, reducing their toxicity to plants. Furthermore, grafting can effectively combat biotic stresses. By selecting disease-resistant rootstocks, plants can be protected against soil-borne diseases, pests, and nematodes, thereby increasing yields and sustainability in agriculture.

*Keywords: Grafting; abiotic stress; biotic stress; vegetable; rootstock; yield; borne diseases; rootstocks.*

## 1. INTRODUCTION

### 1.1 What is Grafting?

"Grafting can be defined as the natural or deliberate fusion of plant parts so that vascular continuity is established between them and the resulting composite organism functions as a single plant."

**Vegetable Grafting:** Vegetable grafting is similar to grafting of fruit trees in the way that the rootstock is selected for vigor and disease resistance and the scion is selected for fruit quality and taste. They also began to graft peppers, eggplant, and melons onto more vigorous, disease- resistant root stocks.

**Rootstock: -** The working part which interacts with the soil to nourish the plant. It provides a strong root system as an absorbing organ for the plant and influences plant growth. Precocity in bearing buds, flowers, fruits, improves fruit quality and makes resistance to pest, disease, and stress.

**Scion: -** The plant part grafted onto the rootstock is usually called the scion. Scion provides above-ground plant parts like stems, branches, and leaves and increases photosynthetic activity of the plant. These provide the desired genes to be duplicated. Scion influences flowering and fruiting with maximum quality traits with the highest yield.

### 1.2 Why Grafting?

- Vegetable production is highly affected by biotic & abiotic stress
- With the ban of chemicals used (fungicides and pesticides), grafting of susceptible scion on resistant rootstocks has become an effective alternative against soil borne pathogens
- Moreover, organic cultivation of vegetable grafting eliminates the use of chemicals in disease control &eco friendly to nature

## 2. 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. Although many machines and grafting robots have been developed but manual grafting is the most popular and widely used method.

- **Mainly following grafting methods use in vegetables**
  - Cleft grafting
  - Tongue Approach/Approach Grafting
  - Hole Insertion/Top Insertion Grafting
  - Slant/ Splice grafting
  - Tube Grafting
  - Automated grafting

### 2.1 Abiotic Stress

#### 1) Salinity

**"**If the concentration of harmful salts increase at the root zone of a plant to such an extent that plant growth is adversely affected, this situation is called Salinity". It is one of the most important abiotic stresses, hampering the plant growth and development. The grafting process itself has no obvious effect on salt tolerance, but it is due to the use of salt tolerant rootstock. Plants grafted onto different rootstocks, respond more or less differently to salinity.Grafting can alleviate ion toxicity by limiting the transport of $Na^+$ to the shoot while storing it in the roots, which is typical tissue tolerance mechanism. Sanwal*et al*. [1]

observed that maximum plant height (67.35, 58.62, 52.82 cm) and fruit yield (2301.87, 1781.70, 1132.25 g/plant), higher amount of $K^+$ content in roots (17.84, 15.48 & 11.24mg $g^{-1}$ DW) and shoots (13.46,12.28 & 10.08 mg $g^{-1}$ DW) with lower $Na^+$ content root (4.82, 7.32 & 10.04 mg $g^{-1}$ DW) shoot (4.18, 4.96 & 8.43)incv. Kashi Aman grafted on salt tolerant eggplant rootstockIC-111056 under control and saline (ECiw 6 and 9 dS $m^{-1}$) condition. Yanyan *et al*. [2] concluded that maximum growth parameters likes plant height (57.8 cm), stem diameter(3.6 mm), dry weight (3.9 g) and number of leaves (7.8) was obtained when W(Jingxin no. 2) grafted on P2 (Kaijia no. 1) under saline condition (200 mmol·$L^{-1}$). El-Kafafi et al [3] proved that grafted Cantaloupe plants had a better performance than the non-grafted ones especially grafted onto Star rootstock. Aydin [4] demonstrated the positive effects of grafting with tolerant rootstocks or scion-stock interactions on the yield and fruit traits of tomatoes. Under saline conditions, plants grafted onto wild rootstocks exhibited higher levels of N, P, K, Ca, Mg, S, Mn, Fe, Zn, and B in their leaf tissues and lower levels of Na and Cl compared to ungrafted plants. The biochemical and physiological analyses indicated that *S. pimpinellifolium* and *S. habrochaites* have inherited salt tolerance from their genetic backgrounds. These wild tomato genotypes can be utilized as rootstocks in tomato breeding programs to develop salt-tolerant varieties or in grafting techniques under saline irrigation conditions.

