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Review Paper

Grafting technique in vegetable crops - A review

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ABSTRACT

Grafting is a joining of two plant tissues, which are forced to develop vascular connection and grow as a single plant. Watermelon (*Citrullus lanatus* L.) plants grafted onto Lagenaria siceraria L. rootstock were the first grafted vegetable seedlings used to combat Fusarium wilt. In the Solanaceae and Cucurbitaceae families, vegetable grafting has been utilized for a variety of purposes, including enhancing resistance to biotic and abiotic challenges, and promoting plant growth and productivity. There are various manual grafting methods that suit each vegetable, and recently, grafting machines have been developed to produce the huge number of grafted plants required. In spite of their advantages, there are some limitations associated with them. These include the additional cost, some graft incompatibility leading to physiological disorders, and reductions in yield, fruit quality, and flower formation. Therefore, resort to the use of grafted plants should be done only after examining their benefits and risks.

Keywords: Fruit yield, low temperature stress, salt stress, soil-borne pathogens

Vegetable grafting is an asexual plant propagation technique by joining two plant parts to grow together by develop vascular connection and grow as a single plant. This eco-friendly technique induces resistance against soilborne disease, low and high temperatures, reduces uptake of persistent organic pollutants from agricultural soils, raises salt and flooding tolerance, and minimises boron and copper toxicity's detrimental effects (Mozafarian and Kappel 2020). Grafting is done by inserting a previously cut shoot into an opening in another plant namely “root stock” growing on its own root system. Scion (cyon) refers to the shoot piece or bud cut from a donor plant that will grow into the upper portion of the grafted plant. From a genetic perspective, grafting is the process of joining two (or more) unique genotypes to form a compound genetic system, with each genotype maintaining its own genetic identity throughout the life of the grafted plant.

History of vegetable grafting

Grafting has been used in agriculture for centuries to improve the health, production, and quality of produce from woody species like fruit trees and grape vines. Grafting was first utilized economically in vegetable cultivation in Asia in the twentieth century. Grafting of eggplants started in the 1950s, followed by grafting of cucumber and tomato around 1960 and 1970. The purpose of grafting has been greatly expanded from reducing infection by soil borne pathogens and pests (King *et al.*, 2008) to increasing low temperature, salt, flood and drought tolerance, enhancing water and nutrient uptake, increasing plant vigor extending the duration of economic harvest time and finally improving quality and increasing the yield (Huang *et al.*, 2009). During the earlier years, growers encountered many problems in growing of grafted vegetables such as lack of suitable rootstocks, grafting and curing techniques and poor quality of produce (Lee, 1994). However, many of these problems have been solved or minimized and the cultivation of grafted vegetables has now become a very basic cultivation technique for cucurbitaceous and solanaceous vegetables.

Recent rapid expansion of the vegetable nursery industry and commercial plug seedling production has stimulated research in developing efficient grafting machines to cut down the expense needed to produce grafted seedlings. Now there are many commercial nurseries specializing in the production of grafted seedlings in Japan and Korea. The development of efficient and reasonable priced grafting robots will undoubtedly increase the commercial supply of grafted vegetables not only in Japan and Korea but also in many other parts of the world.

Objectives of vegetable grafting

Objectives of grafted vegetables includes successfully raising of the crop under biotic and abiotic stresses, precocity, improvement of quality, enhanced plant vigor, bigger harvest of better quality fruit over a long period with fewer harmful inputs and other horticultural attributes. Detail objectives of grafting for each vegetable are given in (Table 1).

Table 1: Crop wise objectives of grafting

Vegetable	Objectives of grafting
Cucumber	Tolerance to *Fusarium* wilt, *Phytophthora melonis*, cold hardiness, favourable sex ratio, bloomless fruit (Yamamoto *et al.*, 1988)
Egg plant	Tolerance to bacterial wilt, *Verticillium albo-atrum*, *Fusarium* wilt, low temperature, nematodes, induced vigor and enhanced yield (Morra, 1998; Oda *et al.*, 1997)
Tomato	Tolerance to corky root, *Fusarium* wilt (Mazzolier, 1999) better color and greater lycopene content (Chung *et al.*, 1997; Oda *et al.*, 1994), tolerance to nematode (Satpathy and Pradhan, 1996)
Melon	Tolerance to *Fusarium* wilt, wilting due to physiological disorders, *Phytophthora* disease, cold hardiness, enhanced growth (Buitelaar, 1987)
Watermelon	Tolerance to *Fusarium* wilt, wilting due to physiological disorders, cold hardiness and drought tolerance (Mondal *et al.*, 1994)

Benefits of vegetable grafting:

Imparting disease and pest resistance: This is probably the most important reason commercial growers initially turned to grafted vegetables. Following the success of Asian growers with grafted melons in the 1920s, tomato grafting became popular in the 1960s as a way to avoid soil-borne diseases like bacterial wilt, which can be difficult to eradicate in a tomato crop due to its wide range of hosts and ability to persist for years in the soil. When a grower raises tomatoes and other solanum (e.g. potatoes, eggplant and peppers) in the same fields or in the ground in greenhouses year after year, a range of fungal, bacterial, viral, and nematode diseases can become established in the soil, leading to a poor yield with each subsequent harvest. Grafting has been found effective against *Verticillium wilt* (*Verticillium albo-atrum,* V. dahliae), *Fusarium* wilt (*Fusarium oxysporum*), corky root rot (*Pyrenochaeta lycosersici*), root-knot nematodes (*Meloidogyne*), bacterial wilt (*Ralstonia solanacearum*), Tobacco mosaic virus, and Tomato spotted wilt virus expanding the use of resistant rootstocks in grafting in combination with integrated pest management (IPM) practice, may help to reduce the need for soil fumigation by methyl bromide for many crops. This could be beneficial to organic food cultivation. Table 2 gives some of the vegetable diseases/pests controlled by grafting.

Minimizing the autotoxic effect: Recently autotoxic potential of some cucurbit crops have been pointed out which are serious problems. There are differences, namely,some species such as watermelon, melon and cucumber exhibit auto toxic potential but others do not. Possibly some phenolic acid of root tissue and root exudates act as auto toxins which affect ion uptake, photosynthesis and phytoharmone balance. It is possible to overcome auto toxicity in cucurbits crops by grafting on *Cucurbita ficifolia* (Yuan *et al.*, 2009).

