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Grafting in Vegetables: A Novel Technology to Augment Sustainable Vegetable Production

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Grafting is a technique typically employed in vegetable crops to increase yield and profitability, improve resistance to biotic stresses and tolerance to abiotic stresses. Grafting is a technique in which a scion (the above-ground part, chosen for desirable fruit traits) is joined onto a rootstock (chosen for its vigour, stress or disease tolerance) so that the two grow as one plant. In order to prevent *Fusarium* wilt, watermelon (*Citrullus lanatus* L.) plants were grafted onto bottle gourd (*Lagenaria siceraria* L.) in Japan in the late 1920s, marking the first documented usage of vegetable grafting (Kawaide, 1985). Grafting has been used all over the world since then. Grafted seedlings are used in watermelon-growing areas in Japan and Korea. Grafting can be a useful technique to handle a variety of abiotic challenges including drought, heat, heavy metal toxicity, salinity and nutrient deficiencies or toxicity, in addition to reducing biotic stress from root-knot nematodes and soilborne fungus. Grafting is mostly utilized in protected horticulture to increase vegetable crop yield and resource efficiency. Establishing appropriate grafting techniques and robust rootstock development through breeding are prerequisites for the adoption of grafting.Even though grafted seedlings have advantages, not all vegetable species can be grafted since grafting success depends on a variety of criteria, including genetic background, growth characteristics, anatomy and physiological and biochemical aspects. Solanaceae family in general (Tomato and Brinjal in particular) and Cucurbitaceae family in general (Watermelon, Melon and Cucumber in particular) are among the vegetable crops that are frequently and profitably grafted.

Purpose of Vegetable Grafting

Vegetable grafting serves several goals, including increasing plant vigour, influencing sex expression (Mibus *et al.,* 2000), developing resistance to soil-borne diseases and pests, improving yield and quality traits and gaining tolerance to abiotic stresses. These goals can all help reduce the need for fertilizers and agrochemicals (Lucas *et al.,* 2017).

Important Pre-requisites for Transplanting Vegetables Grafts

Choosing The Appropriate Scion or Rootstock: Choose a scion with the same diameter as the desired rootstock. The ideal time to graft is between two and three genuine leaf stages.

Graft Compatibility: Even at later stages of growth, a compatible rootstock and scion reduce the mortality rate. Vascular bundles are formed as a result of the quick callus formation that occurs between the scion and rootstock.

Grafting Tools: Grafting blades, tubes, pins, and clips are often used tools for grafting.

Screening House: Before grafting, seedlings are grown in a screening house. 60-mesh nylon net should be used in its construction. To stop UV radiation from penetrating, place a separate UV-resistant polyethylene covering over the upper half of the structure and arrange a double door.

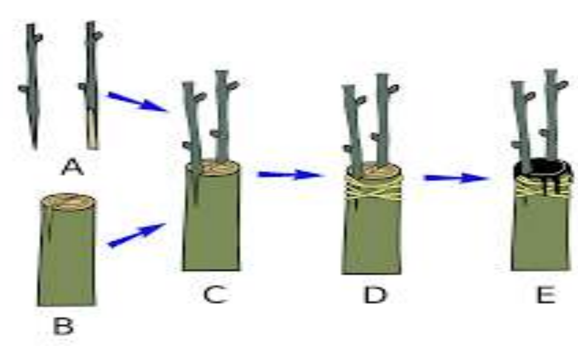
Healing Of Grafts: Graft healing is essential for creating the ideal environment for grafted seedlings to develop calluses. To encourage callus formation at the union, the healing chamber should be kept at 28 to 29˚C with 95% relative humidity for five to seven days in a slightly shaded area (dark for one to two days). By lowering transpiration, maintaining high humidity, maintaining the ideal temperature and reducing light intensity, it aids in the creation of better graft union. The primary goal is to establish a suitable environment by regulating humidity and temperature.

Acclimatization of The Grafted Plants: To avoid leaf burning and wilting, plants may be placed under a clear plastic cover or greenhouse or mist chamber once the callus has developed and the injured areas have healed.

