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Vegetables grafting: A noble technique to increase output and quality: A review

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Abstract
Vegetable grafting is the process of removing the stem (Scion) from a vegetable plant seedling and joining it to the plant's rootstock. Vegetable grafting is a method that increases yield when faced with biotic and abiotic challenges like sub- and supra-optimal temperatures, salt, drought, pest damage, diseases, and other similar problems. Vegetable grafting has been used commercially for a few decades, and its application is rapidly growing. By increasing the area under vegetable growing in unorthodox settings and unstable agro-ecosystems, vegetable grafting can increase production per unit of land available. These days, before being planted in the field, the majority of watermelons, cucumbers and other solanaceous crops are grafted. Grafting is a useful technology that can be used in addition to agricultural production that is more environmentally friendly techniques, such as reduced rates and overall use of soil fumigants. For the development of resistant cultivars, vegetable grafting is a quick and inexpensive substitute for time-consuming and laborious breeding methods.

Keywords: Vegetable grafting, quality, biotic stress, abiotic stress

Introduction

Grafting is the process of attaching two or more plant components to create a single plant, whether naturally or artificially. A genetically composite organism that behaves as a single plant is created when plant components come together and establish vascular continuity between them (Davies *et al*., 2011) [6]. Although there is 17th-century literature mentioning vegetable grafting, it is a relatively recent technique for growing vegetables that was established in the early 20th century. Grafting is one approach to producing vegetables in an environmentally friendly way by using resistant rootstock. Vegetable grafting is the process of fusing two components-a rootstock and scion-from various plants to create a single, thriving plant. Rootstock is a plant that already has a strong root system and is chosen for its resistance to biotic and abiotic stress conditions, as well as its increased vigor, precocity, and improved yield and quality. Due to the regulation of the growth hormone, grafting may impact vegetative development, flowering, flower modification, improve the vigor of the crop, result in faster or greater production, and produce fruit of higher quality. The grafted plant's scion, which represents the top part of the plant, is chosen for its traits that improve the quality of its fruit.

Plant grafting for vegetable crops has many benefits, including managing soil-borne illnesses, removing obstacles to remote hybridization, improving fruit quality (appearance, dimensions, form hue, vegetable characteristics include firmness, texture, pH, carotenoid content, flavor (Sugar, acids, and volatile aroma compounds), and how they respond to abiotic stressors such as salinity, drought, and flooding resistance to the effects of cold and heat.

Vegetable grafting history and Indian perspective

In Japan and Korea in the late 1920s, try to graft watermelon (*Citrullus lanatus*) onto pumpkin (*Cucurbita moschata*) was the first attempt at grafting a vegetable scions (Leonardi, 2016) [16]. A Chinese text from the fifth century and a Korean book from the seventeenth century both mention the use of self-grafting as a method for growing huge gourd fruits (Lee and Oda, 2003) [15]. To manage soil-borne diseases, commercial vegetable grafting did not begin until the early 20th century (Louws *et al*., 2010) [17]. Purple aubergine (*Solanum integrifolium* Lam.), one of the solanaceous crops, was initially cultivated during the 1950s after aubergine (*Solanum melongena* L.) was first grafted onto it (Oda, 1999) [21]. According to Lee and Oda (2003) [15], tomato (*Solanum lycopersicum* L.) grafting began in the 1960s.

In Japan and Korea, respectively, 59% and 81% of vegetables from the Solanaceae and Cucurbitaceae families were grafted by the year 1990 (Lee, 1994) [26]. Dr. RM Bhatt and his colleagues in India have begun grafting work at IIHR Bangalore to choose the finest rootstocks for wet environment circumstances. The IIHR Bangalore launched the first-ever introduction to vegetables grafts in a short course in 2013. In Trissur, Kerala's NBPGR regional station, a crop of dioecious vegetables called *Momordica cochinchinensis* is used for grafting, with male plants serving as rootstock and female plants serving to be scions. To increase output, the female plants were grafted onto male plants. There was 98% graft success. For the purpose of importing resistance to bacterial wilt and nematodes, More than 22 rootstocks of brinjal, chilli, tomato, and cucurbits have been discovered to confer resistance to bacterial wilt and nematodes by CSKHPKV, Palampur, which began work on grafting. Private companies like “VNR Seed Private Limited” & “TAKII SEED INDIA PRIVATE LIMITED” are additionally active in vegetable grafting and seedling supply. Vegetable grafting is becoming more popular worldwide for cucurbits, tomatoes, eggplants, and peppers, employing robust and disease-resistant rootstocks to assure appropriate yields in situations where biotic and abiotic challenges limit productivity (Lee and Oda, 2003; Chang *et al*., 2008; Buller *et al*., 2013) [15, 4, 3].