Providing cold hardiness: Grafting is also useful to initiate the flowering and fruit set at low temperature which saves the energy of polyhouse to maintain day/night temperature regime. Early yield of cucumber was obtained by grafting on *C. ficifolia* through reducing the temperature regime of poly house from 23^0C/20^0C to 20^0C/12^0C and grafted plants survived at very low temperature i.e., 10^0C (Takahashi *et al.*, 1982).

Table 2: Vegetable diseases/pests controlled by grafting

Vegetable	Disease/pest	Reference
Cucumber	*Fusarium* wilt	Pavlou *et al.* (2002)
	Phytophthora	Wang *et al.* (2004)
	Nematodes	Giannakou and Karpouzas (2003)
	Verticillium wilt	Paplomatas *et al.* (2002)
	Black rootrot	Wiggell and Simpson (1969)
	Target Leaf spot	Hazama *et al.* (1993)
Melon	*Fusarium* wilt	Bletsos (2005)
	Vine decline	Cohen *et al.* (2000)
	Nematodes	Siguenza *et al.* (2005)
	Gummy stem blight	Crino *et al.* (2007)
	Verticillium wilt	Alabouvette *et al.* (1974)
	Black rootrot	Alabouvette *et al.* (1974)
Cucurbita spp.	Spider mites	Edelstein *et al.* (2000)
Watermelon	*Fusarium* wilt	Murata and Ohara (1936)
	Nematodes	Maroto and Miguel (1996)
	Verticillium wilt	Paplomatas *et al.* (2002)
	Virus coplexes	Wang *et al.* (2002)
Eggplant	Nematodes	Ioannou (2001)
	Verticillium wilt	Bletsos *et al.* (2003)
	Corky root	Ioannou (2001)
Tomato	Bacterial wilt	Grimault and Prior (1994)
	Fusarium wilt	Harrison and Burgess (1962)
	Corky root	Bradley (1968)
	Nematodes	Ioannou (2001)
	Verticillium wilt	Paplomatas *et al.* (2002)
	Tomato yellow leaf curl	Rivero *et al.* (2003)

Cold tolerance genotypes possess high level of linolenic acid and several other phospholipids than the cold sensitive. Hardening the plants by low temperature treatment results in a higher phospholipid level, more unsaturated phospholipids and a low sterol: phospholipids ratio, all of which may contribute to greater membrane fluidity. Soil heating reduces the phospholipids level in leaves, but results in higher content of 3-trans-hexadecenoic acid phosphatidyl glycerol. Grafting cucumber on cold resistant *C.ficifolia* enhances the level of trans hexadecenoic acid in phosphodialyl glycerol and imparts hardiness (Horvath *et al.*, 1983). Rivero *et al.* (2003) observed that concentration of proline, vitamin C (ascorbic acid) and water-soluble sugars of grafted seedlings were higher and water-soluble proteins was lower than in ungrafted plants. Under low temperature stress conditions, photosynthetic rates, chlorophyll content and soluble protein content decreases but all these traits were significantly higher in grafted seedlings. This indicates that higher photosynthetic rate of grafted seedlings under low temperature stress may be due to higher chlorophyll content, stomatal conductance and initial activity of ribulose-1, 5-biophosphate carboxylase/ oxygenase (Rubisco)

Flood tolerance: Intergeneric grafting imparts the attributes of flood tolerance in cucurbits. Generally flooding reduces photosynthetic rate, stomotal conductance, transpiration, soluble protein and activity of ribulose-1, 5-biophosphate carboxylase/ oxygenase (Rubisco). But these reactions can be minimized by intergeneric grafting.

Improving quality traits: Root stock effect the quality of fruit born on scions; the scion variety affects yield, and quality of fruit in grafted plant , but rootstock effects can drastically alter these characters Obtaining the improved quality with employing the grafting technique has not yet achieved much success. Matsumota. (1980) observed that grafting did not affect quality in cucumber viz. taste, size and shape. However, collar of the grafted plants was greater. More number of commercially acceptable and shiny fruits of cucumber was obtained by grafting on squash hybrids IKKy (Kanizares and Goto 1988). In melon, deterioration in taste and texture, poor fruit quality, showing a yellow, green stripes or spots or necrosis of the fruit flesh have been reported (Matsuda and Honda 1981; Koutsika *et al*,. 2002). Grafting on rootstock of either the melon cultivar Suiker or 841 has been proven to increase sugar content in Galia and Haonmelon. (Buitelaar, 1987). Increase in number of marketable fruits and decreased number of malformed, underdeveloped and gray mold infected fruits have been obtained in tomato by grafting. Further, grafted fruit had a better color and highest lycopene content (Chung *et al.*, 1997). Increased tomato fruit quality of grafted tomato under saline conditions has also been reported by Garcia *et al*. (2004). Colla *et al.* (2006) reported improved fruit quality by increasing firmness, dry matter, acidity and total soluble solid contents in grafted melon fruits.

Grafting and the type of rootstock used have been shown to impact the pH, flavour, sugar, colour, carotenoid content, and texture of fruit vegetables. The rootstock/scion combinations must be carefully chosen for best fruit quality. Because various rootstocks have optimal temperature and moisture ranges, it's also necessary to research rootstock/scion combinations under a variety of climatic and geographic situations. Davis *et al.* (2008) reported an overview of the effect of grafting on vegetable quality.

Manipulating the harvesting period: Altering in harvesting period either early or late often prove to be advantageous to the growers and consumers both. Cucumber grafted on to *C. ficifolia* grew faster and expressed 200 % early yield. This rootstock is also useful for late crops (Ufflen, 1983). The number of harvested fruit in summer cucumber cv. Shogoin-aonanga increased by grafting on Hokushin or Aodai rootstocks (Asao *et al.*, 1999). In melon, highest early yield of Galia and Haon was observed on rootstocks of either of the melon cultivar Suiker or 841 (Buitelaar, 1987).

