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Vegetable grafting: An effective tool for biotic and abiotic stress management: A review

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Abstract
Grafting can be defined as the vegetative and asexual method of plant propagation and done by combining two separate plants i.e. upper part contain shoot system of high yielding commercial cultivar called as ‘scion’ and lower part known as ‘rootstock’ with desired root system characteristics into a single independent plant possessing interested trait. Grafting used for a long time ago to increase uniformity, vigour and resistance to biotic and abiotic stresses of vegetatively propagated plants. Presently, grafting becomes popular technology among the vegetable growers and scientist to develop resistance or improve tolerance against the broad spectrum of biotic and environmental stresses in the various vegetable crops specifically solanaceous and cucurbitaceous crops. Commercial vegetable grafting techniques originated in Japan and Korea and it is currently being globally practiced using local scion cultivars and introduced rootstocks

Keywords: grafting, vegetable, yield, quality, stress

1. Introduction

Agriculture started its journey somewhat 10,000 years ago when ancient people started to cultivate plants and domesticate animals. To feed the ever increasing population wide scale cultivation of crops and animals for mankind paved the way with plant breeding, plant propagation, crop production and food technology. Among the plant propagation techniques grafting has become popular and practiced long time ago for increasing productivity, management of different types biotic and abiotic stress. Grafting can be defined as the natural or deliberate fusion of plant parts so that vascular continuity is established between them (Pina and Errea, 2005) [19] and the resulting genetically composite organism functions as a single plant (Mudge *et al*., 2009) [15]. The first attempt in vegetable grafting was done by grafting watermelon (*Citrullus lanatus*) onto pumpkin (*Cucurbita moschata*) rootstock in Japan and Korea in the late 1920s (Lee 1994) [12]. Soon after water melon (*Citrullus lanatus*) was grafted onto bottle gourd (*Lagenaria siceraria)* rootstock, in 1950s. Grafting of tomato *(Lycopersicon esculenturn Mill.)* was introduced commercially in the 1960s (Lee and Oda, 2003) [10]. Later it was adopted for commercial production pourpose in many countries like Europe, Middle East, Northern Africa, Central America and other parts of Asia (Kubota *et al*. 2008) [9]. In India grafting technology in different vegetables like tomato, brinjal, cucurbits have been initiated at different research institutes like IIHR Bangalore, NBPGR Regional Station, Thrissur, Kerala on cucurbits and by some SAUs. This technique is eco-friendly for sustainable vegetable production and by using resistant rootstock, it reduces dependence on agrochemicals (Rivard *et al*. 2008) [20], so this technology is now rapidly spreading and expanding over the world among the vegetable growers and scientist to develop resistance or improve tolerance against the broad spectrum of biotic and environmental stresses in the various vegetable crops specifically solanaceous and cucurbitaceous crop.

Objectives of grafting in different vegetables

Vegetables	Objectives
Tomato	Tolerance to bacterial wilt (*Ralstonia solanacearum*), *Fusarium oxysporum*, Nematodes(*Meloidogyne* sp), *Verticillium dahlia*.
Eggplant	Tolerance to bacterial wilt(*Ralstonia solanacearum*), *Fusarium oxysporum*, *Verticillium alboatrum*, Nematodes, low temperatures, induction of greater vigour.
Bitter gourd	Tolerance to Fusarium wilt (*Fusarium oxysporum*.f.sp. *momordicae*)
Watermelon	Tolerance to Fusarium wilt (*Fusarium oxysporum*),low temperature, draught tolerance, wilting due to physiological disorder)
Cucumber	Tolerance to Fusarium wilt, *Phytophthora melonis*, low temperature
Melon	Tolerance to Fusarium wilt (*Fusarium oxysporum*),low temperature, wilting due to physiological disorder, Phytophthora disease,

Advantages of Grafting

Manage soil borne diseases

A serious crop loss caused by soil-borne diseases aggravated by successive cropping. Grafting is an environment-friendly approach which is used to control soil borne diseases and increasing the yield of susceptible cultivars (Lee and Oda 2003) [10]. Grafting is used to get rid of soil-borne diseases such as *Fusarium* wilt in Cucurbitaceous crops (cucumber, melon etc.) and Bacterial wilt in Solanaceous crops (tomato, pepper etc.) (Oda *et al*. 1999) [17]. Grafting is a quick method in melon for controlling race 1 and 2 of *Fusarium oxysporum f. melonis* (Nisini *et al*. 2002) [16]. Use of resistant rootstock in grafting in combination with integrated pest management practice is a very good option to reduce the use of methyl bromide for soil fumigation to kill these soil borne pathogens so it is also a boon in organic farming of vegetables.

