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Vegetable Grafting: A Sustainable Strategy for Management of Biotic and Abiotic Stresses in Vegetable Production

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Vegetable production is increasingly threatened by soil-borne diseases, erratic climatic conditions, declining soil health and the growing need to reduce chemical pesticide use. These challenges demand innovative and sustainable production practices that can maintain productivity while protecting the environment. Vegetable grafting has emerged as one such promising technology by combining a vigorous, disease-resistant rootstock with a high-yielding commercial scion. Vegetable grafting helps crops withstand diseases and environmental stresses while maintaining productivity and fruit quality. Today, grafting is widely adopted in crops such as tomato, brinjal, cucumber, watermelon, melon and pepper, where it helps improve plant health, yield and resource-use efficiency. Besides reducing dependence on pesticides, grafting contributes to climate-resilient vegetable production by helping crops withstand drought, salinity, flooding and temperature extremes. This article explains the concept of vegetable grafting, its role in managing biotic and abiotic stresses and its growing importance in sustainable horticulture using practical examples from vegetable production systems.

Introduction

Fresh vegetables are indispensable for a healthy life, supplying essential vitamins, minerals, fibre and antioxidants while contributing to food and nutritional security. As awareness of nutritious food increases and the population continues to grow, the demand for fresh, safe and high-quality vegetables is rising steadily. However, vegetable production is becoming increasingly difficult because of climate change, declining soil fertility and the rising incidence of pests and diseases. Among the various production constraints, many soil-borne pathogens survive in the soil for several years, infecting successive crops and making disease management extremely difficult. Diseases such as Fusarium wilt, bacterial wilt, Verticillium wilt and root-knot nematodes can cause severe yield losses, especially under continuous vegetable cultivation. In addition, environmental stresses such as drought, salinity, flooding and extreme temperatures weaken plants, making them more susceptible to disease and reducing their productivity. Although chemical pesticides and other management practices help manage these problems, their repeated use increase production costs, affects soil health and contributes to environmental pollution and concerns over pesticide residues in vegetables.

To overcome these challenges, more growers are adopting vegetable grafting, a simple yet effective technique that joins a disease-resistant root system (rootstock) with a high-yielding fruit-producing variety (scion). This approach enables vegetable crops to better withstand both biotic and abiotic stresses while maintaining yield and fruit quality. Vegetable grafting was first adopted in watermelon to control Fusarium wilt and other soil-borne diseases. Since then, it has become widely practiced in crops such as tomato, brinjal, cucumber, watermelon, melon and pepper. Today, vegetable grafting is recognized as a sustainable and climate-smart technology. It improves plant resilience, reduces crop losses, enhances resource-use efficiency, minimizes dependence on chemical pesticides and supports environmentally friendly vegetable production (Lee, 1994; Lee and Oda, 2003; Kubota et al., 2008).

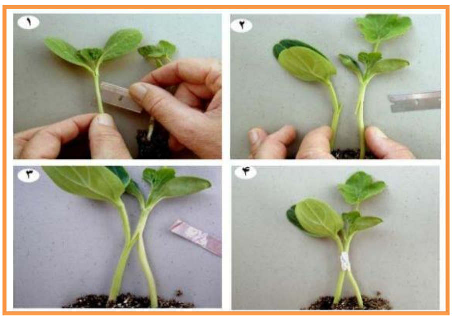
Vegetable Grafting

Grafting is the process of joining two compatible plants so that they grow as one. The upper portion, known as the scion, is selected for its fruit quality, yield, taste and market preference, while the lower portion, called the rootstock, is chosen for its strong root system and resistance to diseases or environmental stresses. The success of grafting lies in combining the best qualities of both plants. The scion continues to produce the fruits preferred by consumers, while the rootstock quietly performs the difficult task of absorbing water and nutrients, resisting soil-borne pathogens and helping the plant tolerate adverse growing conditions. Unlike plant breeding, which may take several years to develop a new resistant variety, grafting can provide a relatively rapid approach for improving tolerance to specific biotic and abiotic stresses without altering the genetic identity of the scion. Farmers can continue cultivating their favourite commercial hybrids simply by grafting them onto suitable rootstocks. This flexibility has made grafting has become an increasingly important technology in modern vegetable production. The practice began in Japan and Korea during the 1920s when watermelon was grafted onto pumpkin rootstocks to overcome Fusarium wilt. Since then, the technology has expanded rapidly across Asia, Europe and North America. Today, millions of grafted seedlings are produced annually for crops such as tomato, cucumber, melon, watermelon, pepper and brinjal because of their superior performance under stressful conditions (Kubota et al., 2008). In India, grafting is steadily gaining recognition, particularly in regions where vegetable cultivation is affected by bacterial wilt, nematodes and waterlogging. Research institutions and private nurseries have developed compatible rootstocks for several vegetable crops, enabling farmers to improve productivity while reducing dependence on chemical pesticides. As awareness increases, grafting is expected to become an integral part of sustainable and protected cultivation systems.