Grafting vegetables is necessary

Vegetable grafting's main goals are to increase quality and yield by using suitable stock plants, impart resistance against harmful diseases and pests, minimize chemical burdens on plants and fruits, and resist abiotic challenges (Dash *et al*. 2021) [7].

Vegetable grafting's importance and use

Biotic and Abiotic factor resistance

Grafting is a technique to lessening biotic and abiotic stressors. In heavy or loamy soils, the watermelon was grafted onto rootstock to a bottle gourd increases surviving flooding on sandy soil, cucurbits grafted on pumpkin provide drought tolerance (Anonyms, 2013) [1]. When cultivated under irrigation stress conditions, mini watermelons grafted onto a commercial rootstock PS1313 (*Cucurbita maxima* Duchesne x *Cucurbita moschata* Duchesne) have demonstrated a 60% increase in yield in comparison to ungrafted melon plants. Cucumber grafted on Shintoza-type rootstock (*Cucurbita maxima* Duchense x *Cucurbita moschata*) has demonstrated low temperature resistance and copper toxicity resistance, according to (Rouphael *et al*. 2008) [23]. In greenhouse cultivation, watermelon grafted onto saline-tolerant rootstocks boosts yield by about 81% (Colla *et al*., 2010) [5]. Watermelon cv. Fantasy grafted onto Strong Tosa rootstock (*C. maxima* Duch x *C. moschata* Duch) increased the shoot weight and leaf area even under saline circumstances, according to Goreta *et al*. (2008) [12]. Vegetable production suffers from biotic pressures such as nematodes and soil-borne diseases including verticilium wilt, bacterial wilt, fusarium wilt, corky root, etc., especially when crops are grown continuously in greenhouses (Lee *et al*., 2003; Pogonyi *et al*., 2005) [15, 22].

Influence of grafting on qualitative and quantitative characters

For the production of vegetables, the adoption of tolerant or resistant rootstock is regarded to an environmentally friendly approach under wide range conditions of biotic and abiotic stress. The nutritional value of fruit is directly impacted by rootstock. (Flores *et al.*, 2010) [10]. Grafted plants showed a greater marketable output and fruit quality when growing tomatoes without soil (Gebologlu *et al*., 2011) [11]. The fruit size increased when eggplants were grafted onto *S. torvum*, without altering the quality or productivity. The selection of rootstock used and grafting might affect sugar levels, flavor, color, content and texture of carotenoids. According to Nicoletto *et al*. (2013) [20], solutes that the affect fruit excellent is transported with the root stock with xylem and right away affect factors including fruit form, color, smoothness, texture, color (flesh), and TSS. However, when grafted between *Solanum sisymbriifolium* and *Solanum torvum*, brinjal's vitamin C concentration and firmness were adversely impacted (Arvanitoyannis *et al*., 2005) [2]. The tomato "Oxheart" grafted onto two inter-specific *S. lycopersicum* and *S. habrochiates* produced total soluble solids did not differ significantly, according to Di-Gioia *et al*. (2010) [8]. Additionally, they found that tomato plants grafted onto Beaufort F1 and Maxifort F1 had higher vitamin C content was reduced through 14-20%. Therefore, more research into the enhancement of qualitative features using grafting procedures is required.

Flowering and harvest period

When Shintosa was used as the rootstock, grafting delayed flowering in pumpkin, bottle gourd, wax gourd, and watermelon. Vegetable plants with grafts may take longer to flower as a result of the scion's age and growth (Maurya *et al*., 2019) [19].

The basic needs for vegetable grafting

1. **Selection of a suitable rootstock and scion:** Choose a desirable thickness of scion and rootstock with that same diameter as the stem. At two to three genuine leaf stages, grafting should be done
2. **Graft compatibility:** Even in later stages of growth, the mortality rate is reduced by compatible rootstock and scion. Vascular bundles are formed as a result of the rootstock and scion's rapid callus development.
3. **Grafting tools:** Tools including grafting clips, tubes, pins, and grafting blades are frequently used for grafting.
4. **Screening house:** Growing seedlings before grafting is done in a screening unit. Its needs to become made that use 60-mesh nylon net. Set up a two door and to stop UV radiation from penetrating, cover the top half of the building has a separate entrance layer of UV-proof polyethylene.
5. **Healing of grafts:** Healing of grafts is essential for creating the ideal environment for grafted seedling callus development. To encourage callus formation at union, the healing chamber's temperature should be between 28 - 29 °C with 95% for relative humidity 5-7 days within a partially darkened area (Shadows for 12 days). By lowering transpiration, maintaining high humidity, preserving the ideal temperature, and lowering light intensity, it aids in the creation of a better graft union. The primary goal is to create an atmosphere by regulating humidity and temperature (Wilson *et al*. 2012) [25].
6. **The grafted plants' acclimatization:** To minimize leaf burning and wilting, after the callus has formed and the damaged parts have healed, plants can be covered with a clear plastic sheet, a greenhouse, or a misting system.

