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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(6): 1709-1714

www.thepharmajournal.com
Received: 03-04-2023
Accepted: 08-05-2023

Sunita Dhar
Department of Horticulture, Assam Agricultural University, Jorhat, Assam, India

Priyanka Borauh
Department of Horticulture, Assam Agricultural University, Jorhat, Assam, India

Dr. Sailen Gogoi
Department of Horticulture, Assam Agricultural University, Jorhat, Assam, India

Corresponding Author:
Sunita Dhar
Department of Horticulture, Assam Agricultural University, Jorhat, Assam, India

Importance of rootstocks in cucurbitaceous vegetables: A review

Sunita Dhar, Priyanka Borauh and Dr. Sailen Gogoi

Abstract
Grafting is a technique of vegetative propagation in plants where two plant parts, *viz*., scion and rootstock are joined together through tissue regeneration so as to develop into a single composite plant. The lower portion of the graft that provides the root system of the composite plant is known as the rootstock whereas the upper portion of the graft that develops into the shoot system is known as the scion. The main objective of vegetable grafting is to physically merge positive qualities of both the parts in an individual plant and harness an integrated result. Among the major vegetable crops, grafting is mainly adopted in Solanaceae and Cucurbitaceae family. The major factors that lead to the increased adoption of this technique in vegetables are to achieve resistance against soil borne pathogens, tolerance to abiotic stresses and potential increase in yield of the crops. It also helps to minimize the cost of production of crops and reduces the enormous use of fertilizers and pesticides, thus, maintaining the soil fertility.

Keywords: Abiotic, biotic stress, cucurbits, grafting, rootstock

1. Introduction

Highest productivity at peak growing season has always been one of the major factors influencing the total income of farmers whereas a customer always prefers a better-quality product from the retail end. Certain studies have given prominence to the fact that quality is more important to consumers than price provided the price remains within the expected range (Harker *et al*., 2003) [8]. Keeping all these in view, it is of utmost importance to increase the yield as well as production of quality products so that demand can be met both at production as well as at consumption level. However, the most common factors affecting the yield and productivity of vegetable crops are high infestation of insect pests and diseases coupled with adversities of soil and climate. Moreover, modern agricultural practices such as succession cropping, crop rotation, off-season cropping have led to decrease in soil fertility and caused various physiological disorders and deterioration of quality of the produce. In addition to these factors, the rampant use of chemical fertilizers to boost productivity has left serious impact on the soil and environment. In 1987 Montreal Protocol, an important decision regarding ban of Methyl bromide was taken (Davis *et al*., 2008) [5]. It is a colorless, odorless gas that can be used to control pests, fungi, rodents, nematodes and weeds. But it causes serious depletion of ozone layer and has environmental impact. Also, use of chlorofluorocarbon-based soil fumigants is banned as they gradually decrease the fertility status of the soil. As a consequence, quest for alternatives have began to increase the production of fruits and vegetables. Thus, use of rootstock for the purpose of grafting came into light and a number of research work related to grafting and rootstock-scion interaction got up scaled. Initially use of rootstocks for grafting has been limited to only fruit crops but recently vegetable production by using the technique of grafting has expanded to a larger scale. Use of rootstocks not only minimized pests and diseases infestation but also vested tolerance against several biotic and abiotic stresses and thus helped to attain the maximum yield. The technique of grafting, a vegetative propagation method, refers to joining of two plant parts *viz*., rootstock and scion obtained from two different plants of same or different species. Rootstock refers to the underground plant part that later develops into the root system whereas scion refers to the above ground part that develops into the shoot system of the stionic plant. The technique of grafting requires skilled hands. Grafting is very common in fruit crops as compared to vegetables. The process has been mainly adopted in two major vegetable Families *viz*., Solanaceae and Cucurbitaceae. Initially research on grafting work started in Japan and Korea in 1920s with the use of *Cucurbita moschata* as a rootstock for watermelon.