Influence on sex expression: Due to flow of substances, changes occur in flowering pattern of the grafted scion (Friedlander *et al.*, 1977). *C. hardwickii* scion grafted on monoecious/gynoecious cultivars of cucumber expressed increased total flowers and pistillate flower (Nienhuis *et al.*, 1979). Inability of cucumber to express flower when grafted on hybrid squash seedlings (*C. maxima* x *C. moschata*) of without meristem indicates that root may control floral formation by the production of inhibitory factors in some day neutral cucurbitaceous plants (Satoh, 1996). *Sicyos angulata*, a natural species with a relatively short day, was induced to flower not only by grafting it onto a flower induced plant, but also by grafting it onto a flower induced plant.

Grafting methods: Various grafting methods have been developed and growers must choose their methods suitable for their requirement. The following are some of the methods:

1. Tongue approach grafting
2. Tube/one cotyledon /splice/slant grafting
3. Hole insertion /terminal/top grafting
4. Cleft/side insertion/ approach grafting
5. Pin grafting
6. Double grafting

Tongue approach grafting (TAG): This method is easy and requires a low relative humidity micro climate after grafting, thus often adopted by farmers. Although this method requires more space and labour compared to other methods, high seedling survival rate can be attained even by beginners. However, the grafting position is close to the ground making it easy for adventitious roots from the scion to reach the soil. This approach is also ineffective for rootstocks with hollow hypocotyls. This method is most commonly used in cucurbits and egg plant. The scion and rootstock should be approximately the same diameter. This is usually the case after the rootstocks have fully developed cotyledons and the scion has cotyledons and the first true leaf. The rootstock is cut through the hypocotyls at 35^0 to 45^0 angles. The developing point can be left in place by cutting halfway through the hypocotyls with a grafting knife or razor blade, or it can be removed with a grafting knife or razor blade. In addition, the scion is sliced at an angle (upward if the rootstock's growing tip stays connected) and joined to the rootstock with the cut surfaces aligned. Lead strips, aluminum foil, or grafting clips are used to hold the grafts together. When metal strips are used, they can remain on the plant once the plant has healed. However, the grafting clips need to be removed once the union is healed. There is an additional cost for clips for labour to remove those 15-20 days after grafting. If the rootstock's top was left on after grafting, it should be removed five days later. Seven to ten days after grafting, the scion hypocotyls are cut off immediately below the graft union. Grafted plants are maintained in the green house until ready for transplanting. This is at least two days after removing the scion roots. A humidity chamber is not required (Lee, 1994; Lee *et al.*, 1998; Oda, 1999; Lee and Oda, 2003; Hassell and Memmott, 2008).

One cotyledon grafting (OCG): This method is used in watermelon, cucumber oriental melon and tomato. OCG, also known as slant/splice or tube graft, is commonly used, and has recently been adopted by commercial plug seedling nurseries (Sakata *et al.*, 2007). Most vegetables may be processed using this method, which can be done by hand, machine, or robot. This approach is preferred when rootstocks have thin stems (Amadio, 2004; Sakata *et al.*, 2007). When the rootstock and scion are of similar size, this approach works well. The rootstock should be grafted when cotyledons and the first true leaf start to develop (about 7 to 10 days after souring). 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 growing tip. The length of the cut on the scion hypocotyls should match that of the rootstock and should be at a 35^0 to 45^0 angle. The grafting tube or clip is used to secure the scion to the rootstock (Oda, 1999; Lee and Oda, 2003). Grafted plants should be maintained in the dark at 25^0C and 100% humidity for three days or until the junction has healed, before moving them into a greenhouse maintained at 21^0C to 30^0C. Plants should not be more than 33 days old before transplating (Kapeil *et al*, 2004). Because scions easily come off at an early stage, this method necessitates thorough post-grafting treatment. When the joined plants are kept together with a length of tube rather than a grafting clip, OCG is known as tube grafting (Hassell and Memmotf, 2008).

Hole insertion grafting (HIG): This method, also known as terminal graft and top insertion graft, is the most popular cucurbit grafting method in China. This method is easy, has high survival rates, and the grafted plants have fewer incidence of soil borne diseases because of the high graft union (Hang *et al*, 2005). One person can produce 1500 or more grafts per day and post grafting acclimatization is simple. This method was described in 1970 by Fujii and has recently been adopted by nurseries (Sakata et al, 2007). For watermelon grafting, a modified HIG method was devised, in which the root system is separated from the rootstock. Rootstock seeds are usually planted 2-4 days before scion seeds. Rootstocks are ready for grafting when both cotyledons and first true leaf start to develop (about 7-10 days after sowing). The rootstock's growing point is removed; a cut is made and then drilled at a 35^0 to 40^0 angle using a bamboo or plastic gimlet. The scion hypototyl is cut to form a 7-8 mm long wedge. The scion is then inserted into the prepared rootstock hole. This method does not require additional labour for clipping, transplanting, cutting off remaining scion roots, or clip removal. It does, however, necessitate a greater level of talent than TAG, as well as an appropriate environmentally controlled humid or healing chamber. To achieve a high rate of success, relative humidity should be maintained at approximately 95%. After the healing process is complete, grafted plants are transferred and maintained at $21\text{-}36^0$C in the green house until junction is healed. Before transplanting, plants should be no more than 33 days old. The main problem with HIG is that the size of the rootstock hole is limited by rootstock size. Therefore, the scion size has to be controlled, narrowing the grafting period (Kubota *et al.*, 2007).

Cleft grafting: The cleft graft (CG) also known as the side insertion graft, is used in tomato, brinjal and cucurbits. The CG has largely been replaced by OCG, HIG and TAG because of the higher success rate and the uniform growth obtained from those methods (Amadio, 2004). However in Italy and France, CG is still one of the most common techniques (Buzi *et al.*, 2002). The CG methods is suitable for rootstocks with wide hypocotyls. Because the grafting junction is high on the hypocotyls, this procedure is straightforward and quick to learn, and it is good for preventing soil-borne illnesses. When cotyledons and the first true leaf start to develop (about 7-10 days after souring), the rootstock is ready to graft. The rootstock's growing tip can be removed during grafting or after the grafted plants have been removed from their high humidity chamber for around five days. A slit is cut on the rootstock hypocotyls with a razor blade and held open with a tooth pick. The width of the cut varies depending on the diameter of the scion's hypocotyls. The scion hypocotyls is cut from both sides at 35^0 to 45^0 angles and then inserted into the slit in the rootstock. The tooth pick is removed. Then the two cut surfaces are matched and held together with a grafting clip or silicon sleeve. Plants that have been grafted should be moved to a humidification chamber or a healing room. Plants should be maintained in the green house until the junction is healed and should not be more than 33 days old before transplanting.

