Global Journal of Science Frontier Research: D
Agriculture and Veterinary
Volume 15 Issue 1 Version 1.0 Year 2015
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Reiview on Role of Grafting on Yield and Quality of Selected Fruit Vegetables

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GJSFR-D Classification : FOR Code: 820299

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Hassen Yassin [α] & Seid Hussen [σ]

Abstract- Grafting can be defined as the natural or deliberate fusion of plant parts so that vascular continuity is established between them and the resulting genetically composite organism functions as a single plant. Grafting used for a long time ago to increase uniformity, vigour and resistance to biotic and abiotic stresses of vegetatively propagated plants (i.e. fruit and ornamental trees and shrubs). The technique also applied in vegetable production to tackle biotic and abiotic stresses. Grafting of vegetables is a common practice in different parts of the world, but not in Ethiopia. However, there is no review attempt made so far pertinent to the issues of vegetable grafting in Ethiopia. Therefore, this paper aimed to review the importance of grafting on selected fruit vegetables yield, quality, disease resistant and stress tolerant. As per the review, fruit vegetables mainly grafted by tongue, cleft and splice method of grafting and their success is varied among the crops being grafted. Investigations conducted on tomato, cucumber, watermelon and eggplant revealed grafting had a pronounced positive effect on yield, quality, on tackling soil borne diseases, stress due to water and salinity, heavy chemical and drins. In spite of the role of grafting in fruit vegetables there are challenges related to the incomplete resistance of grafted seedlings, presence of high number of scion/rootstock combinations, the need for skilled workers, cost of grafted seedlings and limited research works obstruct the diffusion of this technology.Though application of grafting has aforementioned problems, breeding programs for production of multipurpose rootstocks, developing efficient grafting machines and improved grafting techniques will undoubtedly encourage use of grafted seedlings all over the world. In addition introduction of new rootstocks with desirable traits compatible with locally selected scions can boost the status of grafting technology. Therefore, application of grafting in fruit vegetables has bright prospects in the world. As a result of its benefits and value, demand for high-quality grafted seedlings by growers and is expected to rapidly increase in Ethiopia due to the expansion of private farms those intended to sell the produces to local and export market. And producers currently faced problems due to biotic and abiotic stresses in fruit vegetable production that push them to apply grafting techniques as alternative means.

Keywords: grafting, fruit vegetable, yield, quality, stress.

I. Introduction

Agriculture began some 10,000 years ago when ancient peoples, who lived by hunting and gathering, began to cultivate plants and domesticate animals. It is the deliberate cultivation of crops and animals for use by humans which involves plant breeding, plant propagation, crop production and food technology (Hartmann *et al.,* 2002).

Since the origins of agriculture, the progressive domestication of food crops has been intimately related to a series of innovations in plant propagation (Mudge *et al*., 2009). Among plant propagation techniques, grafting is the common and practiced long time ago in fruit industry. 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) and the resulting genetically composite organism functions as a single plant (Mudge *et al*., 2009). In grafting, the upper part (scion) of one plant grows on the root system (rootstock) of another plant. Unlike budding, which can be performed before or during the growing season, most grafting is done during winter and early spring while both scion and rootstock are still dormant.

As Hartmann *et al*. (2002) described the sequence events of the grafted herbaceous plants. First, new parenchymatous cells proliferate from both stock and scion produces the callus tissues that fill up the spaces between the two components connecting the scion and the stock. Following, the new cambial cells differentiate from the newly formed callus, forming a continuous cambial connection between the stock and scion. Furthermore, prior to the binding of vascular cambium across the callus bridge, initial xylem and phloem may be differentiated. The wound repair xylem is generally the first differentiated tissue to bridge the graft union, followed by wound-repair phloem. Finally, the newly formed cambial layer in the callus bridge begins typical cambial activity forming new vascular tissues. Production of new xylem and phloem thus permits the vascular connection between the scion and rootstock.

Leonardi and Romano (2004) reported that, grafting used for a long time ago to increase uniformity, vigour and resistance to biotic and abiotic stresses of vegetatively propagated plants (i.e. fruit and ornamental trees and shrubs). Especially grafting has been used in the horticultural industry for woody species, such as apples and grapes, for centuries (Rivard and Louws, 2006). Not only woody species, grafting of herbaceous seedlings is a unique horticultural technology practiced for many years in East Asia to overcome issues associated with intensive cultivation using limited arable land for vegetable production (Kubota and Michae,

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2008). The technique becoming a common practice in Japan, Korea, the Mediterranean basin and several European countries with several objectives including increasing plant tolerance to environmental stresses like low soil temperatures, salinity, heavy metal toxicity and unsuitable soil conditions (Lee and Oda, 2003; Chang *et al.*, 2008).

Vegetable production with grafted seedlings was originated in Japan and Korea to avoid the serious crop loss caused by infection of soil-borne diseases aggravated by successive cropping. This practice is now rapidly spreading and expanding over the world. 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). Recorded data revealed that, grafting of watermelon onto bottle gourd to increase its tolerance to soil-borne diseases (Heidari *et al.*, 2010) and to diminish fusarium wilt (Rivard and Louws, 2006). The major vegetable crops being grafted are: tomato, cucumber, eggplant, melon, pepper and watermelon (Nichols, 2007). And commonly grafted with splice or tube, tongue and cleft method (Khankahdani *et al.*, 2012).