**2) Water Stress:**

**I) Drought:** Grafting is considered to be an environmentally friendly technique for reducing the yield losses caused by drought.Grafting has been identified as an effective tool for WUE in water stress situations.Grafted plants using tolerant rootstocks, which improved photosynthesis under water stress**.** The increase of nutrient uptake in drought resistance grafting combinations can be related to the considerable soil exploration resulting from the deep and vigorous root system. Al-Harbiet al. [5] observed that maximum stem diameter (14.60, 14.87 mm), plant height (213.2, 219.3 cm), shoot and root fresh weight (1150.3, 1137.7 & 51.83, 51.67 g) were recorded in grafted plant at 100% ETc water stress level followed by the treatment of grafted plants under moderate water stress (80% ETc).Rouphael et al. [6] concluded that in both growing seasons, the seasonal ET of grafted and ungrafted plants decreased with increasing water deficit, whereas yield water use efficiency increased under water stress conditions. The WUEy in grafted plant grown at 0.5 ET increased 14.1kg $m^{-3}$ and 15.0kg $m^{-3}$respectively, compared with those grown under a full irrigation regime. Coskun [7] concluded that under drought stress conditions, non-grafted plants had an average of 6 leaves, while grafted plants had between 6 and 13.16 leaves. The average leaf fresh weight was higher in grafted plants (7.56–9.84 g) compared to non-grafted plants (5.7 g). Leaf chlorophyll content (SPAD) in non-grafted plants was 24.43, whereas in grafted plants, it ranged from 37.83 to 55.36. Additionally, the malondialdehyde (MDA) concentration decreased from 5.66 in non-grafted plants to between 3.23 and 4.36 in grafted plants. The genomic template stability (GTS) rate was found to be 64.1% in the non-grafted treatment group.

**II) Excess Soil Moisture or Flooding:** It refers to a condition where water is present in excess amount than its optimum requirement. Its excess creates an anaerobic situation in rhizophere due to which a plant experience stress. Kumar et al. [8] observed that overall percentage of long styled flowers was observed to be higher in grafted SR pink to the level of 38.04, while much higher percentage of such flowers (43.78) was noticed in grafted SR purple. Consequently, the presence of higher per cent of medium styled flowers in non-grafts was observed, which was at par with grafts of SR pink in 2014 and 2015. But, results of pooled analysis showed significantly higher number of medium styled flowers (54.04%) in non-grafts compared to grafts (51.16%) in SR pink. Likewise, Maximum yield per ha was obtained when *Surati Ravaiya* grafted on *Solanum torvum* and also investigated that significant increase in survival percentage of Surati Ravaiya pink and purple 96.94 and 97.50, respectively having 21.60 and 13.22 percent more plant stand compared to their nongrafted counterparts. The mean plant height among different treatments was observed higher in grafted SR purple (85.71 cm) as well in grafted SR pink (81.46 cm). Both the cultivars responded differently to stem diameter upon grafting. Although, grafted plants in these cultivars presented higher stem diameter, but significantly higher stem diameter of 1.88 cm was shown by only grafted SR pinkfollowed by SR purple.Bhatt *et al.*[9] revealed that maximum number of fruits (41), yield per plant (1262 g) when Arka Neelkanth grafted on Arka Rakshakunder flooding condition for 6 days while, highest leaf water potential in AR/AK.