Higher adaptability to environmental stresses

Abiotic stress significantly affects vegetable production both in open field and greenhouse condition.These include too cold, wet or dry, hypoxia, salinity, heavy metal contaminations, excessive and insufficient nutrient availability, and soil pH stress. Grafts were generally used to induce resistance against low and high temperatures, (Venema 2008) [24]. Grafting shows tolerance against salt and flooding (Yetisir *et al*. 2006) [25], improved water use efficiency (Rouphael *et al*. 2008) [21], increased nutrient uptake (Colla 2010) [3, 4] and alkalinity tolerance (Colla *et al*. 2010) [3, 4]. Highest yield was obtained in chilli under high-temperature conditions when grafted on sweet pepper rootstocks (Palada and Wu 2008). The negative effect of boron, copper, cadmium, and manganese toxicity also can be minimized by grafting (Savvas *et al*. 2008). According to Arao *et al*. (2008) [2], grafting reduce cadmium concentrations by 67–73% in eggplant fruit by grafting onto *Solanum torvum* in comparison to self-grafting or grafting onto *Solanum integrifolium* rootstocks.

Enhance the yield with better fruit quality

Tomatoes grafted on rootstocks BHN 1054, Cheong Gang, BHN 998, and RST 106 had lower bacterial wilt incidence and higher yields than the un-grafted and self grafted controls (Mc Avoy *et al*., 2011).The maximum fruit number (2.6 fruits) and fruit yield (13.60 kg/plant) were observed in grafted watermelons on bottle gourd rootstock by splice grafting against in 1.0 fruit/plant and 4.37 kg/plant respectively for the said parameters in direct seeded watermelon (Khankahdani *et al*., 2012) [8]. Investigation on growth and yield of grafted cucumber on different soilless substrates showed that, grafted plants produced significantly longer stems, longer root systems and 24% increased yield (Marsic and Jakse, 2010) [13]. The higher marketable yield recorded with grafting was mainly due to an improvement in water and nutrient uptake (Schwarz *et al*., 2010) [23].

Effect on fruit quality

Grafting is an important technology for improvement of quality of vegetables. In soilless tomato cultivation, grafted plants had higher marketable yield, fruit quality and pH content of fruits depending on rootstocks (Gebologlu *et al*. 2011) [7]. Watermelon grafted on to different rootstocks has been known to increase fruit quality, fruit firmness and thus increase shelf life of the fruit (Ali, 2012) [1]. Grafting has also an effect on fruit quality of cucumber. Davis *et al*. (2008) [5, 6] reviewed, that different rootstocks affect grafted cucumber quality characteristics such as fruit shape, skin and flesh color and texture, skin smoothness, firmness, rind thickness, and soluble solids content.

Requirements for successful grafting/precautions

The knife needs to be very sharp. A grafting knife needs to be razor-sharp to insure success.

Promising rootstock for grafting different vegetable crops

Scion	Rootstock
Cucumber	*Cucurbita moschata, Cucurbita ficifolia, Cucurbita maxima, Sicyos angulatus, Lagenaria siceraria.*
Melon (for open field)	*Cucurbita sp., C. Moschata x C. Maxima, Cucumis melo*
Melon (for green house)	*Cucumis melo, Benincasa hispida, Cucurbita sp., C. Moschata x C. Maxima*
Watermelon	*Citrullus lanatus, Cucurbita maxima, C. Moschata, Lagenaria siceraria*
Bitter gourd	*Cucurbita moschata, Lagenaria siceraria, Luffa aegyptica.*
Bottle gourd	*C. moschata, Luffa sp.*
Tomato	*Solanum pimpinellifolium, Solanum nigrum, Solanum lycopersicum*
Eggplant	*Solanum torvum, Solanum integrifolium, Solanum melongena, Solanum nigrum, solanum sissymbrifolium, solanum khasianum*

Infrastructure facilities for Pre and Post Grafting Management

Screen house: It is used for growing seedlings prior to grafting. This chamber is used for hardening the grafted seedling prior to transplanting to prevent leaf burning and wilting, to protect from rain. The grafted seedling takes 7 to 10 days for hardening treatment. It is also used to check the infestation of virus transmitting insect vectors such as whiteflies and aphids. It should be constructed with 60-mesh nylon net. Double door system, the upper half of the structure should be covered with a separate UV resistant polyethylene to prevent UV light penetration.

Grafting chamber: It is used for formation of better graft union. It should be constructed with two 70% green mesh shade cloth and one layer of 100% black shade cloth. In this chamber grafts should be kept for 5-7 days. Reduces water stress by reducing transpiration, maintains high humidity (95%), temperature of 28-29 ^{0}C and reduces light intensity in the healing chamber increase the callus formation

Grafting methods

Different grafting techniques are standarised for different scions and rootstocks, grafting objectives, farmers' experience, and post-grafting management conditions. Different grafting methods includes cleft grafting, tube grafting, whip and tounge grafting, splice grafting, bud grafting, flat grafting, hole insertion grafting, tounge approach grafting etc. This to review the importance and exploitation of grafting technique on selected fruit vegetables for yield, quality, disease resistant and stress tolerant. As per the review, Tomato and eggplant are mainly grafted by, cleft and tube method of grafting and toung appoarch is adopted for cucurbits mainly for cucumber, Hole insertion grafting is the most popular grafting method in watermelon, Slant-cut grafting is easier and has recently become popular for watermelon and melon. This method was developed mainly for robotic grafting and their success is varied among the crops being grafted. Small-scale farmers select tongue approach grafting for most vegetables whereas large-scaled experienced professional seedling producers like to adapt splice grafting. Manual or hand grafting is the major grafting method even though several grafting machines and semi-automatic machines or robots have been developed and commercially available.