Grafting Methods

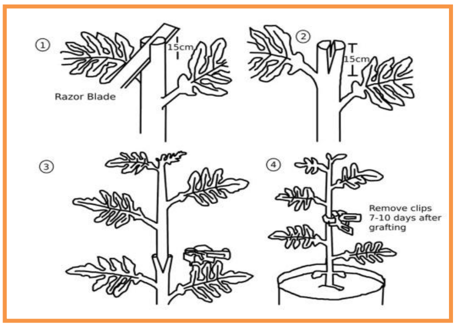
1. Splice Grafting

In splice grafting, the rootstock and scion should have nearly similar stem/hypocotyl diameter. First, the growing point of the rootstock is removed by making a single smooth diagonal cut, generally at about 45°, usually below the cotyledons. The scion is then cut at the same angle and at a position where its stem diameter matches that of the rootstock. The two cut surfaces are immediately brought together, ensuring close contact between the cut surfaces and alignment of the vascular tissues and the union is secured using a silicone/plastic grafting clip. The grafted seedlings are subsequently transferred to suitable healing conditions. In cucurbits, the one-cotyledon splice method is also commonly used, in which one cotyledon is retained on the rootstock while the growing point and the other cotyledon are removed.



2. Cleft Grafting / Wedge Grafting

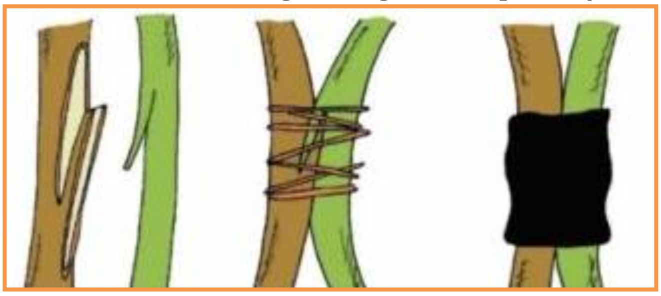
In cleft grafting, the **rootstock is generally cut horizontally,** and a vertical slit is made in the centre of the cut stem. The scion is prepared by making **two slanting cuts at its basal end to form a wedge,** usually about 1 cm long. The wedge-shaped scion is then carefully inserted into the slit of the rootstock so that the vascular tissues of at least one side are in close contact. The graft is secured using a grafting clip and placed



under suitable healing conditions. This method is particularly useful when the **rootstock is somewhat thicker than the scion,** because the wedge can be positioned to obtain good vascular contact.

3. Tongue Approach Grafting

In tongue approach grafting, the rootstock and scion seedlings are grown separately but positioned close to each other. A downward-sloping cut is made on the rootstock stem, and a corresponding upward-sloping cut is made on the scion stem. A short additional cut is then made into each sloping surface to create interlocking tongue-like structures. The two seedlings are brought together so that the tongues interlock and the cut surfaces have close contact. The union is secured with a grafting clip. Unlike splice grafting, both the rootstock and scion remain connected to their own roots during the initial healing period, which reduces water stress. After the graft union becomes strong, the scion is gradually or completely separated from its original root system, and the unwanted rootstock shoot is removed.

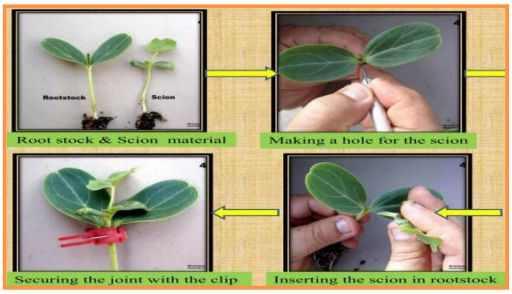


4. Approach Grafting

Approach grafting differs from splice and cleft grafting because both the rootstock and scion remain attached to their own roots during graft union formation. The two seedlings are first positioned side by side. A shallow, matching portion of the stem is removed from each plant, usually by making slanting cuts through part of the stem rather than completely severing it. The exposed surfaces are brought into close contact and secured with a clip or grafting tape. The plants are maintained under favourable conditions until the vascular connection becomes strong. After successful union formation, the scion stem is cut below the graft union to eliminate its original roots, while the rootstock shoot above the union is removed.