Ethiopia has favorable conditions for the production of a number of vegetable crops. The wide range of altitude from below sea level to over 3000 m.a.s.l., gives it wide range of agro-ecological diversity ranging from humid tropics to alpine climates, where most types of vegetable crops can be successfully grown. Further, the abundant labor, vast land and water resources give her an opportunity and facilitation for the production of different types of vegetable crops (Fekadu and Dendena, 2006). Currently there are commercial farms that engaged in exporting vegetables like potato, beans, shallot, cucurbits, tomato, etc.

However, lack of high-yielding, multiple pest and disease resistant cultivars, proper agronomic practices, appropriate pest and disease control techniques and lack of sufficient quantity of seed supply are some of the constraints in vegetable production in Ethiopia (Fekadu and Dendena, 2006). Abiotic and biotic stresses preclude crop varieties from displaying their full genetic potential and fuel the development of new, improved varieties bur development of new is time-consuming, expensive, technically-demanding, and marked by compromise since gains in one attribute can be offset by declines in another. Grafting is a proven technique for enhancing crop genetic potential but it is under-utilized in vegetable production (Kleinhenz *et al.,* 2009).

Continuous cropping is inevitable in greenhouses, but this reduces the yield and quality of produce. Soil borne diseases and nematodes has become a problem in Ethiopia for vegetable producers in green house and in particular Jittu Farm has these problems. Since soil sterilization can never be complete, grafting has become an essential technique for the production of repeated crops of vegetables grown in both greenhouse and open field condition. Hence, the aim of this paper is to review the recent literatures on the responses of grafted plants to some biotic and abiotic stress so as to increase yield and quality of selected fruit vegetables.

II. Overview of Fruit Vegetable Grafting

Grafting is one of the techniques used to combine one plants part with another to encourage a unified plant using different methods so as to minimize or avoid biotic and abiotic stresses. Even though, there are some challenges in application of the technique, but producers used as alternative solution for production problems.

a) Grafting

Most plants multiply from seeds whereas certain plants are preferentially multiplied from their parts such as stem, roots, or leaves. Multiplication of plants using parts other than seeds is known as vegetative (asexual) propagation and the resultant plants are referred to as clones. For various reasons, some plants are multiplied by combining vegetative plant parts (stem or vegetative buds) from two separate plants into one. Grafting and budding are techniques used to combine one plant part with another to encourage growth as a unified plant (Kumar, 2011).

According to Besri, (2008) grafting is a method of asexual plant propagation that joins plant parts for them to live together. So they will grow as one plant. Grafting is accomplished by inserting a piece of stem containing three to four vegetative buds onto the stem of the plant that will serve as the root system for the unified plant (Kumar, 2011). There are points should be considered during grafting and these are: incompatibility, plant species and type of graft, environmental conditions during and following grafting, growth activity of rootstock and craftsmanship of grafting (Hartmann *et al.,* 2002).

Furthermore, for a successful graft union to form, the cambium of the rootstock and scion must be well aligned and in contact with one another. The scion and rootstock plants must therefore have similar stem diameters at the time of grafting. However, the scion and rootstock may not germinate or grow at the same rate. Conducting a preliminary trial to determine the growth rates of rootstock and scion plants in the growing environment is vital (Johnson *et al.,* 2011).

Normally the method has been largely applied to propagate trees that will not root well as cuttings or whose own root systems are not strong enough or resistant to several soil-borne pathogens. But now the method is used for other crops, as vegetables, such as solanaceous plants (tomato, eggplant and pepper) and cucurbits (melon, cucumber and watermelon) (Besri, 2008).

b) Methods of Grafting for Fruit Vegetables

Grafting methods vary considerably with the type of crops being grafted, and the sowing time for scion and stock seeds vary with grafting method and crop. However, the most common methods for grafting fruit vegetables are the splice or tube, tongue and cleft grafting method. Splice grafting also known as top grafting, tube grafting, and slant-cut (45°) grafting (Appendix Figure 1). This is the most widely used grafting technique for tomatoes and also works well for eggplants (Johnson *et al.,* 2011).

Tongue-approach grafting also known as side-by-side grafting which is one of the grafting techniques in which the rootstock and scion while are on itself roots is grafted together (Appendix Figure 2). After confidence of graft place union, scion and rootstock are cut below and above of graft place, respectively (Khankahdani *et al.,* 2012).

Cleft grafting also known as apical grafting and wedge grafting (Appendix Figure 3). According to Johnson *et al.,* (2011) it can accomplish through making horizontal cut to remove the top of the plant. Then a 0.5cm long vertical incision made in to the centre of the rootstalk and scion has to be cut a 0.5cm long wedge so as to insert it into the vertical incision in the rootstalk. Finally, a scion roots from the grafted plants such that the two are completely separated within three days.

Hole insertion grafting is also one of the other grafting technique in vegetables which in this technique rootstock is cut from above of cotyledons and is made a hole in cutting place and the scion (consist cotyledons and hypocotyl axis) is placed into hole (Khankahdani *et al.,* 2012).

The methods used for different vegetables depend on different factors and research proved this fact. Hole-insertion grafting was highly effective in watermelon and cucumber (Salehi *et al.,* 2008). While one may choose "one cotyledon graft" is also known as "splice", "slant" or "tube" graft due to its simplicity and less labour intensive than the approach graft (Hassell and Memmott, 2008) cited in Ali (2012). Table 1 depicted the fact that, irrespective of rootstalk used, grafting techniques alone affect the graft union percent efficiency for watermelon (Khankahdani *et al.,* 2012).