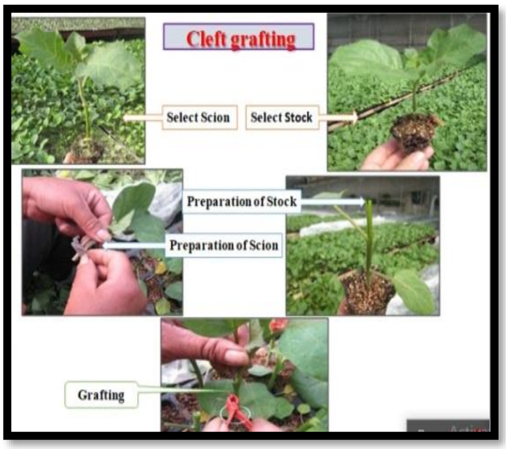


**Fig. 1. Cleft grafting**

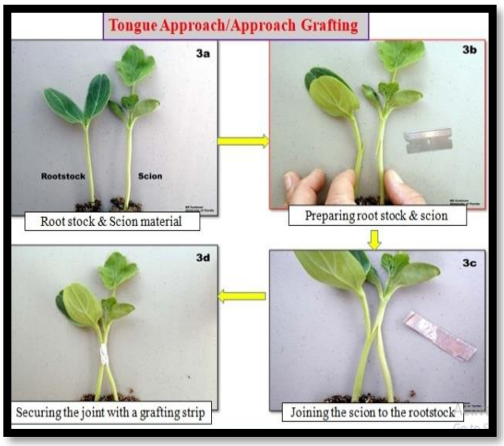


**Fig. 2. Tongue approach/approach grafting**

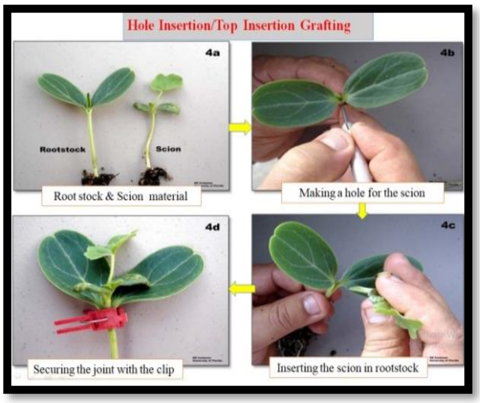


**Fig. 3. Hole insertion/top insertion grafting**

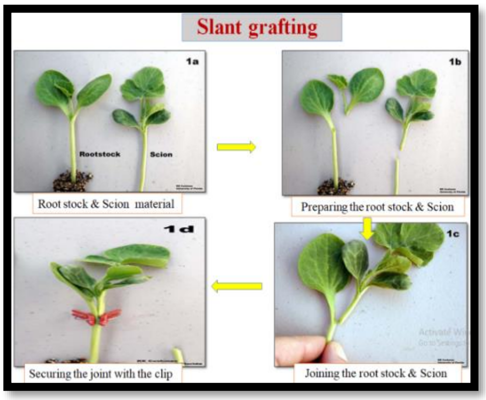


**Fig. 4. Slant/ splice graftingtube grafting**

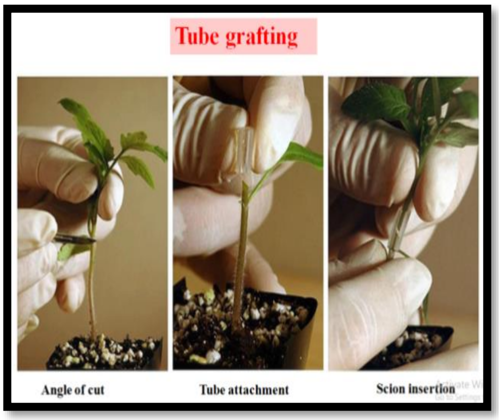


**Fig. 5. Tube graftingfig**


**Fig. 6. Automated grafting**

### 3) Temperature stress

**I) Low temperature Stress:** Gao et al. [10] found that grafting with the 'Hiranasu' rootstock ($T_2$) increased Plant height (18.26 cm), Stem diameters (0.36 cm), Shoot fresh weight (20.46 g/plant) and Root fresh weight (6.76 g/plant).There was no difference in the stem diameters of the eggplant seedlings and They also concluded that the chlorophyll content of young eggplant leaves decreased gradually with low temperature stress. On the 9th day of growth, the chlorophyll contents of the control, $T_1$ and $T_2$ were 0.876, 0.901, and 0.960 mg·g$^{-1}$FW, which were 68.8%, 74.1% and 87.4% of that of the pre-treated samples, respectively. After recovery, the chlorophyll contents of the eggplant seedlings increased, but the recovery capacity of $T_2$ was most rapid.

**II) High Temperature Stress:** Abdelmageed and Gruda et al. [11] observed that leaf area and the fresh weights of the leaves and stem for both T/E and T/T were significantly higher than that from 'UC 82-B' at the high temperature regime. This might be attributed to the ability of these plant types to produce more assimilates than the heat sensitive cv. 'UC 82-B'. Furthermore, it is interesting that grafted T/T plants showed better vegetative parameters compared to the heat tolerant cv. 'Summerset' and also concluded that the leakage of electrolytes through the plasma lemma results in reduced photosynthetic and mitochondrial activity of plant cells and there was a significant difference between the grafted and non-grafted plants; grafted plants showed lower electrolyte leakage than in non-grafted ones, irrespective of the growth temperature. Minimum leakage of electrolytes recorded with heat sensitive UC 82-B scion of tomato grafted on heat tolerant eggplant cv. Black Beauty.