Techniques for vegetable grafting

The grafting techniques used in vegetable crops vary. In solanaceous crops, cleft grafting and tube grafting is employed, whereas tongue or approach grafting be used for cucurbits like cucumbers. Using a slant-cut graft is a more practical with well-liked technique for watermelon and melon harvests. For watermelon and melon, slant-cut grafting is simpler and has recently gained popularity. The crop, the farmer's expertise, personal preference, the quantity of grafts needed, the goal of the graft, labour accessibility, and the accessibility of equipment and infrastructural facilities are all factors that influence the choice of grafting method (Lee *et al*., 2010) [27].

a) **Tongue or Approach grafting**: During successful grafting, identically sized rootstock and scion materials were employed. Therefore, scion seed is sowed before rootstock seeds 5-7 days in order to be achieve consistent dimension. The majority of farmers and smaller nursery utilize this method since it is labor-intensive and takes up more room, but because seedling survival is excellent. For rootstocks having hollow hypocotyls, a different approach is required.
b) **Cleft graft:** it is also called wedge or apical grafting. The bottom the scion's stem plant is sliced at a diagonal form a clip and a tapered wedge put to establish a connection between the scion and rootstock inserting caused the break (Johnson *et al*., 2011) [13]. Here, the scion plants are cut down to one to three genuine leaves. In solanaceous crops, this technique is most frequently utilized.
c) **Hole insertion/ Top insertion grafting:** When watermelon seedling are lesser than those from bottle gourd otherwise pumpkin rootstock, that approach is ideal for producing grafted watermelon transplants. The ideal temperature for this procedure is between 21 and 36 °C prior to transplanting. Because it produces a stronger union and vascular union than a tongue grafting procedure, this technique is particularly popular in China (Oda, 1999) [21].

Merits

- The absence of a grafting clip eliminates the need to collect grafting clips after healing, saving time and labor.
- Has a propensity to be highly successful.
- Increases the contacting surface area between the scion and rootstock, which aids in forging a solid graft union.

Demerits

- Needs a little bit more skill than the majority of other grafting techniques.
- Depending on the skills of the grafter during the grafting process, it could take longer to graft than some of the other grafting techniques.
- If any of the tissue in the meristem has not been destroyed, the rootstock will grow again.

Splice grafting/ tube grafting/ one cotyledon splice grafting: Generally used while growing seedlings in plug trays. In comparison to traditional vegetables grafting, it is more convenient, quicker, and easier. Plants that are of a tiny size can fit in a healing room or an acclimation chamber. Underneath the cotyledon, stem is yielding in a steep 450-degree cut. Scion receives a similar cut as well. Rootstock and scion are joined using a tube, and the tray is then placed in a healing chamber for up to 7 days.

Merits

- The simplest and fastest method for grafting watermelons.
- Grafting automation is a practical solution.

Demerits

- After grafting, it requires careful regulation of temperature, light, and humidity.
- If the healing environment is not appropriate, significant losses could occur in addition to potential diseases or physiological issues.
- The rootstock may still have some meristem tissue, which will need to be removed later in the production cycle.

Pin grafting: The splice grafting and pin grafting are similar. Specially made pins are utilized to retain the grafted position rather than grafting clamps.

Post-graft healing environment

A higher grafting success rate can only be achieved with proper maintenance of newly grafted transplants. As a result, maintaining humidity is necessary to prevent 95% water loss. Water loss the first two days could cause the scion to wilt, which would ultimately lead to the grafting's failure procedure. For a period of 5-7 days following grafting, grafted plants should be covered with black plastic sheet to improve moisture, limit daylight exposure and speed up the heal procedure. Healing chambers are made of plastic tunnels. On a commercial scale, a healing room can achieve grafting success rates of 95% (Dong *et al*., 2015) [9]. When the grafted plantlets are healed, keep them out of direct sunlight.