5. Hole-Insertion Grafting

In hole-insertion grafting, the rootstock is prepared by removing the growing point and making a **small hole in the hypocotyl/stem** using a suitable grafting tool. The scion is cut appropriately at its basal end and inserted into the hole so that the tissues of the rootstock and scion are in close contact. The scion is then supported in position and the grafted plant is maintained under suitable healing conditions. This method is particularly useful in cucurbit grafting because the scion can be inserted into the rootstock without requiring a large split in the rootstock stem.



Grafting Process

Selection of Compatible Rootstock & Scion

Select healthy, vigorous and compatible rootstock and scion seedlings. Rootstock should possess desirable resistance/tolerance traits, while the scion should be the desired commercial cultivar.

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Sowing & Synchronization

Rootstock and scion seeds are sown at suitable intervals so that both seedlings reach the appropriate grafting stage at nearly the same time.

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Selection of Suitable Seedlings

Choose disease-free, actively growing seedlings with well-developed stems and similar size. Seedlings should be free from mechanical injury and pest damage. The stem diameter of the rootstock and scion should be as similar as possible to ensure proper contact between the cut surfaces and vascular tissues.

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Cutting of Rootstock & Scion
Using a clean and sharp grafting blade, make smooth and matching cuts according to the selected grafting method. Avoid crushing or splitting the stem.
↓
Joining of Rootstock & Scion
Place the cut surface of the scion carefully against the cut surface of the rootstock. Proper alignment of the vascular tissues is essential for successful graft union formation.
↓
Securing with Grafting Clip
Hold the grafted portions firmly using a suitable grafting clip, tape or other support to prevent displacement during healing.
↓
Healing under Controlled Conditions
Keep grafted seedlings in a protected healing chamber with high humidity, moderate temperature and reduced light. These conditions minimize water loss and promote graft union formation.
↓
Acclimatization
Gradually reduce humidity and increase light and ventilation after the graft union has formed. Sudden exposure to direct sunlight and dry conditions should be avoided.
↓
Hardening of Grafted Seedlings
Expose grafted plants gradually to normal nursery conditions and reduce irrigation slightly before transplanting. This improves their ability to withstand field conditions.
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Transplanting
Transplant healthy grafted seedlings into the main field after adequate hardening. Keep the graft union above the soil surface to prevent scion rooting and maintain the benefits of the rootstock

Flow chart of grafting process

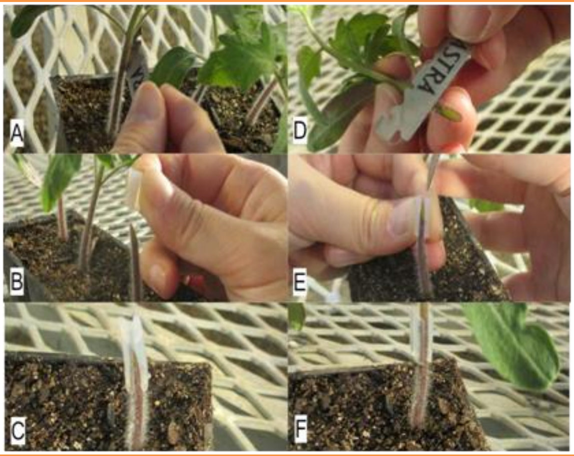
Role of Grafting in Managing Biotic Stress

Soil-borne diseases are among the most serious constraints in vegetable production because the pathogens survive in the soil for several years and infect crops through their roots. Unlike foliar diseases, they cannot be controlled effectively with repeated sprays once the roots are infected. Diseases such as bacterial wilt, Fusarium wilt, Verticillium wilt, *Phytophthora* root rot and root-knot nematodes often cause heavy crop losses, particularly in fields where vegetables are cultivated continuously. Vegetable grafting offers a practical and sustainable solution by replacing the susceptible root system of commercial cultivars with a vigorous and stress-tolerant rootstock (Lee and Oda, 2003; Kubota et al., 2008).

Table 1: Rootstock–Scion Combinations and Benefits of Grafting in Major Vegetable Crops

Crop	Common rootstock(s) used	Major target diseases / problems	Major benefits of grafting	References
Tomato	*Solanum habrochaites, S. peruvianum* and other vigorous wild *Solanum* rootstocks	Bacterial wilt, Fusarium wilt and other soil-borne diseases	Vigorous root system restricts pathogen damage; improves water and nutrient uptake; maintains flowering and fruiting; enables good yield even in wilt-infested soils	Lee and Oda, 2003; Rivard and Louws, 2008
Brinjal	*Solanum torvum*	Bacterial wilt, root-knot nematodes	Provides a vigorous and disease-tolerant root system; improves plant survival and growth; maintains fruit size, shape and quality of the commercial scion; increases marketable yield	Lee and Oda, 2003; King et al., 2010