Pin grafting: This method is similar to OCG, except that specially designed pins are used instead of grafting clips to secure the graft union. The rootstock and scion cotyledons are cut horizontally and a ceramic pin is placed into the cut surface. This helps align and secure the joining sections. This method's limiting factor is that the scion and rootstock should be approximately the same diameter so the cambial regions are in close contact. This method is easy, reducing labour cost, but ceramic pins add expense and a special environmentally controlled chamber are needed to acclimatize the grafted plants.

Double grafting: Double grafting is used when a perfect rootstock for a specific scion is unavailable. For example, if the rootstock is too large and an intermediate sized stem is needed to bridge the rootstock (Fig. 1). The middle rootstock is then grafted on to another rootstock, which has good resistance to soil borne diseases. Unfortunately, this method increases labour and cost while decreasing survival rate.

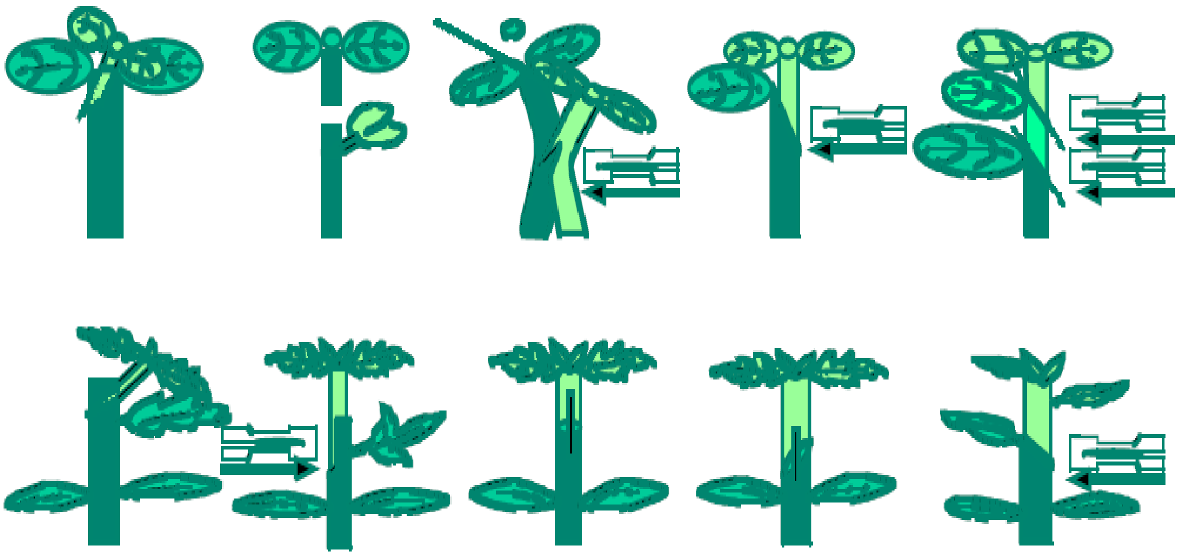

Fig. 1: Various grafting methods for cucurbits (top) and solanaceous plants (bottom) from top left: Hole insertion grafting, tongue approach grafting, splice grafting and double splice grafting for cucurbits. From bottom left epicotyl insertion grafting, cleft grafting, and splice grafting

Species and varieties for grafting: Many fruit-bearing vegetables use inter-generic grafting, such as cucumber (Cucumis sativus L.) grafted on pumpkin (*Cucurbita* spp.), watermelon (*Citrullus lanatus* Matsum. et Nakai) grafted on bottle gourd (*Lagenaria siceraria* Standl.), and melon (*Cucumis melo* L.) grafted on white gourd (also (*Benicasa hispida* Cogn.). In most cases, inter-specific grafting is used on eggplant (Solanum melongena L.). Scarlet eggplant (*S. integrifolium* Poir.) and scarlet torvum Swartz are common eggplant rootstocks. A large number of varieties for rootstock (Table 3) have been bred and released for use by growers.

Production of rootstock and scion and grafting compatibility: Quality seed and proper plant growth procedures of both rootstock and scion material are critical for grafting to be successful. It's critical to use high-quality seed with consistent germination. Take advantage of primed seed if it is available. This seed germinates more quickly and uniformly. Regardless of whether rootstock seed is placed in cell trays or germination beds, rootstock seed is usually sown 5 to 7 days before scion seed. When the scion emerges, the cotyledon of rootstocks should be fully grown, and the scion should be kept at low relative humidity before grafting to avoid pathogen infections. The rootstocks should have good tolerance to biotic and abiotic stresses and not negatively affect fruit quality. The compatibility between rootstock and scion should be high and stable. In general, grafting compatibility is related to taxonomic affinity. For example, luffa and melon have higher compatibility with netted melon compared with Chinese pumpkin and wax gourd (Wei *et al.*, 2006).

As grafting is a composition of two different plants, some beneficial or negative effects (besides the effect of soil borne pathogens), may arise after grafting. Graft in compatibility, as reviewed by Andrews and Marquez (1993), is differentiated from graft failure that often results from environmental factors or lack of skill of the grafter. Graft incompatibility could be attributed to various issues such as failure of the rootstock and scion to form a strong union, inability of the grafted plant to grow, or premature death of either rootstock or scion after grafting when grafting conditions have been effectively provided. Also, physiological incompatibility may occur due to lack of cellular recognition, wounding responses, presence of growth regulators, or incompatibility toxins. Johkan *et al.*, (2008) reported that ascorbic acid promotes graft-take in pepper plants.

Because the vascular link cannot establish adequately after grafting, grafting incompatibility can arise at an early stage. Incompatibility with grafting can also be postponed until the fruiting stage, when vast volumes of nutrients and water are required. Grafted plants then succumb early, making harvesting impossible. Compatibility is also influenced by the age of the rootstock and scion. For different species and grafting methods, the optimal seedling age varies. Seedlings that are too young are too delicate to handle during the grafting procedure, while seedlings that are too mature might generate undesirable meristematic development on rootstocks.