**4) Heavy metals stress**

**"**The most common heavy metal contaminants are Cd, Cr, Ni, Hg, Pb and generally produce common toxic effects on plants.According to the monitoring results of the Agricultural Environment Monitoring Station of the Ministry of Agriculture, cadmium pollution in sewage irrigation area is the largest, reaching 38.5 million hectares, accounting for 56.9% of the excess area of heavy metal and cadmium exceeding standard rate of agricultural products produced in sewage irrigation area was 10.20%" [12]. **"**A survey in Japan showed that approximately 7% of eggplant fruits contain cadmium (Cd) concentrations above the international limit for fruiting vegetables**.** Cadmium and its compounds are highly toxic and exposure to this metal may cause cancer. He observed that among the five treatments, the roots and rootstock stems cadmium content under treatment S. melongena grafted with *S. alatum* reached the maximum, which were 33.87% ($p < 0.05$), 29.48% ($p < 0.05$), 44.48% ($p < 0.05$), 20.19% ($p < 0.05$) and 266.13% ($p < 0.05$), 18.85% ($p < 0.05$), 19.96% ($p < 0.05$) and 87.96% ($p < 0.05$) higher than the treatments of ungrafted, *S. melongena* grafted with *S. diphyllum,S. melongena* grafted with *S. nigrum* and *S. melongena* grafted with *S. nigrumhumile*. The cadmium content of root and rootstock stem of S. melongena grafted with *S. alatum* were higher than control, but lower than other three treatments, and scion stems, scion leaves and whole scion cadmium content of the treatment were lowest. The cadmium content of scion stem and scion leaves for the treatments of ungrafted, *S. melongena* grafted with *S. diphyllum, S. melongena* grafted with *S. nigrum* and *S. melongena* grafted with *S. alatum* were significantly higher 330.69% ($p < 0.05$), 134.98% ($p < 0.05$), 120.46% ($p < 0.05$), 53.14% ($p < 0.05$) and 126.24% ($p < 0.05$), 204.46% ($p < 0.05$), 196.70% ($p < 0.05$), 151.32% ($p < 0.05$) than *S. melongena* grafted with *S. nigrumhumile*, respectively. The order of whole scion cadmium content was ranked in the following order: *S. melongena* grafted with *S. nigrum*> *S. melongena* grafted with *S. diphyllum*>ungrafted> *S. melongena* grafted with *S. alatum*>*S. melongena* grafted with *S. nigrumhumile"* [12].

## 3. BIOTIC STRESS

**1. Disease:** Shalabyet al. [13] concluded that "minimum disease Incidence (20.8%& 16.6 %) Days after Transplanting were recorded with VSS-61 F1 rootstock in both locations respectively, which significantly at par with Ferro and Super Shintoza rootstocks". Kausik et al. [14] observed that "maximum percent disease reduction was recorded in USVL482-PMR (*Lagenariasiceraria)* rootstock and followed by two rootstock of bottle gourd USVL482351- F1 and USVL351-PMR.Grafting watermelon on resistant rootstocks may help mitigated the effect of powdery mildew on susceptible scion seedling".

**2.Insect Pests:** Kumar et al. [15] observed that the tolerance of grafted plants to shoot and fruit borer was indicated by significantly less infestation while grafted *Surati Ravaiya* Purple recorded 17.86%. The overall infestation of 22.79% was observed in grafted plants of *Surati Ravaiya* Pink compared to 32.72% and 30.47% in normal plants of the cultivar.

**3. Nematode Tolerance:** Dhivya and Sivakumar [16]revealed that "all the rootstocks and scions developed characteristic galls caused by *M. incognita*. Among the rootstocks and scions, significant differences were noticed on number of galls per 10 g of root, number of egg masses per g of root and number of females per g of root. *S. sisymbrifolium* (4.45, 1.30 and 1.70) followed by

*Physalisperuviana* (4.87, 1.43 and 1.87) and *S. torvum* (5.51, 1.87 and 2.10) recorded the lowest number of galls, number of egg masses and number of females per g of root, respectively and showed resistant reaction". Sharma *et al.* [17]investigated "sixteen different rootstocks were screened for their resistance to *Meloidogyne incognita.* Out of total rootstocks, one rootstock of tomato 'Green Gourd' with RKI-1, one brinjal ' VI-034845' with RKI-5 and 'VI-047335' were found moderately resistant with RKI-16, two chilli rootstocks ' PI-201232' with RKI-2 and 'AVPP0205' with RKI-3 were found resistant to root knot nematode". Punitha [18]concluded that "among the seven cucurbitaceous species rootstocks and two cucumber scions screened against the incidence of RKN, the highestshoot length were recorded in fig leaf gourd (253.80 cm) and NS 408 hybrid scion(112.55 cm) followed by African horned cucumber, the shoot weight (45.36 g), shoot dry weight (5.03 g), root fresh weight (2.83 g) and root dry weight (0.45 g) were significantly higher in winter squash and NS 408 hybrid scion(22.50, 2.89,0.83, 0.10 g)followed by pumpkin and maximum root length was found in Pumpkin rootstock followed by winter squash with NS 408 hybrid scion (24.76 cm )".

## 4. CONCLUSION

In conclusion, grafting offers a multifaceted approach to enhance plant resilience against a wide range of environmental and biological challenges. Selecting the appropriate rootstocks tailored to specific stressors can significantly contribute to improving crop productivity and ensuring food security in a changing climate and evolving agricultural landscape.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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