Table 1: Shows the Scion plant Rootstock and its Methods

Scion plant	Rootstock	Methods
Eggplant	*Solanum torvum, S. sisymbriifolium, Solanum khasianum*	Tongue and cleft method.
Tomato	*L. pimpinellifolium, S. nigrum*	Only Cleft method
Cucumber	*C. moschata, Cucurbita maxima*	Hole insertion and tongue method
Water melon	*Benincasa hispida, C. moschata, C. melo, C. moschata × C. maxima, Lagenaria siceraria*	Hole insertion and cleft method Splice Grafting
Bitter gourd	*C. moschata, Lagenaria siceraria*	Hole insertion and tongue method

Modern innovation in vegetable grafting

Recently, grafting vegetables has been made possible by a number of new inventions, some of which are listed below:

- **Double and single grafted tomato:** A plant that has been grafted from a vegetable is a tomato. Potato rootstocks were used to graft tomato scions onto clefts using cleft grafting. With a TSS of 10 ºBrix, more than 500 cherry tomatoes were collected above ground. Single tomato grafts include Sun Sugar, Brandywine, and Indigo Rose. In 2010, Log House pioneered the practice of cultivating double-grafted tomato plants in the United States using Big Beef or Geronimo rootstock with red and yellow pear tomato scions.

- **Micro-grafting:** *In vitro* grafting with small or micro explants (1/1000th mm^3) from meristematic tissues is employed to eliminate viruses from afflicted plants. Micro-grafting has been used to study the physiology of grafting and the chemical underpinnings of cell-to-cell contacts in herbaceous plants. This method, however expensive, enables the quick propagation of virus-free plants.
- **Grafting Robots:** The Netherlands produced a full automation model that can graft 1,000 tomato or aubergine seedlings every hour and includes additional features, such as automatically matching rootstock and scion seedling selection, which is essential to increasing the success rate. According to Kobayashi there were many semi- and fully automated grafting robots available for cucurbits in 1993, including the first commercial model of a grafting robot (GR800 series; Iseki & Co. Ltd., Matsuyama, Japan).

Problems faced during vegetable grafting
The following are a number of issues with the manufacture and administration of grafted transplants:

a) This method requires specialized, trained people and is labor-intensive.
b) The need time management for the sowing of rootstock and scion seeds.
c) Need a controlled setting for the graft to heal.
d) Grafting can increase the danger of pathogen dissemination, particularly for diseases in the nursery that are propagated by seed. Heat stress and discomfort are issues that workers who undertake grafting in a greenhouse and growth chamber must deal with, especially from April to June, September, and October (Marucci *et al*., 2012) [18].

Present position of vegetable grafting
The main market for vegetable grafting is in East Asia due to the high concentration of grafted vegetables, such as cucurbits, there. China, Japan, and Korea all grafted transplants produce 40%, 94%, and 100% of the watermelon in that order. Graft transplant produce 60-65 percent of tomatoes, 10-14 percent of peppers, and 60-65 percent of eggplants in solanaceous crops. In the Netherlands, all grafted tomato transplants are grown in soilless circumstances. Growing regions for vegetable grafting include North and South America, India, the Philippines, and Eastern Europe. In China, graft transplants are produced in more than 1500 commercial nurseries. With Canada shipping grafted transplants to Mexico, the global commerce in transplanted vegetables is steadily expanding (Singh *et al*., 2021) [24].

Upcoming information is essential for grafting
Drawback of obtainable rootstock in sequence: about the use of different rootstocks, compatibility with open-field cultivars and grafted seedling performance in the field under varied climatic environment, there is little information.

- **Automation technology:** In classify to produce grafted seedling taking place a large range for commercial use, herbaceous plants must be automated. Several agricultural enterprises have created grafting robots that are partially or entirely automated and several models are obtainable within East Asia, Europe, and the US. It is necessary to create the new attentiveness for business use.
- **High cost of production:** The cost of grafted seedlings is rather high due to labor-demanding propagation methods, a longer manufacturing period along with additional rootstock costs. Potential users of grafted seedlings are frequently deterred by these costs.
- **Controlled environment:** Controlled environments made it possible to alter the way things were produced and the survival rate.

Conclusion
Grafting is a site-specific method of plant propagation. By using specific rootstock and scion combinations, nematodes and soil-borne illnesses can be managed. It might expand the area used for vegetable cultivation due to hotspots for illness or unconventional and frail agro-ecosystems. It is a quick replacement for the relatively sluggish breeding process. Currently, grafting applications have limited the use of harmful soil disinfectants, which reduce vegetable contamination and toxic residues. Therefore, it has been suggested that we can realise the commercial use of grafting to achieve low-input sustainable horticulture in the future by adopting contemporary advances and indigenous wild cousins. Because it provide ailment patience along with outcome in order to improve the vigor of the crop, it will soon be useful in low-input sustainable horticulture.

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