Mechanism of graft compatibility – incompatibility: The mechanism of graft compatibility - incompatibility is not fully known, and many studies have focused on this issue in attempt to better understand graft development mechanisms. These studies look at cytological and biochemical responses that occur early in the grafting process, as well as the impact these events have on the long-term graft response. Some ideas suggested that cellular recognition could play a role in the development of a functional vascular link starting with the formation of the first callus. Callus development, on the other hand, can be a passive response to a wound that has no bearing on future compatibility responses. Pina and Errea (2005) looked at a number of factors that could affect graft success, including the presence of growth regulators and peroxidases, the inherent system of cellular incompatibility, the formation of plasmodesmata, vascular tissue connections, and the presence of growth regulators and peroxidases. Furthermore, when graft bridging is established and functional, phloem mobile proteins have been found to cross the graft interface. The review gives an overview of the graft response as well as recent improvements in our understanding of the mechanisms involved in the establishment of cohesiveness between the stock and scion during graft ontogeny.

Acclimatization: Once grafting has been taken place and the necessary procedures followed, the proper healing chamber is critical to ensure that complete union has formed. With the case of TAG, this means only an adequate green house with temperature controls. Other approaches, on the other hand, necessitate the use of a specific healing chamber with light, humidity, and temperature controls. Some nurseries producing grafted plants, have chambers (growth chambers or healing chambers) to maintain temperature above 20^{0}C to 25^{0}C with relative humidity (RH) controls maintained between 85% and 100% (Miguel, 1997). Other nurseries acclimate grafted plants in small plastic tunnels within greenhouses where a high relative humidity can be maintained (above 85 percent). When using a healing chamber in the summer, shading is frequently essential. After 6 to 8 days, grafted plants are acclimated to the natural conditions of the greenhouse by slowly dropping the humidity and increasing light. Temperatures of 22 to 280°C, RH close to 100 percent, and extremely low light intensity for the first 5-7 days are ideal for grafting (Miguel, 1997; Lee and Oda, 2003, Hassell and Memmott, 2008).

Table 3: Rootstocks and major grafting methods

Vegetables	Rootstock species	Grafting methods
Watermelon	Gourd	Hole insertion
	Interspecific hybrids	Hole insertion and tongue
	Wax gourd	Hole insertion and Cleft
	Pumpkin	Tongue and cleft
	Squash	Hole insertion and tongue
	Sicyos angulatus	Tongue
Cucumber	Fig leaf Gourd	Tongue
	Interspecific hybrids	Hole insertion and tongue
	Cucumber	Tongue
	Sicyos angulatus	Tongue
Oriental melon	Interspecific hybrids	Tongue
	Cucurbita moschata	Tongue
	Cucumis melo	Cleft
Melons	*Cucumis melo*	Tongue and cleft
Tomato	*Lycopersicon.pimpinellifolium* L	Cleft
	Lycopersicon.hirsutum	Cleft
	Lycopersicon.esculentum	Cleft
Egg plant	*Solanum.integrifolium*	Tongue and cleft
	Solanum.torvum	Tongue and cleft

Manual vs mechanized/automated graft: Grafting is done in two ways: manually and mechanically (robotic grafting). The grafting and post-grafting activities in hand grafting require three to four workers, each of whom is allocated to a certain step in the process. Manual grafting techniques yield approximately 100 grafts each day per individual (Lee and Oda, 2003). Grafting is arduous task and efforts are being made to reduce the labour cost. Since 1987, attempts have been made to automate grafting. The first semi-automatic cucumber grafting system was commercialized in 1993 and others have been developed since. A simple grafting machine can produce 350-600 grafts per hour with two operators (Gu, 2006). That is an increase of 400 to 3000 grafted plants per person per day. Grafting robots for plug have been developed by combining the adhesive and grafting plates (Kurata, 1994, Oda ,1995). This robot makes it possible for eight plugs of tomato, egg plant or pepper to be grafted simultaneously. Recently a fully automatic grafting system for cucurbitaceous vegetables has been designed in which seedling quality estimation is done by using fuzzy logic and neutral network.

The first grafting robot developed was the "Cutting-off Cotyledon Grafting" (CCG) system developed by IAM BRAIN (Suzuki *et al.*, 1995 a and b) to graft cucurbit vegetables. The robot takes into account seedling morphology, cutting and gripping locations, cutting, and attaching. Seedlings were cut at the point of attachment of the cotyledon to the hypocotyls at an angle of 10^0 for the scion and 30^0 for the rootstock. The first grafting robot was built in 1987, followed by the second in 1989. A grafted plant with a 95% survival rate was created in three seconds (Onoda, et al 1992). Various other prototype grafting robots were also described by Kurata, (1994) three grafting robots have been developed in Korea, two in 1998 and one in 1999 and one was commercialized in 2001. The pin grafting robot developed by Rural Development Administration for Solanaceous crops can graft 1200 seedlings per hour. Yupoong invented a simple and inexpensive grafting machine that has become highly popular in Korea. This machine priced about $ 400, has been exported for more than 10 years to many Asian countries and some European countries. Tongue approach grafting allows the machine to graft up to 600 seedlings per hour, especially in cucurbitaceous crops. However, to operate this equipment successfully and efficiently, an expert operator is required.

Table 4: Problems associated with grafting and cultivating grafted vegetable seedlings

Factors	Category	Possible mitigating measures
Labor	Grafting operation	Specifically designed knives, grafting apparatus, grafting machines, grafting robots
	Post graft care	Experience needed and post graft conditioning chamber may be required for automation
Techniques	Rootstocks	Wise selection of rootstock suitable for type of crops and cultivars
Management	Fertilizer application	Different field management, especially reduced fertilizer application
Compatibility	Uneven senescence	Proper timing of growing season and rootstock type and selection
Growth	Excessive vegetative growth	Reduced fertilizer and soil moisture
	Physiological disorders	Wise selection of rootstocks to reduce excessive water and nutrient uptake
Fruit quality	Size and shape Appearance Insipid taste Soluble solids, Yellow band in fresh Internal decay	Partly controlled with rootstocks. Proper cultural management. cultivar and rootstock selection Proper soil moisture conditions. May appear in red flesh of watermelon Foliar Ca application and reduced N
Expense	Rootstock seeds	Inexpensive rootstock seeds (Domestic or imported)
Scion rooting	External Rooting	Careful management and during seedling stage and at transplanting
	Internal or fused rooting	Different grafting methods to avoid scion root development through internal cavity of rootstock hypocotyl, which often cannot be recognized externally.

