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Review Paper

Grafting in Vegetables: Transforming Crop Production with Cutting-Edge Techniques

Mohsin Raza

Institute of Horticultural Sciences, University of Agriculture Faisalabad, Pakistan

*Corresponding Author Email: mr8835555@gmail.com

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Abstract

Vegetable grafting is the process of removing the stem of a seedling plant and connecting it to the rootstock of another plant, such as wild brinjal or pumpkin. The grafted seedling is cultivated under regulated climate conditions after attachment, it can be sown in a field. It is a basic propagation technique that results in the acquisition of desirable rootstocks to promote vigor, precocity, improved yield and quality, and improved survival in the face of biotic and abiotic stress. Grafting has created new opportunities in organic vegetable cultivation and lessened the need for chemicals to treat soil-borne illnesses. Vegetable farmers and researchers use grafting as a common technique to increase crop resistance or tolerance to biotic and environmental challenges in a variety of crops, including cucurbitaceous and solanaceous crops. It is important to choose rootstock and scion cultivars carefully to prevent any loss. The production of vegetables in a specialized and delicate agricultural environment may be encouraged using grafting technology. It is a substitute tool that is good for sustainable horticulture that requires less input for the agricultural system of the future and quick in situations where breeding methods are comparatively slow. This innovative, environmentally beneficial strategy has also been boosted by developments in robotic and automated grafting. The cost of producing grafted seedlings will go down significantly in the future due to mechanization.

Introduction

Grafting in Vegetables

The diversification of horticulture to provide adequate nutrition and food for the expanding population includes vegetables as a key element. Vegetable production in Pakistan is restricted by some biotic (soil and environmental stress) and abiotic biotic (disease and insect) variables (Shafique et al., 2016). These limitations have been overcome partly by standardizing crop management techniques and creating new hybrids or types. Grafting is one of these that has gained popularity as an agricultural technique (Kharal et al., 2021).

Through grafting, two distinct plant parts, a rootstock, and a scion are combined to create a single plant. A rootstock plant is one that already has a well-established, strong root system and is chosen for its capacity to withstand abiotic and biotic stress or to boost vigor, premature growth, and improved yield and quality. The upper part of the plant is obtained by the grafted scion, which can be chosen based on the fruit's quality and attributes.

Using selected rootstocks, vegetable grafting enhances growth, production, and quality while lowering soil-borne pathogen infection and fostering tolerance to abiotic stress (Arya et al., 2024). In crops including Cucurbitaceae and Solanaceae family (pepper, eggplant, cucurbits, and tomatoes), the grafting method is a widely used technique that produces high yields and tolerance to abiotic and biotic challenges with the use of strong and disease-resistant rootstocks (Awazade and Verma, 2024). The different uses of vegetable grafting as shown in Figure 1. Grafting is used in protected crops to increase vegetable crop yield and resources. It is assumed that grafting depends on applying suitable grafting techniques and that breeding allows for the vigorous growth of rootstock. Grafting has created new opportunities in organic vegetable production and lessens the need for chemicals to treat the soil to prevent soil-borne illnesses. Grafting is an environmentally beneficial method that boosts cultivar output and reduces soil-borne illnesses (Suansia and Samal, 2021).

Purposes of Vegetable Grafting

Figure 1 illustrates the various purposes of vegetable grafting: acquiring tolerance to abiotic stresses, influencing sex expression, achieving resistance to soil-borne diseases and pests, enhancing yield, improving quality traits, and promoting increased plant vigor, which can reduce the need for agrochemicals and fertilizers.

Figure1. Different uses of vegetable grafting (Tirupathamma et al., 2019).

Different Grafting Methods

The experience of farmers, management conditions of post-grafting, and grafting objectives all influence the grafting techniques used for different stocks and scions. Additionally, the grafted plants' rate of survival is influenced by the compatibility of the rootstock and scion, the quality and age of the seedlings, post-grafting management, and the quality of the joined section. Cleft grafting was the first grafting technique used for melon, but its use significantly decreased with the advent of the tongue approach grafting technique. Due to its better success rate and the consistent development of grafted seedlings, the tongue approach method gained popularity across Asia. Over 90% of watermelon plants in Spain are grafted using the one cotyledon technique (Ali, 2012; Devi et al., 2020). Cleft and tube grafting is the most common method used to graft eggplants and tomatoes. The tongue method is employed for grafting Cucurbitaceae, particularly cucumbers. For watermelon and melon, slant-cut grafting is simpler and has gained popularity recently (Chauhan et al., 2021). The primary use of this technique was robotic grafting. Here is a discussion of these techniques:

Approach/ Tongue grafting

For tongue grafting, the scion and rootstock are of the same size. Small nursery producer use this technique often and involve more work and space, but the seedling survival rate is great. Hollow hypocotyl rootstocks are not treated with this technique.

Wedge grafting

It is also known as Apical or cleft grafting. The technique involves cutting the scion with one to three true leaves, splitting the scion, attaching a clip between the rootstock and scion, and making a slant angle in the lower stem (Ilakiya et al., 2021). Mostly, solanaceous crops are used for this.