Table 1 : Comparison the effect of grafting techniques, rootstocks and interaction between them on graft union percent on watermelon at Iran

	Grafting Technique			
Rootstock	Hole insertion	Splice	Tongue-approach	Mean
Bottle gourd	6.8^{c}	75.4^{a}	25.8^{bc}	36.0^{A}
Shintoza	5.4^{c}	41.5^{b}	15.7^{bc}	20.9^{B}
Pumkin	0.0^{c}	12.8^{bc}	6.4^{c}	6.4^{C}
Mean	4.1^{C}	43.2^{A}	16.0b^{B}	

Means with small letters, followed by similar letters are not significantly different at the 1% level according to Tukey's test (HSD). In below row or right column, means with capital, followed by similar letters are not significantly different at the 1% level according to Tukey's test (HSD). Source: (Khankahdani et al., 2012).

In general, grafting methods varied based on different factors. And research has to be done to evaluate the efficiency of grafting methods for specific crop. Tomato and eggplants are mainly grafted by conventional splice and cleft grafting. The survival ratio of grafted *Cucurbitaceae* plants is higher if a tongue approach grafting is used, especially for cucumber. This is because the root of the scion remains until the formation of the graft union. Splice grafting is easy to do and has recently become popular for watermelon and melon (Marsic and Osvald, 2004).

c) Reasons for Grafting of Fruit Vegetables

The rationale behind grafting of plants may be to get benefits from rootstocks, aimed to changing the cultivars of established plants, hastening plant growth rate and earlier fruit production and or to study and elimination of virus diseases (Hartman *et al.,* 2002). In addition, grafting is used to reduce infections by soil-borne pathogens and to enhance the tolerance against abiotic stresses (Krumbein and Schwarz, 2011).

Investigation done on tomato showed that, 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). Vegetable grafting is nowadays extremely popular in some countries and is mainly used to improve plant tolerance to biotic stresses occurring particularly in intensive agro-systems. This technique has also been proposed as a way to enhance vegetable tolerance to abiotic stresses (Leonardi and Colla, 2011). In addition to avoid soil-borne diseases, watermelon grafting onto cucurbit rootstocks is another agronomic interest for plant vigour and production (Ali, 2012).

Environmental stresses represent the most limiting conditions for horticultural productivity and plant exploitation worldwide. Important factors among those are temperature, nutrition, light, oxygen availability, metal ion concentration etc. One direction out of these problems is to develop crops that are more tolerant to such stresses. This is carried out with tremendous efforts particularly at breeding companies; however, due to a lack of practical selection tools like genetic markers, it is a slow and inefficient process so far. As one effect, each year a high number of new cultivars are released which can be used by the growers. A special method of adapting plants to counteract environmental stresses is by grafting elite, commercial cultivars onto selected vigorous rootstocks (Lee and Oda, 2003).

In line with this, one of the possible applications of grafting in commercial vegetable production is the mitigation of stress caused by adverse chemical soil conditions in the root environment (Schwarz *et al.,* 2010). Studies revealed that, grafting fruit vegetables onto appropriate rootstocks may be used to mitigate or even eliminate yield restrictions owing to nutrient and heavy metal toxicities and minimize intake of heavy metals by consumers (Savvas *et al.,* 2010).

The other stress in vegetable production is water which quickly becoming an economically scarce resource in many areas of the world, especially in arid and semiarid regions. Ethiopia has also arid and semiarid regions those showed shortage for water. The increased competition for water among agricultural, industrial, and urban consumers creates the need for continuous improvement of irrigation practices in commercial vegetable production. One way to reduce losses in production and to improve water use efficiency under drought conditions in high-yielding genotypes would be grafting them onto rootstocks capable of reducing the effect of water stress on the shoot as observed in tree crops (Garcia *et al.,* 2007).

Furthermore, growers go for grafting to alleviate problems related to organic pollutants. Drins (aldrin (oxidized to dieldrin) and endrin) have been categorized as a group of persistent organic pollutants because of their high toxicity, high bioaccumulation and persistency in the environment. Since 1995, aldrin was permitted for import to Congo, Ethiopia, Malaysia, Nepal, SriLanka, Sudan, Tanzania, Thailand, Trinidad and Tobago, and Venezuela. Fortunately, grafting can reduce the uptake of these pollutants to the plant tissue. Investigation on cucumber revealed that, it is possible to reduce aldrin pollution in cucumber by about 50% using a low-uptake rootstock like 'Yuyuikki-black' (Schwarz *et al.,* 2010). For better result, selecting of low-uptake rootstock varieties is a promising practical technique to reduce dieldrin concentration in cucumber fruits grown in contaminated fields.

d) World Status of Fruit Vegetable Grafting

Intensive labour input and resulting high costs of grafted seedling production have been issues preventing this technology from being widely adopted outside of Asia. However, along with the development of efficient commercial production techniques for grafted seedlings and the introduction of new rootstocks with desirable traits compatible with locally selected scions, grafting technology was introduced to European countries in the early 1990s (Oda, 2002) mainly through marketing efforts of international seed companies and through information exchanges among research communities. As a result, many countries in Europe, the Middle East, Northern Africa, Central America, and other parts of Asia (other than Japan and Korea) adopted the technology and the areas introducing grafted plants increased rapidly during the past two decades (Kubota *et al.,* 2008).