In India, grafting work first started at Indian Institute of Horticultural Research, Bangalore by Dr. R M Bhatt and his associates. CSKHPKV, Palampur identified more than 22 rootstocks in solanaceous and cucurbit vegetables to impart resistance against biotic stresses. A good rootstock is one that has taxonomical similarity and close genetic relationship with the scion in order to form a successful graft union. In addition to this, a particular chosen rootstock should provide resistance to various soil borne pathogens and diseases that are prevalent in the concerned area. It should have high adaptability to the prevailing environmental conditions of the specific location where it is to be grown. Moreover, it should be able to increase the potential yield and productivity of the crop, thus giving a higher benefit. The mechanism of graft union formation depends upon certain physiological and biochemical processes. A successful graft union requires joining of rootstock and scion, formation of callus and formation of vascular cambium. Phytohormones play a very important role in formation of the graft union starting from secretion of pectin to initiate the joining or adhesion of rootstock-scion to the formation of vascular tissues. Plant hormones mainly auxin, cytokinin, gibberellin, abscisic acid and jasmonic acid play a crucial role in successful graft union. Auxin helps in differentiation of vascular tissues. Low concentration of auxin causes callus to transform into phloem whereas high concentration causes both phloem and xylem formation (Aloni R., 2021) [1]. Cytokinin and ethylene helps in callus formation and cell proliferation during graft union formation. Gibberellin helps in the formation of cortex during the joining of scion and rootstock.

2. Importance of rootstock in cucurbits

2.1 Tolerance to environmental stress

Environmental stress such as high salinity, temperature fluctuations, flooding affects the growth of the crops resulting in decrease in yield. The bottle gourd rootstocks are used for grafting watermelon to enhance flood tolerance in heavy or loamy soils while pumpkin rootstocks provide drought tolerance in sandy soil (Anonymous, 2013) [2]. High amount of salt concentration in soil and irrigation water is one of the major factors leading to non-availability of arable land. It has been found that 20% of the cultivated land is affected by soil salinity and about half of the irrigated region around the world has high amount of salt concentration (Zhu, 2001) [33]. Saline soils can be defined as the soils having an electrical conductivity (EC) of more than 4 dSm^{-1} at 25 °C (Richards, 1954) [19]. Cucumber (*Cucumis sativus*) is a moderately sensitive plant to salt stress (Jones *et al*., 1989) [9]. Ploegman and Bierhuizen (1970) [18] reported that cucumber plants can tolerate an EC of about 2.5 dSm^{-1} but the yield decreases by 13% with each unit increase in EC above the threshold value. Therefore, there is need of salt tolerant rootstocks to increase yield and boost productivity. It has also been found that cucumber plants have a better growth in cocopeat media under salinity stress condition. Cocopeat has high water and nutrient holding capacity and high cation exchange capacity that provide stability in its pH and helps hold nutrients even under high saline conditions. A study conducted by Usanmaz and Abak (2019) [29] showed that cucumber grafted on *Cucurbita moschata* L. rootstocks *viz*., Nun 9075, TZ148 and Local-3 increased tolerance of the grafted plants towards salinity stress under an EC of 5.0 dSm^{-1} and RS841 rootstock increased plants tolerance under an EC of both 5.0 dSm^{-1} and 7.5 dSm^{-1} by decreasing the accumulation of Na^+ in its leaves. Ahn *et al*. (1999) [3] observed that cucumber grafted onto fig-leaf gourd rootstock conferred tolerance to the grafted plant against cold temperature. Higher water absorption capacity of fig-leaf gourd roots from the soil was attributed to the imparted tolerance. Use of compatible rootstocks for watermelon grafting prompts its planting date during cool periods (Taussig *et al*., 1996; Miguel *et al*., 2004) [27, 13]. Temperature has an effect on the sex expression of cucurbit crops especially in cucumber where low temperature causes more female flower production leading to higher yield whereas high temperature causes production of more male flowers (Malhotra S.K., 2016) [14]. An interspecific hybrid between *Cucurbita maxima* and *Cucurbita moschata* gave rise to 'Shin-tosa'-type rootstocks which exhibited superior growth under low-temperature conditions (Okimura *et al*., 1986) [17]. Zhang (2002) [32] opined that cucumber grafted onto suitable rootstocks resulted in higher net photosynthesis, higher stomatal conductance and higher intercellular CO_2 concentrations than the individual non-grafted plants. Grafted watermelons using commercial rootstock PS1313 (*Cucurbita maxima* × *Cucurbita moschata*) exhibited around 60% increase in yield when grown under irrigation stress conditions as compared to ungrafted plants.