The demonstration model robot was deemed practical and the results were transferred to an agricultural machinery company that developed machines for the market (Kobayashi *et al.*, 1996). A prototype semi automatic grafting system was also developed by Hwang *et al.*, (2000) in Korea. Several grafting robots have been manufactured by the Rural Development Administration (RDA), Korea (Kang, 2000) and distributed to the commercial plug seedling growers at relatively reasonable prices. In Spain, automated methods represent less than 5% of the total cucurbit grafts, but are much higher in Japan. At present 40% of watermelon grafting in Japan is done by the automated method (Lee and Oda, 2003). Grafting robots are being developed in Japan and Korea that are more forgiving or seedling uniformity and require less labour to operate than older grafting machines. They're pricey and necessitate very consistent germination. The robots typically use the root pruning OCG method. First commercial model of a grafting robot (GR 800 series, Iseki 2 Co. Ltd, Matsuyama, Japan), became available for cucurbits in 1993 (Kobayashi, 2005) Kubota *et al.*, (2008) report a fully automated grafting robot for cucurbits with scion and rootstock feeders that pick, orient and feed the scion and the rootstock shoots to the grafting processor, performing 750 grafts per hour with a 90% success rate. In a few years, the new robot will be available for purchase.

Problems associated with grafting: Various problems are commonly associated with grafting and cultivated grafted seedlings (Table 4). The labour and skills necessary for the grafting process, as well as the post-graft care of grafted seedlings for speedy healing for 7 to 10 days, are major issues. A skilled grafter can graft up to 1200 seedlings every day (150 seedlings per hour), but the numbers vary depending on the grafting process. Similarly, the post-graft management procedure is largely determined by grafting techniques. In general, the problems listed in (Table 4) could be minimized or easily overcome by careful cultural management and wise selection of scion and rootstock cultivars.

CONCLUSIONS

Grafting technology besides imparting the resistance, reduce the need of soil disinfectants like methyl bromide and provide opportunity to produce vegetables in biotic and abiotic stress conditions, without use of chemicals. Despite the numerous challenges associated with cultivating grafted vegetables, the demand for effectively grafted vegetables is steadily increasing. Breeding multipurpose rootstocks and the availability of efficient grafting machines and grafting robots will undoubtedly encourage cultivation of grafted vegetables worldwide. Automatic grafting machines can increase grafting speed and increase the survival rate of grafted plants. So, further research needs to focus on rootstock development, more efficient grafting robots and development of acclimatization facilities. This research should considerably reduce the cost of grafted seedlings in future.

REFERENCE

Alabouvette, C., Rouxel, F., Louvet, J., Bremeersch, P. and Metion, M. 1974. REcherche d'un portegreffe resistant an phomopsis sclerotioides et au Verticillium dahliae pour la culture du melon et du concombre en serre. *Pepinieristes Hort Maraichers,* **152**: 19-24.

Amadio, A. 2004. Alternatives to methyl Bromide adopted for cucurbit production in projects funded by *Montreal Protocol. Proc Fifth International Conference on Alternatives to Methyl Bromided, Lisbon,* 71-74.

Andrews, P. K. and Marquez, C. S. 1993. Graft incompatibility. *Horticulture Reviews,* **15**: 183-232.

Asao. T., Shimizu. N., Ohta, K. and Hosoki. T. 1999. Effect of rootstocks on the extension of harvest period of cucumber (*Cucumis sativus* L.) grown in non-renewal hydroponics. *Journal of the Japanese Society for Horticultural Science*, **68**: 598-602.

Bletsos, F. A. 2005. Use of grafting and calcium cyanamide as alternatives to methyl bromide soil fumigation and their effects on growth, yield, quality and *Fusarium* wilt control in melon. *Journal of Phytopathology*, **153:** 155-61.

Bletsos. F., Thanassoulopoulos, C. and Roupakias, D. 2003. Effect of grafting on growth, yield and verticillium wilt of eggplant. *HortScience,* **38**: 183-86.

Bradley, J. 1968. Tomato grafting to control root diseases. *New Zealand Journal of Agriculture*, **116**: 26-27.

Buitelaar, K. 1987. Cultivars for the very early culture of melon. *Groenten en Fruit*, **42**: 26-29.

Buzi, A., Chilosi, G., Reda, R. and Magro, P. 2002. *Le principali fitopatie che colpiscono il melone. Colt. Prott.* **9***:* 31–45.

Chung, H. D., Youn, S. J. and Choi, Y. J. 1997. Effects of rootstocks on seedling growth and prevention of root rot *Fusarium* wlt (race J3) in different tomato cultivars. *Journal of Korean Society of Horticultural Science,* **38**: 327-32.

Cohen, R. S., Pivonia, S., Burger, Y., Edelstein M, Gramiliel, A. and Katan, J. 2000. Toward integrated management of *Monosporascus* wilt of melons in Israel. *Plant Diseases,* **84:** 496-505.

Colla, G., Rouphael. Y., Cardarelli, M., Massa, D., Salerno, A. and Rea, E. 2006. Yield, fruit quality and mineral composition of grafted melon plants grown under saline conditions. *Journal of Horticultural Science and Biotechnology*, **81**: 146-52.

Crino, P., Bianco, C. L., Rouphael, Y., Colla, G., Saccardo, F. and Paratore, A. 2007. Evaluation of rootstocks resistant to *Fusarium* wilt and gummy stem blight and effect on yield and quality of grafted 'Inodorus' melon. *HortScience,* **42:** 521-25.

Davis, A. R., Veazie, P. P., HAssell, R., Levi, A., King, S. R. and Zhang, X. 2008. Grafting effects on vegetable quality. *HortScience,* **43**: 1670-72.

Edelstein, M., Tadmor, Y., Albo, M. F., Karchi, Z. and Mansour, F. 2000. The potential of langenaria rootstock to carmine spidermite, in cucurbitaceae. *Bulletin of Entomological Research,* **90**: 113-17.