Furthermore, with the rapid development of intensive protected cultivation technologies using high tunnels and greenhouses, which presumably prevented farmers from continuing traditional crop rotation, vegetable grafting became a crucial tool to overcome soil borne diseases and other pests. In the 1990s, nearly 60% of open fields and greenhouses in Japan producing muskmelon, watermelon, cucumber, tomato, and eggplant were reportedly planted with grafted seedlings (National Research Institute of Vegetables, 2001) and 81 % in Korea. Over 500million grafted seedlings are produced annually in Japan (Kobayashi, 2005). Surveys conducted in North America in 2002 and 2006 showed that the total number of grafted seed-lings used in North America was over 40million with the majority of these used in hydroponic tomato greenhouses (Kubota et al., 2008).

In Greece, grafting is highly popular, especially in southern areas, where the ratio of the production area using grafted plants to the total production area, amounts to 90-100% for early cropping of watermelon and 40-50% for melons under low tunnels, 2-3% for tomato and egg plants, and 5-10% for cucumbers (Khah *et al.,* 2006). Report of status of grafting in countries is presented in Table 2.

Table 2 : Use of grafted vegetables in the world (2007)

Country	Watermelon	Cucumber	Melon	Tomato	Eggplant	Pepper
Israel	70%	*	5%	15%	5%	*
Japan	93%	72%	30%	48%	65%	5%
Korea	98%	95%	95%	15%	2%	25%

Greece	100%	5 -10%	40-50%	2-3%	*	*
Spain	98%	*	3%	4500ha	*	*
Morocco	*	*	*	75%	*	*
Cypres	80%	*	*	170ha	*	*
Italy	30%	*	5-6million	1200ha	*	*
France	*	3%	1000ha	2800ha	*	*
Netherlands	*	5%	*	50%	*	*
Turkey	30%	5%	*	25%	10%	*

**= No data available. (Source: Hishtil South Africa (PTY), 2007).*

With respect to Ethiopia, at present, different vegetable crops are produced in many home gardens and also commercially in different parts of our country. These include onion, garlic, shallot, capsicum, tomato, cole crops, Ethiopian kale, head cabbages, watermelon, muskmelon, pumpkin, beetroot, carrot, snap bean, sweetpotato, Irish potato, anchote, colocosia, yam, taro, moringa etc. Most of them are produced by individual growers and others by private investors as well as state enterprises (Fekadu and Dendena, 2006).

Nevertheless, application of grafting on fruit vegetables in Ethiopia is not well known and not used by individual growers and private sectors too, except grafting trials of cucurbits, pepper and tomato to combat soil borne diseases at Jittu farm (Bishoftu site).

III. Role of Grafting on Selected Fruit Vegetables

Grafting in fruit vegetables play a great role in increasing yield and quality and helps to provide resistance/tolerance to biotic and/or abiotic stress.

a) Role of Grafting on Tomato

Tomato (*Lycopersicon esculentum* Mill.) is a crop of high importance in many countries (Marsic and Osvald, 2004). It is also popular and widely grown vegetable crop in Ethiopia ranking 8th in terms of annual national production (Ambecha *et al.,* 2012). However, there are production problems like weeds, insect pests and diseases including late blight and Fusarium wilt reducing the yield (Ambecha *et al.,* 2012). Among other mechanisms, grafting is one of the techniques to solve some of the aforementioned problems existed in tomato (Pogonyi *et al.,* 2005).

i. *Effect of grafting on yield and quality of tomato*

Tomato is one of the most important horticultural crops in the world and grafting has become an important cultural practice for this fruit vegetable. Continuous cropping is inevitable in vegetable production especially in indoor areas, and this reduces the yield and quality of the produce (Marsic and Osvald, 2004).

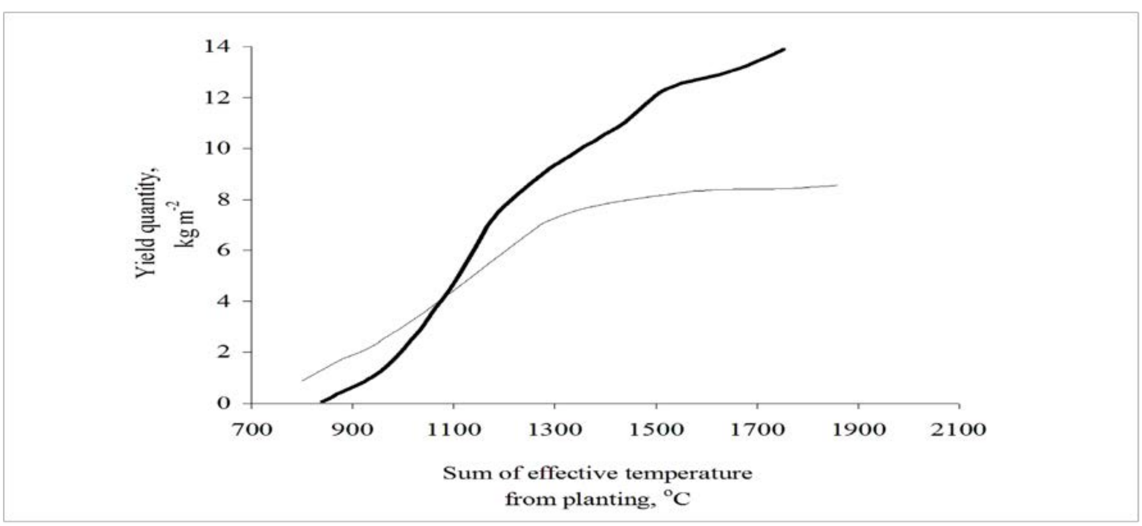

Figure 1 : Accumulated yield quantity of tomato fruits from grafted (solid line) and un-grafted (light line) plants at Hungary. Source: (Pogonyi *et al.,* 2005)

A perusal of Figure 1 showed that, accumulated fruit yield of tomato was significantly higher on grafted plants than on un-grafted ones (the difference is 62%). This change was caused partly by the increased fruit number (14%) and partly by the fruit weight (45%) (Pogonyi *et al.,* 2005).