2.2 Resistance against pests and diseases

One of the major factors that led to the adoption of grafting technique was to develop healthy plants to counter the infestation by insect-pests and diseases. Cucurbit crops are highly affected by Fusarium, a soil borne fungus that causes serious damage reducing the yield and productivity. Fumigation of soil was a common practice to control the fungus and lessen the damage but due to the harmful effects of methyl bromide several alternatives have been tried (King *et al*., 2008) [10]. As a result the research on grafting technology for production of disease free vegetable crops and rootstock-scion interaction expanded. In cucurbits, grafting work to develop Fusarium resistance was started in Japan in 1920. In watermelon initially *Cucurbita moschata* was used as a resistant rootstock, but soon bottle gourd became the most preferred rootstock (Tateishi, 1927; Sakata *et al*., 2007) [26, 21]. Crino *et al.* (2007) [4] reported that melon grafted onto squash inter-specific hybrids provided resistance to *Fusarium oxysporum* f. sp. *Melonis* and also *Didymella bryoniae*, the causal agent of gummy stem blight. Another serious disease occurring in the cucurbits is the Phytophthora blight, caused by *Phytophthora capsica*. Wang *et al.*, (2004) [31] reported that cucumber showed higher resistance to Phytophthora blight, caused by *Phytophthora capsica* when grafted into suitable rootstocks. Toporek *et al.* (2018-19) [28] observed that cucurbit rootstocks showed variable response of resistance against mixed inoculation of *Pythium aphanidermatum* and *P. myriotylum* under field conditions whereas inter-specific hybrid of squash and bottle gourd rootstocks showed consistency in providing resistance to these species in a growth chamber. Sakata *et al.* (2008) [20] reported that Burr cucumber provided resistance against fusarium wilt and root knot nematode. However, it was susceptible to damping-off and gummy stem blight. African horned cucumber was suggested as a resistant rootstock against root knot nematode infestation by Lee and Oda, (2003) [11]. Edelstein *et al*. (2000) [6] observed that use of *Lagenaria* rootstock for grafting provided resistance against *Tetranychus cinnabarinus* in cucurbits.

2.3 Increasing yield
The total yield obtained from a plant is directly related to the net return earned by the grower. Yield of a plant depends upon the optimum time of flowering and fruiting. A proven paradigm has been established that grafted vegetable plants produce higher yield as compared to the non-grafted ones. As cucurbits exhibit a large variation of sex forms, it is of utmost importance to give more attention towards early production of female flowers for higher production of fruits. Sakata *et al.* (2007) [21] observed that watermelon grafted onto bottle gourd rootstocks resulted in early formation of female flowers. Cucumber scions when grafted onto pumpkin rootstocks yielded 27% more fruits per plant than the non-grafted ones (Seong *et al*., 2003) [22].

2.4 Improving quality and vigour
Quality is one of the major factors which determine the marketability of the harvested produce. It is often found that quality of fruits produced by the grafted plants is significantly better than the self-rooted ones. The extensive root system produced by the vigorous rootstocks helps in uptake of essential minerals and nutrients from the soil for production of better-quality fruits. Scions of mini watermelon grafted onto the commercial hybrid rootstock 'PS 1313' (*Cucurbita maxima* × *Cucurbita moschata*) exhibited higher titratable acidity (TA) and a higher TSS/TA ratio (Proietti *et al.*, 2008). Bloomless cucumber, highly popular in Japan for its smooth texture and longer shelf life, tends to produce inferior quality fruits having tougher rind, low sugar content etc. and with other physiological disorders could be significantly improved upon through grafting (Sakata *et al.*, 2008) [20]. Melons grafted onto inter-specific hybrid rootstocks (*Cucurbita maxima* × *Cucurbita moschata*) showed severe incidence of premature internal decay in the fruits as because the roots absorbed excess nitrogen fertilizer but transported lesser calcium into the fruits (Chung., 1995).

2.5 Effect on flowering
Both rootstock and scion have an effect on the flowering time and behavior in grafted crops. Watermelon grafted onto bottle gourd rootstock produces female flowers early in the lifecycle of the crop. Whereas pumpkin, bottle gourd, watermelon and wax gourd grafted onto 'Shintosa'-type rootstock showed a delay in flowering. The time of flowering also has a pronounced effect on time of harvest which may directly have an impact on the harvest quality of the produce (Sanket *et al*., 2017) [23].