Hole insertion grafting

The optimum temperature for transplanting ranges between 21 to 36°C. This method is used in China especially in watermelon as watermelon seedlings are smaller than squash and bottle gourd rootstock. It is also known as top insertion (Thakur, 2020).

Splice grafting

Growers are the ones who employ this technique the most. In most cucurbits and solanaceous vegetable crops, it can be done manually or with a machine.

Pin grafting

Grafting clips are not employed in this approach instead, the grafted position is held in place by specially made pins. The technique resembles splice grafting.

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

Plant(scion)	**Grafting Technique**	**Rootstock**	**Ref**
Watermelon	Slice grafting, cleft technique, and top insertion	*Lagenaria siceraria Cucurbita moschata, Cucurbita melo, Cucurbita moschata × Cucurbita maxima, Benincasa hispida*	*(Majhi et al., 2023)*
Cucumber	Top insertion and Tongue grafting	*Cucurbita maxima, Cucurbita moschata*	*(Das et al., 2023)*
Bottle gourd	Top insertion and Tongue grafting	*Luffa sp., Cucurbita moschata*	*(Salaria et al., 2020)*
Bitter gourd	Top insertion and Tongue grafting	*Lagenaria siceraria and Cucurbita moschata*	*(Das et al., 2023)*
Brinjal	Tongue and Cleft grafting	*Solanum khasianum, Solanum sissymbrifolium, Solanum torvum*	*(Imandi and Bahadur, 2023)*
Tomato	Tongue and Cleft grafting	*Solanum nigrum, Lycopersicon pimpinellifolium*	*(Rakhi and Sarada, 2024)*

Requirement for Vegetable Grafting

To ensure successful vegetable grafting, it is important to consider several key factors. As illustrated in Figure 2, these measures include selecting the appropriate rootstock and scion, ensuring compatibility between the grafts, using grafting aids, establishing a screening house, allowing for the healing of the grafts, and acclimatizing the grafted plants.

Present Status of Vegetable Grafting

Cucurbits and other grafted vegetables are highly concentrated in East Asia, making it the region with the greatest market for vegetable grafting (Maurya et al., 2019). Grafted transplants are used in the production of 94% of watermelon in Japan, 99% in Korea, and 94% in Japan.

Grafted transplants are used to generate around 10%–14% of peppers and 60–65% of eggplants and tomatoes within the solanaceous vegetable market. Grafted tomato transplants are used in the Netherlands for all tomatoes grown in soilless culture (Thies, 2021). Vegetable grafting is currently becoming more and more popular around the world, especially in the Philippines, South and North America, Eastern Europe, and India. Grafted transplants are being produced by more than 1500 commercial nurseries in China. The grafted vegetable transplant trade is expanding quickly on a global scale as a result of Canada shipping grafted transplants to Mexico.