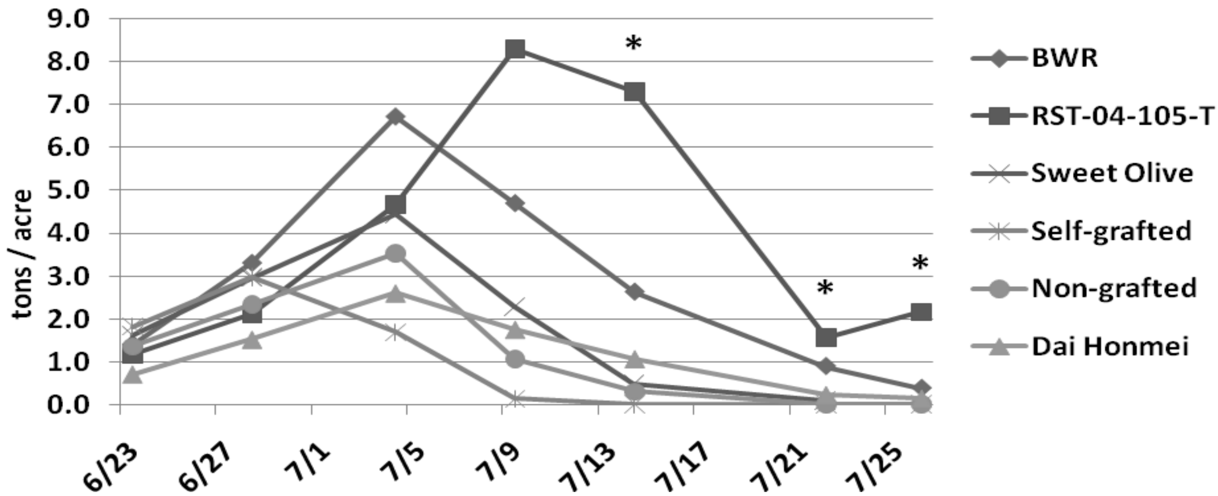

Figure 2 : Total weekly fruit yield for grafted and non-grafted 'Celebrity' tomatoes over time at North Carolina

Source: (O'Connell, 2009).

In parallel research conducted at Black River Organic Farm in North Carolina also confirmed that, fruit yield of tomato significantly affected through grafting techniques (Figure 2). Fruit yield collected on weekly based showed that, on the corresponding sample date the 'Celebrity-RST-04-105-T' grafts had significantly greater values compared to the 'Celebrity-Sweet Olive' grafts, non-grafted, and self-grafted treatments (O'Connell, 2009). Similarly, increase in yield of tomato due to grafting also reported (Marsic and Osvald, 2004; Pogonyi *et al.,* 2005; Khah *et al.,* 2006; Kleinhenz *et al.,* 2009; Garden News, 2011).

Concerning fruit quality traits and how grafting affects them, there are some contradictory results. Traka-Mavrona *et al* (2000) cited in Nicoletto *et al.* (2012) reported that the solutes associated with fruit quality are translocated in the scion through the xylem, whereas quality traits, e.g. fruit shape, skin colour, skin or rind smoothness, flesh texture and colour and soluble solids concentration are influenced by the rootstock (Nicoletto *et al.,* 2012). Presumably, fruit quality affected due to the rootstock–scion interaction. This could induce overgrowth and undergrowth of the scion, leading to important changes in water and nutrient flow uptake. In contrast to this result, Vrcek *et al.* (2011) reported, nutritional properties of grafted tomatoes indicated satisfactory quality.

ii. *Grafting of tomato in resistance/tolerance to biotic and abiotic stress*

The primary purpose of grafting vegetables worldwide has been to provide resistance to soil borne diseases (King *et al.,* 2008). Soil borne diseases (corky root, fusarium wilt, verticillum wilt, bacterial wilt) and nematodes, are some of the biotic stress cause damages in vegetable production and especially in continuous cropping in greenhouses (Lee and Oda, 2003; Pogonyi *et al.,* 2005). The most common disease controlled by grafting appears to be fusarium wilt on tomato crops caused by various pathovars *of Fusarium oxvsporum* Schltdl (King *et al.,* 2008). The list of diseases that are shown to be reduced by grafting listed in Appendix Table1.

Most greenhouse tomato growers are using grafting techniques to decrease susceptibility to root disease and to increase fruit production through increased plant vigour (Vrcek *et al.,* 2011). Investigation revealed that, disease pressure is severe (96-100%) of the non- and self-grafted 'celebrity' controls were killed by southern blight (Figure 3). Furthermore, two weeks after first harvest >80% of the non- and self-grafted celebrity had been infected. However, the examined rootstock-specific hybrids (celebrity grafted on to RST-04-105-T) had lower southern blight incidence (54-64%) than the non- and self-grafted controls (O'Connell, 2009).