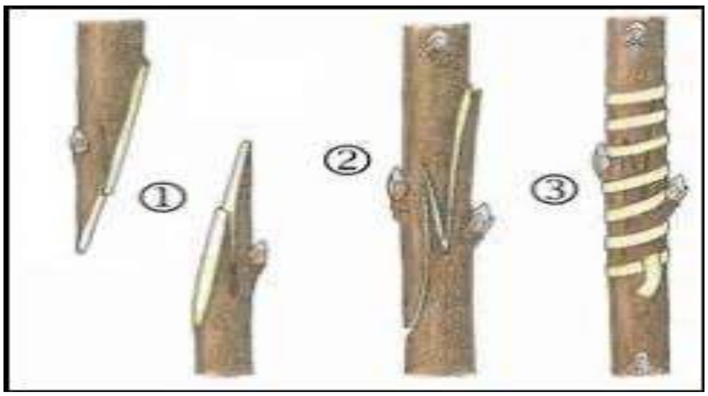
Different Grafting Methods used in Vegetable Grafting

The crop, the farmer's expertise, personal preference, the quantity of grafts needed, the goal of grafting, labour availability and the availability of infrastructure and machinery all influence the choice of grafting technique. The most common and extensively utilized technique is hand grafting, despite the development of numerous machines and grafting robots.

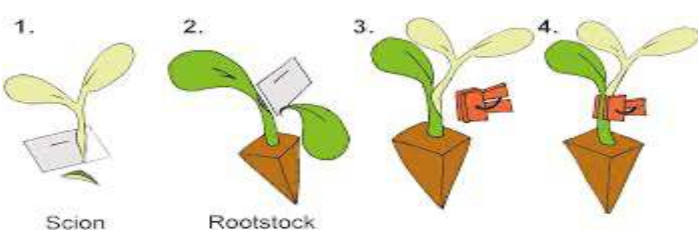
(a)Cleft Grafting: Another name for it is wedge grafting or apical grafting. Here, scion plants with one to three true leaves are clipped, and the lower stem is trimmed at an angle to create a tapered wedge. After the scion is placed into the split, a clip is inserted to allow the scion and rootstock to come into contact (Johnson *et al.,* 2011). The most common usage of this technique is in solanaceous crops.



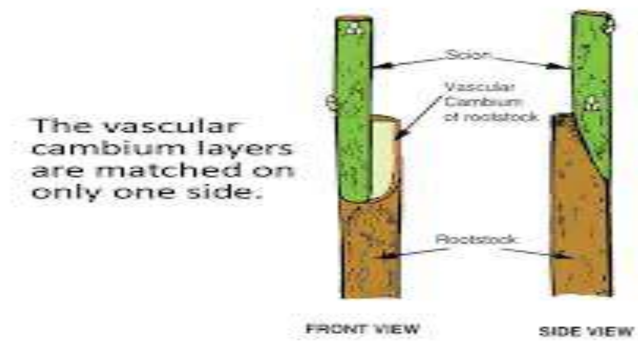
(b) Tongue/Approach Grafting: For this grafting, the rootstock and scion materials are of equal size. Therefore, scion seeds are placed five to seven days before rootstock seeds in order to achieve a consistent size. Farmers and small nurseries utilize this approach the most since it is labour-intensive and takes up more room, but the seedling survival rate is good. Rootstocks with hollow hypocotyls are not suitable for this technique.



(c) Hole Insertion/Top Insertion Grafting: This is the most widely used technique for cucurbits, and it prefers rootstock with hollow hypocotyls. Because watermelon seedlings are smaller than bottle gourd or squash rootstock, this technique is recommended for producing grafted watermelon seedlings. Up until transplanting, this technique requires an ideal temperature of 21–36˚C. Compared to the tongue grafting technique, this procedure yields a stronger union and vascular connection, which is why it is so widely used in China.



(d) Splice Grafting/ Tube Grafting / One Cotyledon Splice Grafting: Commercially graded transplant producers and growers are the ones who employ this technique the most. It can be done manually or with machinery on the majority of vegetables. Cucurbits and other solanaceous vegetable crops are commonly grown using this technique.



(e) Pin Grafting: Splice grafting and pin grafting are comparable. To maintain the grafted position, specifically made pins are utilized in place of grafting clips.

Figure 6: Pin grafting position specially designed pins are used.