Friedlander, M., Atsmon, D. and Galvn, E. 1977. The effect of grafting on sex expression in cucumber. *Plant and Cell Physiology* **18**: 1343-50.

Garcia, F. N., Carvajal, M. and Enrique, O. 2004. Grafting union formation in tomato plants. *Annals of Botany*, **93**: 53-60

Giannakou, I. O. and Karpouzas, D. G. 2003. Evaluation of chemical and integrated strategies as alternatives to methyl bromide for the control of root knot nematodes in Greece. *Pest Management Science,* **59:** 883-92.

Grimault, V. and Prior 1994. Grafting tomato cultivars resistant or susceptible to bacterial wilt analysis of resistant mechanism. *Journal of Phytopathology- Phytopathologische Zeitschrift,* **141:** 330-34.

Gu, S. 2006. Development of 2JC-350 automatic grafting machine with cut grafting method for vegetable seedlings. *Transactions of the Chinese Society of Agricultural Engineering,* **22:** 103-06.

Hang, S. D., Zhao, Y. P., Wang, G. Y. and Song, G. Y. 2005. Vegetable grafting, China Agriculture Press, Beijing, China.

Harrison, D. J. and Burgess, P. G. 1962. Use of rootstock resistance for controlling *Fusarium* wilt of tomatoes. *Plant Pathology,* **11**: 23-25.

Hassell, R. L. and Memmott, F. 2008. Grafting methods for watermelon production. *HortScience,* **43**: 1677-79.

Hazama, W., Morita, S. and Kato, T. 1993. Resistance to corynespora target leaf spot in cucumber grafted on bloomless rootstock. *Annals of Phytopathological Society of Japan,* **59:** 243-48.

Horvath, I., Vigh, L., van Hasselt, P. R., Woltjecs, J. and Kuiper, P. J. C. 1983. Lipidcomposition in leaves of cucumber genotypes as affected by different temperature regimes and grafting. *Physiologia. Plantarum,* **57**: 532–536.

Huang, Y., Rui, T., Cliuling, C. and Zhilong, B. 2009. Improving the fruit yield and quality of cucumber by grafting onto salt tolerant rootstock under NaCl stress. *Scientia Horticulturae* **122:** 26-31.

Hwang, H., Kim, S. C. and Ko, K. D. 2000. Development of prototype automatic grafting system for fruit bearing vegetables. *Korean Journal of Agricultural Machinery,* **24**: 217-24.

Ioannou, N. 2001. Integrating of soil solarization with grafting on resistant rootstocks for management of soil borne pathogens of egg plant. *The Journal of Horticultural Science and Biotechnology*, **76:** 396-401.

Johkan, M., Oda, M. and Mori, G. 2008. Ascorbic acid promotes graft-take in sweet pepper plants (*Capsicum annuum* L.). *Scientia Horticulturae,* **116:** 343-47.

Kang, C. H. 2000. Status of vegetable grafting machine development in Korea and practical problems. Problems and Counterplans of vegetable seedling production. *Korean Research Society of Horticultural Science and Technology,* **19**: 122-23.

Kanizares, K. A. L. and Goto, R. 1998. Growth and yield of cucumber hybrid as a result of grafting. *Horticultura Brasileira* **16**: 110-13.

Kapiel, T., Rhodes, B., Dane, F. and Zhang, X. 2004. Advances in watermelon breeding. *Journal of New Seeds,* **6:** 289-322.

King, S. R., Davis, A. R., Liu, W. and Levi, A. 2008. Grafting for disease resistance. *HortScience,* **43**: 1673-76.

Kobayashi, K. 2005. Vegetable grafting robot. *Research Journal of Food and Agriculture* **28:** 15-20.

Kobayashi, K., Onoda, A., Suzuki, M. and Otsuka, H. 1996. Development of grafting roboto for cucurbitaceous vegetables. Part 4. Test for practical use. *Journal of the Japanese Society of Agricultural Machinery,* **58**: 59-68.

Koutsika, S. M., Traka, M. E., Paroussi, G., Vayiatzis, D. and Paraoussis, E. 2002. The cultivation of grafted melon in Greece, current Status Prospects. *Acta Horticulturae* **579**: 325-30.

Kubota, C. and McClure, M. A. 2008. Vegetable grafting: History, use and current technology status in North America. *HortScience,* **43**: 1664-69.

Kubota, C., McClure, M. A., Burelle, N. K., Michael, G. B. and Rosskopy, E. N. 2007. Vegetable grafting: history, use and current technology status in North America. *HortScience,* **43**: 1664-69.

Kurata, K. 1994. Cultivation of grafted vegetables. 2. Development of Grafting robots in Japan. *HortScience,***29:** 240-44.

Lee, J. M. 1994. Cultivation of grafted vegetables. I. Current status, grafting methods and benefits. *HortScience,* **29:** 235-39.

Lee, J. M. and Oda, M. 2003. Grafting of herbaceous vegetable and ornamental crops. *Hortic Rev,* **28:** 61-124.

Lee, J. M., Bang, H. J. and Ham, H. S. 1998. Grafting of vegetables. *Journal of the Japanese Society of Horticultural Sciences,* **67:** 1098-114.

Maroto-Borrego, J. N. and Miguel, A. 1996. El injerto herbaceo en la sandia (*Citrullus lanatus*) como alternativa a la desinfeccion quimica del suelo. *Investigacion Agraria. Produccion Y Proteccion Vegetales,* **11:** 239-53.

Matsuda, T. and Honda, I. 1981. Studies on physiological disorders of melon fruits. I. Influence of grafting and fruit pruning in 'Prince' melon. *Bulletin of the Vegetable and Ornamental Crop Research Station,* **5:** 31-50.

Matsumota, M. 1980. The mechanism of bloom occurrence on the surface of the cucumber fruits and methods for its prevention. *Bulletin of Toyama Agricultural Experiment Station,* **11**: 29-35.

Mazzolier, C. 1999. Grafting of tomato under protected cultivation. *PHM Revue Horticole ,* **404:** 44-48.

Miguel, A. 1997. Injerto do hortalizas, Serie Divulgacion Tecnica Conselleria de Agricultura, Pesca Alimentaci acuteon, Generalitat Valenciana, Valencia, 50-52.