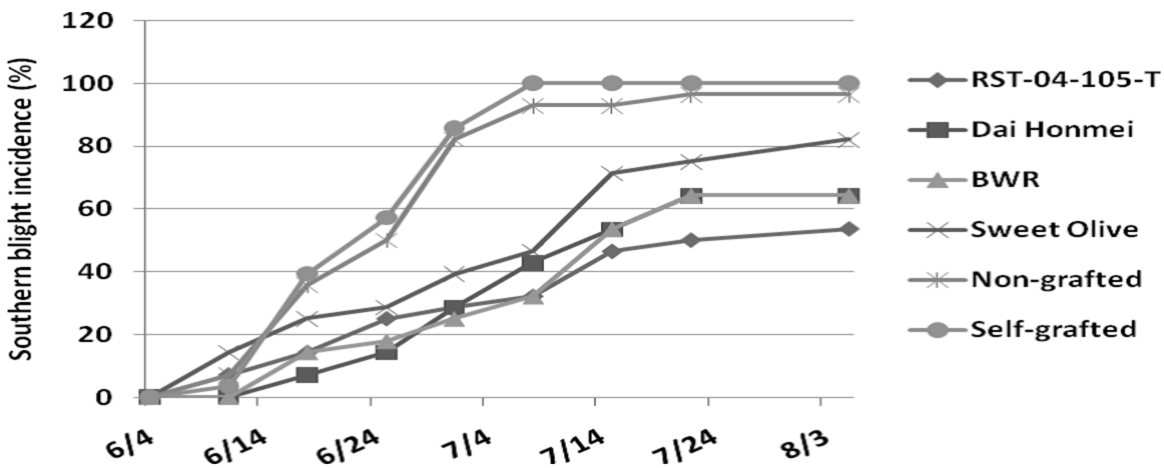

Figure 3 : Southern blight disease progress curve grafted and non-grafted 'Celebrity' tomatoes over time at North Carolina

Source: (O'Connell, 2009).

In the same fashion grafting on tomato contributed in combating root not nematode in which the susceptible tomato cultivar grafted on beaufort dramatically reduced root galling due to root-knot nematodes, and this was the best treatment among all other treatments (Kaskavalci, *et al.,* 2009).

Abiotic stress significantly affects tomato 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. These conditions cause various physiological and pathological disorders leading to severe crop loss (Savvas *et al.,* 2010). Nevertheless, grafting can provide resistance and or tolerance to tomato for such conditions. Salinity in soil or water is one of the major abiotic stresses that reduce plant growth and crop productivity worldwide (Arzani, 2008). Grafting tomato plants for increased salinity tolerance is a promising practice to improve the crop performances in saline soil conditions (Colla et al., 2010).

b) Role of Grafting on Cucumber

Cucumber is one of the most cultivated crops in the world both in open field and greenhouse condition and application of grafting help to counterattack soil borne pathogens especially in controlled environment (Marsic and Jakse, 2010).

i. *Effect of grafting on yield and quality of cucumber*

Investigation on growth and yield of grafted cucumber on different soilless substrates showed that, grafted plants formed a significantly larger stems and longer root systems which led to 24% increased yield (Marsic and Jakse, 2010). Based on result Table 3, irrespective of substrate, grafting treatment alone increased the yield of cucumber.

Table 3 : Main effects of substrate and grafting on marketable yield of cucumber fruits

Treatment	Marketable yield Kg/plant	Number of fruits/plant
Substrate		
Perilite	7.90[a]	24.00[a]
Clay pellets	6.10[b]	18.30[b]
Grafting		
Grafted on	7.72[a]	23.60[a]
Un-grafted	6.22[b]	18.80[b]

Means followed by different letters are significantly different at $P < 0.05$ using Duncan's Multiple Range Test Source: (Marsic and Jakse, 2010).

Yield increment due to grafting of cucumber also proved by Reid and Klotzbach in 2011. A perusal use of Figure 4 depicted that, grafted plants of both varieties Manar and Diva out yielded their un-grafted counterparts.

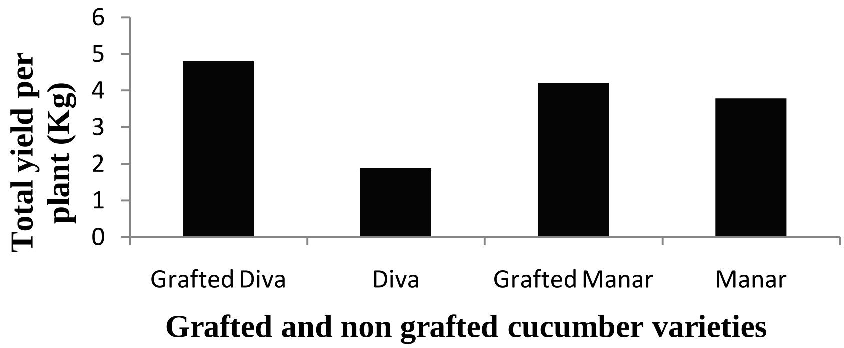

Figure 4 : Cucumber fruit yield per plant of grafted and non grafted varieties

Source: (Reid and Klotzbach, 2011).