3. Recent research done in Cucurbit Grafting
Cucurbit vegetables are widely used worldwide for human consumption. But the yield and productivity of the crop has greatly reduced as they are highly susceptible to various soil borne diseases and nematodes. However, to mitigate these problems and to increase the yield and quality of the fruits several research works has been done in the field of Cucurbit grafting. Lecholocholo *et al*., 2020-21 conducted an experiment in South Africa to analyse the effect of rootstock on quality and volatile constituents of Cantaloupe and Honeydew Melons. Two rootstocks *viz*., Kickstart and Carnivor developed from a cross between sweet melon and watermelon were used. These were grafted with four melon cultivars. The results showed that grafted fruits contained higher soluble sugar to titratable acidity ratio, higher pH and fruit firmness and higher ascorbic acid content as compared to the non-grafted control. All the grafted cantaloupes also showed higher β-carotene and lutein content than the non-grafted ones. Similar reports were established by Liu *et al*. in 2011 [12] where Honeydew Melon and Cantaloupe showed higher rate of photosynthesis and increased carbohydrate metabolism when grafted onto suitable rootstocks. Thus, it was concluded that rootstock Carnivor can be successfully used for grafting Cantaloupe and Honeydew Melons. Several approaches has also been made to bring disease tolerance to the crops by using suitable resistant rootstocks. In 2020 Reyad *et al.* conducted an experiment in Cairo University, Giza, Egypt and found that Cucumbers grafted onto *Cucurbita maxima* and *C. moschata* showed greater resistance to Fusarium wilt and possessed higher nutritional quality than the non-grafted ones.

Rootstocks also improved the salinity tolerance of the crop. This fact was demonstrated by Usanmaz *et al*., 2019 [29] at North Cyprus, Turkey where four commercial cucumber rootstocks (TZ148 F1, RS841 F1, Nun9075 F1 and Avar F1) and two local landraces of *Cucurbita moschata* (Local-1 and Local-3) were used as rootstocks in three different salinity concentrations. The study revealed that growth and yield of the grafted crops under different saline conditions were higher than the non-grafted ones.

Some new cucurbit rootstocks were developed in the recent years such as Cobalt RZ which can be successfully used for grafting in Cucumber, Watermelon and Melon. It gives an early yield along with good plant vigour. Another new rootstock *viz*., Sphinx RZ was developed for use in Melon grafting showed resistance to Fusarium wilt and Powdery Mildew. It also provided an early yield and showed good fruit setting in colder regions.

4. Certain drawbacks associated with grafting
Grafting in vegetables is sometimes associated with a high risk of incompatibility between the rootstock and scion. Such incompatibility may result into hindrance in transportation of essential minerals and nutrients from the soil into the scion through the rootstock. Thus, leading to several mineral deficiencies in the crop which in turn reduces its yield and productivity. Another possible disadvantage of vegetable grafting includes the high cost of labour (Davis *et al*., 2008) [5]. The process of grafting requires highly skilled and efficient labours. Thus, making the entire process a cost effective one. Moreover, limited availability of grafting tools also poses as a major disadvantage in the process of grafting. In addition to all such limitations, grafting being a cost and labour-intensive process results into high cost of grafted seedlings.

Table 1: Different rootstocks used for cucurbit vegetables (Davis *et al*., 2008) [5]

Rootstock	Used for
1. Cucumber	
Fig leaf Gourd	Good Fusarium resistance and low temperature resistance
Burr cucumber (*Sicyos angulatus*)	Southern Root-knot Nematode resistance
Interspecific hybrid squash (*Cucurbita maxima x C. moschata*)	Fusarium Wilt and low temperature resistance
African horned cucumber (*Cucumis metuliferus*)	Excellent fusarium resistance and good nematode tolerance
Cucurbita moschata	"Blooming-less" cucumber fruit.
Cucurbita moschata	Improves stress tolerance
TRC 11550 (Intraspecific Hybrid)	Nematode resistance
Ardito/TRC 1401	Very strong and uniform rootstock with highly vigorous root system.
TRC 15NTB4	Resistance to soil-borne diseases and abiotic stress factors.
2. Watermelon	
Bottle Gourd (*Lagenaria siceraria*)	Fusarium wilt and chilling tolerance
Shintoza	Fusarium wilt and chilling tolerance
Wax Gourd	Greater drought tolerance
Squash (*Cucurbita moschata*)	Resistant to fusarium and low temperature
Pumpkins (*Cucurbita pepo*)	Vigorous root system, resistant to fusarium and low temperature
Watermelon (*Citrullus lanatus*)	Fusarium tolerance, but not resistance
Citron melon	Root knot Nematode
African horned cucumber (*Cucumis metuliferus*)	Excellent fusarium resistance and good nematode tolerance
Interspecific hybrid squash (*Cucurbita maxima x C. moschata*)	Resistant to fusarium wilt and vigorous root system, high temperature tolerance
Ash gourd (*Benincasa hispida*)	Good disease resistance
3. Summer Squash	
Fig leaf Gourd (*Cucurbita ficifolia*)	Low soil temperature tolerance
4. Bitter gourd	
Sponge Gourd (*Luffa cylindrica*)	Resistant to fusarium wilt, good tolerance to heat and flooding
5. Melon	
Squash	Good fusarium and low temperature tolerance
(*Cucurbita maxima x C. moschata*)	Good fusarium resistance, low and high soil temperature tolerance, and high soil moisture tolerance
Cucurbita pepo	Good fusarium resistance, low and high soil temperature tolerance, and high soil moisture tolerance
Melon (*Cucumis melo*)	Fusarium tolerance and good fruit quality
African horned cucumber (*Cucumis metuliferus*)	Good fusarium tolerance, low and high soil moisture tolerance and nematode tolerance