Miguel, A., Maroto, J. V., San-Bautista, A., Baixauli, C., Cebolla, V., Pascual, B., Lopez, S. and Guardiola, J. L. 2004. The grafting of triploid watermelon is an advantageous alternative to soil fumigation by methyl bromide for control of *Fusarium* wilt. *Scientia Horticulturae,* **103:** 9-17.

Mondal, S. N., Hossain, A. K. M. A., Hossain, A. E., Islam, M. A. and Bashar, M. A. 1994. Effect of various rootstocks in the graft culture of watermelon in Bangladesh. *Punjab Vegetable Grower*, **29:** 15-19.

Morra, L. 1998. Potential and limits of grafting in horticulture. *Informatore Agario,* **54**: 39-42.

Mozafarian, M. and Kappel, N. 2020. Grafting plants to improve abiotic stress tolerance. **In**: *Plant ecophysiology and adaptation under climate change* (Ed. M. Hasanuzzaman),: mechanisms and perspectives II. *Springer, Singapore,* pp. 477–490

Murata, J. and Ohara, K. 1936. Prevention of watermelon fusarium wilt by grafting Lagenaria. *Japanese Journal of Phytopathology,* **6**: 183-89.

Nienhvis, J., Lower, R. L. and Pharr, D. M. 1979 Interspectific grafting to promote flowering in cucumis hardwickii, Cucurbit. *Genet Cooperative,* **2**: 11-12.

Oda, M. 1995. New grafting method for fruit bearing vegetables in Japan. *Japan Agricultural Research Quarterly (JARQ),* **29:** 187-94.

Oda, M. 1999. Grafting of vegetables to improve greenhouse production under protective structure. *International Seminar on Protective Structure for Improved Crop Production,* April 12-17, Suwen, Korea.

Oda, M., Nagaoka, M., Mori, T. and Sei, M. 1994a. Simultaneous grafting of young tomato plants using grafting plates. *Scientia Horticulturae,* **58:** 259-64.

Oda, M., Okada, K., Sasaki, K., Akazawa, S. and Sei, M. 1997. Growth and yield of eggplants grafted by a newly developed robot. *HortScience,* **32:** 848-49.

Onoda, S. A., Kobayashi, K. and Suzuki, M. 1992. The study of grafting robot. *Acta Horticulturae,* **319:** 535-40.

Paplomatas, E. J., Elena, K., Tsagkarakou, A. and Perdikaris, A. 2002. Control of verticillium wilt of tomato and cucurbits through grafting of commercial varieties on resistant rootstocks. *Acta Horticulturae,* **579:** 281-84.

Pavlou, G. C., Vaklounakis, D. J. and LigoxigaskisE, K. 2002. Control of root and stem rot of cucumber by *Fusarium oxysporum* f. sp. Radicis-cucumerinum, by grafting onto resistant rootstocks. *Plant Disease,* **86:** 379-82.

Pina, A. and Errea, P. 2005. A review of new advances in mechanism of graft compatibility-incompatibility. *Scientia Horticulturae,* **106:** 1-11.

Rivero, R. M., Ruiz, J. M. and Romero, L. 2003. Role of grafting in horticultural plants under stress conditions. *Journal of Food, Agriculture and Environment,* **1**: 70-74.

Sakata, Y., Takayoshi, O. and Mitsuhiro, S. 2007. The history and present status of the grafting of cucurbitaceous vegetables in Japan. *Acta Horticulturae,* **731:** 159-70.

Satoh 1996. Inhibition of flowering of cucumber grafted on rooted squash stock. *Physiologia Plantarum,* **97**: 440-44.

Satpathy, B. and Pradhan, K. 1996. By grafting, get a disease free tomato crop. *Indian Horticulture,* **40**: 31.

Siguenza, C., Schochow, M., Turini, T. and Ploeg, A. 2005. Use of *Cucumis metuliferus* as a rootstock for melon to manage *Meloidogyne Incognita. Journal of Nematology,* **37:** 276-80.

Suzuki, M., Kobayashi, K., Indooku, K. and Miura, K. 1995a. Development of grafting robot for cucurbitaceous vegetables (Part II). *Journal of the Japanese Society of Agricultural Machinery,* **57**: 103-10.

Suzuki, M., Kobayashi, K., Indooku, K., Miura, K. and Hirata, K. 1995b. Development of grafting robot for cucurbitaceous vegetables (Part I). *Journal of the Japanese Society of Agricultural Machinery,* **57**: 67-75.

Takahashi, H., Satio, T. and Suge, H. 1982. Intergeneric translocation of floral stimulus across a graft monoecious Cucurbitaceae with special reference to the sex expression of flowers. *Plant and Cell Physiology,* **23**: 1-9.

Uffelen, J. A. and Van, M. 1983. Rootstocks for grafting cucumbers. *Groeten-en Fruit*, **38**: 34-35.

Wang, J., Zhang, D. W. and Fang, Q. 2002. Studies on antivirus disease mechanism of grafted seedless melon. *Journal of Anhui Agricultural University,* **29:** 336-39.

Wang, H. R., Ru, S. J., Wang, L. P. and Feng, Z. M. 2004. Study on the control of *Fusarium* wilt and phytophthora blight in cucumber by grafting. *Acta Agriculturae Zhejiangenesis,* **16**: 336-39.

Wei, S. Y., Wu, Z. and Huang, J. 2006. Effects of rootstocks on growth and photosynthetic properties of grafted plants of netted melon. *Acta Agriculturae Shanghai,* **22:** 114-17.

Wiggell, P. and Simpson, C. J. 1969. Observations on the control of phomopsis root rot of cucumber. *Plant Pathology,* **18**: 71-77.

Yamamoto, Y., Hayashi, M., Majamuru, T. and Tanaka, Y. 1988. Studies on bloom on the surface of cucumber fruits. I. The degree of bloom occurrence and trichome characteristics. *Bulletin of the Fukuoka Agricultural Research Centre,* **13**: 23-26.

Yuan, H., Rui, T., Quiliang, C. and Zhilong, B. 2009. Improving the fruit quality of cucumber by grafting onto the salt tolerant rootstock under a NaCl stress. *Scientia Horticulturae,* **122**: 26-31.