Grafting has also a pronounced effect on cucumber fruit quality. As Davis *et al.* (2008) reviewed, 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.

ii. *Grafting of cucumber in resistance/tolerance to biotic and abiotic stress*

Greenhouse experiment conducted to evaluate the effect of different cucurbit rootstock on growth and yield of cucumber under the impact of root-knot nematode revealed that, rootstock type affected the fruit yield where Strongtosa and Shintosa produced higher marketable yield ranging from 260% to 280% of that un-grafted plants (Al-Debei *et al.*, 2011).

Grafted cucumber better survives and gave acceptable yield and quality that un-grafted one under abiotic stress. Research conducted to evaluate grafting effect on cucumber under stress caused due to NaCl showed that, grafted cucumber showed comparable flavor, taste and nutrient contents to those of non-grafted plants and the least impact registered on grafted cucumber (Zhou *et al.*, 2010).

c) Role of Grafting on Watermelon

Grafting is widely used for the production of fruit bearing vegetables in Japan, Korea and some other Asian and European countries where intensive and continuous cropping is performed. And currently, watermelon is one of the vegetables in which grafting is performed intensively in the world (Bekhradi *et al.*, 2011).

i. *Effect of grafting on yield and quality of watermelon*

The greatest fruit number was observed in grafted watermelons on bottle gourd rootstock by splice grafting (2.6 fruits) and the least in direct seeded watermelon (1.0 fruit). According to Table 4, Fruit yield is greatest in grafted watermelons on 'Bottle gourd' rootstock by splice grafting technique (13.60 kg/plant) and the least recorded in seedy watermelons (4.37 kg/plant) (Khankahdani *et al.*, 2012).

Table 4 : Comparison of different types of watermelon plant based on evaluated characters

Plant type	Fruit yield (kg/plant)
Seedy	4.37^{e}
Transplant	5.63^{d}
Shintoza rootstock Splice grafting	11.97^{b}
Bottle gourd rootstock Splice grafting	13.60^{a}
Shintoza rootstock Tongue-approach grafting	10.67^{c}
Bottle gourd rootstock Tongue-approach grafting	12.17^{b}

Means in each column, followed by similar letters are not significantly different at the 5% level according to Tukey's test (HSD). Source: (Khankahdani et al., 2012).

With regard to watermelon fruit quality, grafting on to different rootstocks has been known to increase fruit firmness and thus increase shelf life (Ali, 2012). In support of this study, irrespective of cultivars of watermelon cultivars, grafting treatment alone affected firmness which was greater from plants grafted to rootstock '451' and '1330' (Table 5). Fruit soluble solid content (SSC) and lycpopene also varied with the cultivar and rootstock (Davis and Perkins-Veazic, 2005).

Table 5 : Comparison of fruit quality from grafted and non-grafted watermelons

Cultivar	Rootstock	Type	SSC	Firmness (Pa)	Lycopene (ug/g)
SF800	None	Control	12.20^{a}	7.90^{b}	63.7^{b}
	1330	Squash	10.90^{b}	10.50^{a}	65.8^{a}
	451	Gourd	10.70^{b}	11.80^{a}	60.1^{b}
SS5244	None	Control	11.70^{ab}	7.50b	56.00^{b}
	1330	Squash	10.70^{b}	10.20^{a}	61.10^{a}
	1332	Gourd	11.60^{ab}	6.30^{b}	64.20^{a}
	451	Gourd	12.20^{a}	10.50^{a}	65.40^{a}

Means followed by the same letter are not significantly different by the Bonferoni method at the 5% level of probability. Source: (Davis and Perkins-Veazic, 2005).

ii. *Grafting of watermelon in resistance/tolerance to biotic and abiotic stress*

The role of grafting in giving resistant to diseases provides boosting production. Research proved the resistant gourd rootstocks to disease has been led to double production of watermelon in south eastern of United State of America (Khankahdani *et al.*, 2012). In line with this, grafting of watermelon onto other cucurbitaceae rootstocks to provide soil-borne disease resistance has been highly successful (Ali, 2012). Furthermore, researches proved that, grafted watermelon plants onto wild watermelon rootstocks (*C. Lanatus* var. *citroides*) were resistant or moderately resistant to the southern root knot nematode, *M. incognita*. (Thies and Levi, 2007). Grafted watermelon has potential to survive under abiotic stress. Research showed that, grafted mini-watermelons onto a commercial rootstock (PS 1313: Cucurbita maxima Duchesne X Cucurbita moschata Duchesne) revealed a more than 60% higher marketable yield when grown under conditions of deficit irrigation compared with un-grafted melons. The higher marketable yield recorded with grafting was mainly due to an improvement in water and nutrient uptake (Schwarz *et al.*, 2010). In consistent to this result, grafting watermelons with saline-tolerant rootstocks showed yield increases up to 81% under greenhouse production in the Mediterranean (Colla *et al.*, 2009).

d) Role of Grafting on Eggplant

Eggplant (*Solanum melongena* L.) is widely cultivated in tropical and temperate regions around the world and is amenable to grafting (King *et al.*, 2010). Eggplant is susceptible to numerous diseases and parasites, in particular to *Ralstonia solanacearum*, *Fusarium* and *Verticillum* wilts, nematodes and insects (Collonnier *et al.*, 2001).

i. *Effect of grafting on yield and quality of eggplant*

Like the mentioned crops grafting in eggplant play role in increasing yield (Figure 5). However, the economic feasibility has to be studied before application of the techniques (Reid, 2012).