To achieve a higher success rate for the grafting procedure, newly grafted grafts must be properly cared for. In order to prevent (95%) water loss, humidity should be maintained. If the scion loses water during the first two days, it may wilt, and the grafting operation may fail. To improve humidity, reduce light intensity, and accelerate the healing process, grafted transplants should be covered with black plastic sheeting for five to seven days following grafting.

Table 1: Recommended techniques of grafting and rootstocks in vegetable crops

Plant (Scion)	Grafting Technique	Rootstock
Watermelon	Slice grafting, cleft technique and top insertion	*Lagenaria siceraria, Cucurbita moschata, Cucurbita melo, Cucurbita moschata × Cucurbita maxima, Benincasa hispida*
Cucumber	Top insertion and Tongue grafting	*Cucurbita maxima, Cucurbita moschata*
Bottle gourd	Top insertion and Tongue grafting	*Luffa sp., Cucurbita moschata*
Bitter gourd	Top insertion and Tongue grafting	*Lagenaria siceraria, Cucurbita moschata*
Brinjal	Tongue and Cleft grafting	*Solanum khasianum, Solanum sisymbriifolium, Solanum torvum*
Tomato	Tongue and Cleft grafting	*Solanum nigrum, Solanum lycopersicon, Solanum pimpinellifolium*

Survival Rate and Compatibility with Grafts

The quality of fruit borne on the scion is influenced by rootstocks for a variety of reasons. The most evident is rootstock/scion incompatibility, which causes the scion to grow either excessively or insufficiently, thereby reducing the flow of nutrients and water through the grafted union and ultimately resulting in wilting. However, rootstock/scion pairings should be carefully chosen for specific climatic and geographic conditions to achieve a positive influence of grafting on vegetable quality. Grafted plants utilizing *Solanum torvum* rootstock had the highest survival rate.

Issues Encountered during Transplanting of Grafted Vegetables

The following are some issues related to the creation and administration of grafted transplants:

- This method is labour-intensive and calls for people with particular training.
- Needs time management for the sowing of scion and rootstock seeds.
- Need a regulated setting in order to heal grafts.
- Grafting may make it more likely for diseases to spread, particularly those that are seed-borne in the nursery.
- Grafting workers in greenhouses and growth chambers frequently experience discomfort and heat stress, particularly in April, June, September and October (Marucci *et al.,* 2012).

Current Status of Vegetable Grafting

Due to the significant concentration of cucurbits and other grafted vegetables, East Asia is the largest market for vegetable grafting. Grafted transplants are used to produce 90%, 94%, and 40% of watermelon in China, Japan and Korea, respectively (Bie *et al.,* 2017). Grafted transplants are used to generate roughly 60–

65% of tomatoes and brinjal and 10%-14% of peppers, which are considered solanaceous vegetables. Grafted tomato transplants are used for all tomatoes grown in the Netherlands without soil. Vegetable grafting is gaining popularity worldwide, particularly in India, the Philippines, North America, South America, and Eastern Europe. Grafted transplants are being produced in more than 1500 commercial nurseries in China. Grafted vegetable transplants are becoming increasingly traded internationally, as evidenced by Canada's shipments of grafted transplants to Mexico (Bie *et al.,* 2017).

Conclusion

Grafting is a green technology that encourages the production of organic vegetables. The management and production of nurseries require a lot of labour. To improve grafting efficiency and reduce labour costs, scientists must focus on developing and promoting facilities, tool and grafting robots. Researchers must consider grafted transplant storage technologies. The creation of databases, software, mobile applications and crop models related to grafted vegetables will help farming communities and nursery managers select the best scion and rootstock cultivars. The grafted transplant trade is growing rapidly on the global market and as the grafted vegetable industry in India develops, this option can be utilised to generate foreign exchange. This technology can positively contribute to crop output. Improvements have been made to increase the technique's adoption, such as the development of more efficient grafting robots that can complete numerous tasks quickly and reduce the cost of grafted seedlings. Another breakthrough is the creation of rootstocks that offer a strong root system, resistance to diseases carried by the soil, the ability to promote greater shoot vigour by increasing nutrition and water absorption and preservation of plant health, all of which would boost output. Vegetable grafting offers a promising and practical way to combine the best traits of two plants, high fruit quality from the scion and resilience from the rootstock, enhancing productivity and sustainability. But it demands careful choice of combinations, proper technique and controlled healing conditions to succeed.

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