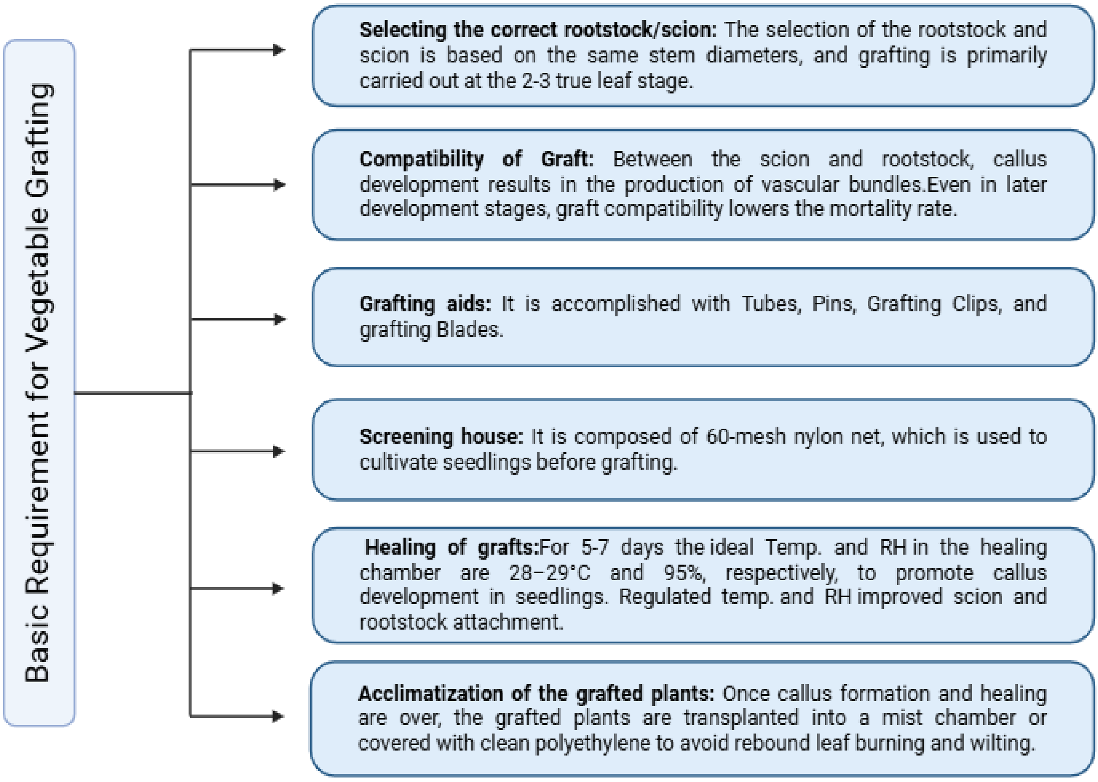

Figure 2. Flowchart illustrating essential prerequisite for vegetable grafting for vegetable grafting (Thakur, 2020).

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Vegetable Grafting Associated Problems

The process of grafting and raising grafted seedlings is frequently linked to several issues. The labor and methods needed for the grafting procedure and the post-graft management of grafted seedlings for short-term (7–10 days) healing are the main issues. Although the numbers vary depending on the grafting technique, an expert can graft 150 seedlings/hour (1200/day) (Draie, 2017). In the same way, the grafting techniques largely determine the post-graft management strategy. Moreover, poor after-grafting environmental management; direct overhead water, too much and low light, high humidity, direct overhead water, and high temperature. The post-grafting environment's excessive light forces the freshly grafted plant to execute functions like photosynthesis that are challenging for it to develop and repair (Tirupathamma et al., 2019). In well-maintained conditions, inconsistent senescence can accelerate the development and spread of the disease at any point from seeding to the healing of grafted plants. Expensive grafting tools and rootstock seeds, among other things, are a big issue.

Modern Methods of Vegetable Grafting

Adapting modern methods of vegetable grafting the problems related to vegetable grafting can be minimized. The following are some of the most recent unique advancements in grafting of vegetables:

Single and Double grafted tomato

Pomatoe is the result of the grafting of vegetables. In this case, potato rootstock is used, and tomato scions are grafted via (cleft) method (Thakur et al., 2022). Harvest more than five hundred cherry tomatoes with 100 Brix TSS above ground. Indigo Rose, Brandywine, and Sun Sugar are examples of single tomato grafts. In 2010, Log House began selling double-grafted tomato plants in the United States utilizing the Big Beef or Geronimo rootstock to produce red and yellow pear tomatoes as scions.

Micro-grafting

To remove the viruses from infected plants, very small explants (3mm) from meristematic tissues are employed in vitro grafting (Wang et al., 2022). To determine the genetic basis between cell connections and evaluate grafting physiology, herbaceous plants have used micrografting. Despite being costly, this technique allows for the quick multiplication of virus-free plants.

Grafting Robots

A complete automation model created in the Netherlands can graft 1,000 tomato or eggplant seedlings every hour and offers additional features including the ability to automatically choose scion seedlings and rootstock that match, which is an essential step in raising the success rate. In 1993, the first commercially accessible grafting robot model (GR800 series; Iseki & Co. Ltd., Matsuyama, Japan) was made available for cucurbits. Since then, other partially and completely automated grafting robots have been developed (Chaudhari et al., 2023).

Conclusion

In harsh environments, grafting is an achievable technique that revives contemporary vegetable production. The purpose of grafting vegetables is cropping preservation as well as variety preservation. Despite challenging growing circumstances, the approach helps farmers come in with a strong crop by providing a measure to minimize soil-borne illnesses and waterlogged soils. It is suitable for organic and integrated crop management techniques. Grafted vegetable seedlings will be used and supplied commercially more frequently worldwide because of the rapid expansion of large-scale commercial production of vegetable seedlings in many industrialized nations. Additionally, advancements in automated and mechanized grafting provide a boost to this environmentally beneficial strategy. The management and production of nurseries require a lot of labor. To address this issue, scientists are working to create new tools, decrease labor costs, and increase grafting efficiency with the use of robots. Grafting reduces the amount of environmental pollution and vegetable toxicity by lowering the incidence of soil-borne diseases. This led to the conclusion that using innovative and domestic methods reduces the amount of input that grafting requires in future horticulture.

Future Prospective

Grafting is a feasible method to apply to the modern production of vegetables especially when the growth conditions are unfavorable. It is useful in the conservation of both crops and varieties and provides ways and means to fight against diseases, which are forced from the soil, and water logging, the reason to make it desirable for organic and integrated crop management. This reveals that grafted vegetable seedlings are on the rise internationally because of the massive production of horticultural products by industrialized countries for commercial production. The development in the technologies of automatic and mechanical grafting also makes this environmentally friendly process more effective. As it has been established that nursery management is time-consuming, scientists have had to work hard to ensure that they invent gadgets as well as robot machines that may make the process of grafting less expensive. Since fewer diseases result from grafting, the environment is less polluted, and vegetables are less toxic. In future horticulture, new and site-specific techniques will also build on these procedures to improve the efficiency of grafting and cut down on needed inputs.

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