5. Mechanized grafting

In order to reduce the risk of graft union failure and to overcome the unavailability of sufficient skilled labours, mechanisation of the grafting process is adopted in many parts of the world. The mechanisation of grafting have been attempted since 1987 which led to the development of commercial robot for grafting in Cucumber (Sabir *et al*., 2012) [24]. In India, an automated grafting robot has been developed under NAHEP-CAAST-DFSRDA-VNMKV, Parbhani under Agri-bot division. The robot can clip, move, position, cut, bind and wrap rootstock and scion together. The grafting success rate of the robot is 87.3% and the binding success rate is 68.9%. it can effectively graft 700-800 rootstocks per hour (Source: Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, India, https://nahep.vnmkv.org.in).

6. Future prospects

Grafting not only enhances plant performance but also promotes vegetable production during the off-season. It can also be used as a major component under Integrated Pest Management for organic vegetable production. Grafting, being a time consuming and labor-intensive process, availability of planting materials for adoption in large areas of production is limited. However, in view of the increasing thrust on organic and natural farming there lies a tremendous scope for commercialization of this eco-friendly technology. Thus, development of more efficient grafting methods, manual or mechanical, is required. Moreover, most of the existing as well as recently developed rootstocks is mostly obtained from exotic sources. Therefore, effort should be made for identification, collection and conservation of indigenous and wild rootstocks that have a greater adaptability to our local environment.

7. Conclusion

It can be summarised from the above discussion that use of rootstocks for grafting in Cucurbitaceous crops increases yield and productivity of the crop. Grafted plants have a better adaptability and higher disease tolerance than the non-grafted counterparts. Many countries have adopted the process of grafting and development of healthy and vigorous rootstocks and thus have attained higher profit. The major pre-requisite for successful grafting is the rootstock-scion compatibility. However, the compatibility reaction and mechanism of graft union formation is a subject that is yet to be explored. Certain theories have been developed in this aspect but a detailed explanation is still lacking. Therefore, more focus should be given towards understanding the physiology of graft union formation as rootstock-scion incompatibility leads to the failure of the process many a times. Cucurbit crops being highly susceptible to pests and diseases show significant reduction in growth of the crop. Moreover, certain abiotic factors such as soil salinity and drought also lead to the decrease in the crop productivity. Therefore, the use of rootstocks in the grafting of Cucurbits has proved to be one of the best remedial measures in overcoming all such limitations. It also reduces the cost of production of the crop and benefits the farmers as it cuts off the use of massive amount of fertilizers and pesticide or other disease control measures thus promoting organic production of crops. It is an environment friendly technique and can be used to produce off season crops. However, grafting is a labour-intensive process and requires skill and efficiency. In the recent years several automated and semi-automated grafting robots have been developed which reduces the requirement of labour and at the same time increases the efficiency of the process resulting into formation of successful grafts.

Grafting is also associated with certain drawbacks. Although it is used to decrease the rate of pest and disease infestation but it sometimes might cause transmission of viral diseases. Therefore, all the equipment and tools that are used in the process of grafting needs to be properly sanitised before use. Moreover, the availability of grafting tools is still very limited. Thus, focus should be given on mitigating such limitations. Rootstock-scion incompatibility is another disadvantage in the process of grafting and thus certain breeding techniques must be developed in order to increase the compatibility between the scion and the rootstock. Additionally, research works must be carried out in identification of local rootstocks, development of suitable environmental conditions and developing efficient grafting robots.

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