Hole insertion grafting (HIG)

It is also known as terminal or top insertion grafting. This method is mostly used for cucurbits, mainly for watermelon. This method was described in 1970 by Fujii and has recently been adopted by nurseries. This method is very easy with high survival rates and less proon to soil born disease. scion seedling size needs to be smaller than the rootstock seedlings. In this method squash or bottle neck gourd are used as rootstock. Watermelon seeds are sown 7–8 days after the sowing of gourd rootstock seeds or 3–4 days after sowing squash rootstock seeds. Grafting is made 7–8 days after the sowing of watermelon seeds. The true leaf including the growing point should be carefully and thoroughly removed with a scoping motion. A hole is made with a bamboo or plastic gimlet or drill at a slant angle to the longitudinal direction in the removed bud region

The hypocotyl portion of the watermelon scion is prepared by slant cutting to a tapered end for easy insertion into rootstock hole. After that the grafted plant is placed into a healing chamber.

Tongue approach grafting (TAG)

It is usually done in watermelons, cucumbers, and melons. Scion and rootstock seedlings need to be similar height and stem diameters. In this method, seeds of cucumber are sown 10-13 days before grafting and pumpkin seeds 7-10 days before grafting, to ensure uniformity in the diameter of the hypocotyls of the scion and rootstock. The growing point of the rootstocks should be carefully removed so that the shoot cannot grow. The grafting cut for rootstock should be made in a downward direction and the scion cut in an upward direction at an angle, usually 30°–40° to the perpendicular axis in such a way that they tongue into each other. Grafting clips are placed to secure graft position at the graft union site. The hypocotyl of the scion is left to heal for 3-4 days and crushed between fingers and later the hypocotyle is cut off with a razor blade 3 or 4 days after being crushed.

Splice grafting (SG), tube grafting (TG), and one cotyledon splice grafting (OC-SG)

This grafting method is mainly used for the vegetables seedlings which are grown in plug trays i.e. cucumber, watermelon two or three times faster than the conventional method and it is also popular among the Japanese seedling producers. The rootstock should be grafted when cotyledons and the first true leaf start to develop (about 7 to 10 days after sowing). One cotyledon and the growing tip are removed. The seedling is cut at a slant from the base of one cotyledon to 0.8–1.0 cm below the other cotyledon, removing one cotyledon and the growing tip. The length of cut on the scion hypocotyl should match that of the rootstock and should be at a 35° to 45° angle. The scion is attached to the rootstock and fixed tightly by a grafting tube or clip. OCG is called tube grating when the joined plants are held together with a length of tube instead of a grafting clip.

Cleft grafting (CG)

Cleft grafting had been used in cucurbits for a while in several countries, but the use is usually confined to solanaceous crops. The seeds of the rootstock are sown 5-7 days earlier than those of the scion. The stem of the scion (at four leaf stage) are cut at right angle with 2-3 leaves remaining on the stem. The rootstock (at the four to five leaf stage) are cut at right angles, with 2-3 leaves remaining on the stem. The stem of the scion is cut in a wedge, and the tapered end fitted into a cleft cut in the end of the rootstock. The graft is then held firm with a plastic clip. Move the tray filled with grafted plants to proceed for healing up.

Pin grafting (PG)

Pin grafting is basically the same as the splice grafting. Instead of placing grafting clips to hold the grafted position, specially designed pins are used to hold the grafted position in place. The cotyledons of the rootstock and scion are cut horizontally and a ceramic pin about 15 mm long and 0.5 mm in diagonal width of the hexagonal cross-section is inserted into the cut surface this helps align and secure the joined sections. This is very easy method, reducing labor cost, but ceramic pins are expensive, and a special environmentally-controlled chamber is needed to acclimatize the grafted plants.

Conclusion

So, we can conclude that Vegetable grafting has been safely adapted for the production of organic as well as environmentally friendly produce and minimizes uptake of undesirable agrochemical residues (Lee *et al*., 2010) [11] as well as the problems related to biotic and abiotic stress in vegetable production. Altough it has many benefits but due to lack of information it is not commercially used for vegetable production, so the researchers, extension specialist need to work together to integrate this modern technology as an effective tool for sustainable horticultural production.

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