Watermelon	Bottle gourd (*Lagenaria siceraria*); interspecific squash (*Cucurbita maxima* × *C. moschata*)	Fusarium wilt and other soil-borne problems	Reduces wilt damage; improves water and nutrient uptake; maintains vine vigour; increases yield and performance in wilt-infested fields	Lee and Oda, 2003; Davis *et al*., 2008
Muskmelon	Vigorous squash/pumpkin rootstocks	Fusarium wilt and other soil-borne diseases	Provides a resistant and vigorous root system; supports continuous growth until harvest; reduces losses in disease-infested soils	Davis et al., 2008
Cucumber	Figleaf gourd (*Cucurbita ficifolia*); interspecific squash rootstocks	Fusarium wilt, root diseases and root-knot nematodes	Improves early establishment; develops a larger and efficient root system; enhances plant vigour and reduces damage from soil-borne pathogens	Lee and Oda, 2003



Splice grafting in tomato


Hole-insertion grating in cucurbits


Wedge grafting in brinjal

Role of Grafting in Managing Abiotic Stress

Besides managing soil-borne diseases, grafting has become an effective strategy for improving the tolerance of vegetable crops to abiotic stresses such as drought, salinity, flooding and temperature extremes. Instead of relying on the sensitive root system of commercial cultivars, grafting uses rootstocks that are naturally adapted to these adverse conditions, enabling plants to maintain better growth and yield under stress (Lee and Oda, 2003; Schwarz et al., 2010). Watermelon grafted onto interspecific squash (*Cucurbita maxima* × *C. moschata*) or bottle gourd (*Lagenaria siceraria*) has produced higher marketable yields under limited irrigation than non-grafted plants (Davis et al., 2008). Similarly, cucumber and melon are grafted onto figleaf gourd (*Cucurbita ficifolia*) or squash rootstocks, which improve their performance under drought and saline conditions (Colla et al., 2010). In tomato, grafting onto brinjal (*Solanum melongena*) or wild tomato-derived rootstocks enhances plant survival in poorly drained and waterlogged soils, while bitter gourd grafted onto luffa (*Luffa cylindrica*) rootstock has shown better tolerance to temporary flooding (Lee and Oda, 2003). Grafted vegetables have also been reported to perform better under temperature extremes by maintaining flowering, fruit set and yield stability (Schwarz et al., 2010). These examples highlight that grafting is not only a disease-management technique but also a practical climate-resilient technology that helps vegetable crops sustain productivity under challenging environmental conditions.

Beyond biotic and abiotic stress management

- **Higher and stable yields:** Grafted vegetables often produce higher marketable yields, particularly under stress-prone environments (Kubota et al., 2008).
- **Extended harvesting period:** Healthier plants remain productive for a longer duration, allowing repeated harvests and increased overall production.
- **Maintained fruit quality:** Suitable rootstock–scion combinations preserve fruit size, shape, colour, taste and market acceptability.
- **Reduced pesticide dependence:** Better tolerance to soil-borne diseases lowers the need for repeated pesticide applications, supporting safer vegetable production.
- **Improved profitability:** Higher yields, longer crop duration and reduced crop losses increase farmers' returns, making grafting an economically viable technology.
- **Supports sustainable agriculture:** Grafting integrates well with Integrated Pest Management (IPM), protected cultivation and climate-smart vegetable production, contributing to environmentally friendly farming practices.

Challenges and Future Prospects

Although vegetable grafting offers several advantages, its wider adoption is still constrained by the high cost of grafted seedlings, the need for skilled labour and the availability of compatible rootstock–scion combinations. Successful grafting also requires proper nursery management and healing facilities to ensure high survival of grafted plants. In India, the limited availability of quality grafted seedlings and awareness among farmers remain major challenges. However, with increasing concerns over climate change, soil degradation and the demand for safe and sustainable vegetable production, the scope for grafting is expanding rapidly. Continued research on improved rootstocks, establishment of specialized nurseries and farmer training programmes will further promote the adoption of grafting, making it an important technology for climate-resilient and sustainable vegetable cultivation.

Conclusion

Vegetable grafting has emerged as an effective and sustainable technology for improving vegetable production under both biotic and abiotic stress conditions. By combining high-yielding commercial varieties with suitable rootstocks, grafting helps reduce losses from soil-borne diseases, enhances tolerance to environmental stresses and ensures stable yields without compromising fruit quality. Although the technology requires skilled nursery management and compatible rootstocks, its long-term benefits in terms of productivity, reduced pesticide use and sustainable cultivation outweigh the initial investment. As climate change continues to challenge vegetable production, grafting is poised to play an increasingly important role in building resilient and profitable horticultural systems.

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