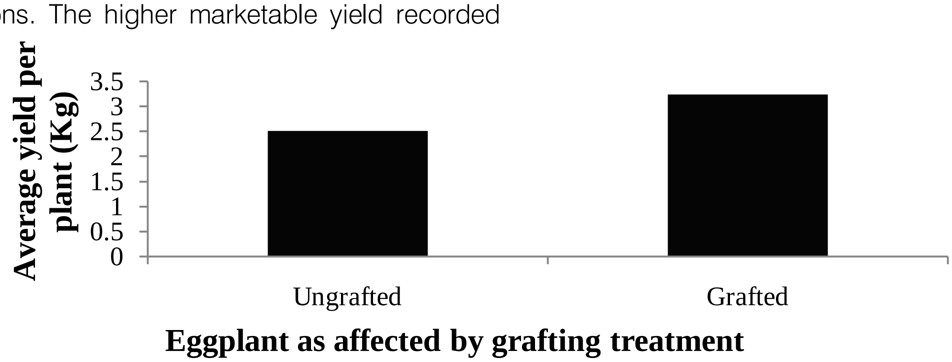

Figure 5 : Average yields per plant of grafted and un-grafted eggplant. Source: (Reid, 2012)

In horticultural industry, the focus has traditionally been on yield. However, in recent years consumer interested in the quality of vegetable products has increased worldwide. Vegetable quality is a broad term and includes physical properties, flavor, and health-related compounds (Rouphael *et al.*, 2010). Although there are many conflicting reports on changes in fruit quality resulting from grafting in vegetables (Davis *et al.*, 2008a), Oxalic acid content of eggplant fruit differed significantly depending on grafting and cultivar (Table 6). The average oxalic acid content of Faselis was 18% lower than that of Pala. Grafting resulted in a significant reduction (9%) in average oxalic acid content in both cultivars (Çuruk *et al.*, 2009).

Table 6 : Mean values of oxalic acid of eggplant cultivars grown with or without rootstock

Treatment	Oxalic acid (%)
Cultivar	
Pala	0.113[a]
Faselis	0.093[b]
Grafting	
Un-grafted	0.108[a]
Grafted	0.098[b]

Means in each column, followed by similar letters are not significantly different in Duncan's multiple range tests at 5% probability. (Source: Çuruk et al. 2009).

In contrast grafting of eggplant on *Solunum torvum* and *Solunum Sisymbriifolium* negatively affected vitamin C content, firmness and some sensory attributes but overall impression was not influenced (Arvanitoyannis *et al.*, 2005). The differences in reported results may be due in part to different production environments, type of rootstock used, interactions between specific rootstocks and scions, and harvest date. There are many reasons why rootstocks affect scion fruit quality. The most obvious is rootstock/scion incompatibility, which induces undergrowth and/or overgrowth of the scion, leading to decreased water and nutrient flow through the grafted union, ultimately causing wilting (Davis *et al.*, 2008b). Nevertheless, to get positive effect of grafting on vegetable quality, rootstock/scion combinations should be carefully selected for specific climatic and geographic conditions (Davis *et al.*, 2008a).

ii. *Grafting of eggplant in resistance/tolerance to biotic and abiotic stress*

Grafting of eggplant on to appropriate rootstalk is environmentally friendly solution to counter biotic stress. Investigation proved that, grafted eggplant which was planted on infected soil with wilt disease produced better yield over the non-grafted plants (Bletsos *et al.*, 2003).

Non-nutrient heavy metals such as cadmium, arsenic, lead, and mercury, which are harmful for both plants and humans, are introduced to agricultural ecosystems from various sources, including industry, reclaimed wastewater, and soil amendments originating from various sources (Diacono and Montemurro, 2010). Even though, problem of heavy metal contamination in fruit vegetables is currently not widespread, some recent reports are worrying (Savvas *et al.*, 2010). Survey conducted in Japan showed that, approximately 7% of eggplant fruit contain cadmium at concentrations exceeding the internationally acceptable limit for fruiting vegetables (Arao *et al.*, 2008). Hence, grafting fruit vegetables onto appropriate rootstocks, may limit the heavy metals accumulation in the aerial parts, thereby mitigating their adverse effects on crop performance and human health (Savvas *et al.*, 2010).

According to Arao *et al.* (2008), grafting reduce cadmium concentrations in eggplant fruit by grafting onto *Solanum torvum*. In particular, grafting *Solanum melongena* plants onto *Solunum torvum* reduced the leaf and stems cadmium concentrations by 67–73% in comparison to self-grafting or grafting onto *Solanum integrifolium*, in both cadmium polluted and unpolluted soils.

IV. Challenge and Prospects of Grafting on Fruit Vegetables

a) Challenges

Though grafting play significant role in fruit vegetable production, it has challenges that might attributed for low diffusion of the technology. Among those, the presence of different rootstocks for each species that are proposed by seed companies as being resistant or tolerant to soil born diseases and nematodes. Besides, lack of detailed information on the degree of this resistance/tolerance poses problems for an appropriate choice of rootstock. It is interesting to observe that commercial rootstocks, considered tolerant to some diseases, react differently to inoculation under controlled conditions (Trionfetti *et al.*, 2002). On the other hand, lack of information is also related to the high number of available rootstocks (i.e. commercial cultivars or relative species used as rootstocks). And also regarding to the problems related to diffusion of grafting are the incomplete resistance and high number of scion/rootstock combinations (Leonardi and Romano, 2004).

Grafting of nursery plants can be performed manually, but it requires precise techniques and is becoming increasingly difficult due to the need for advanced age of skilled workers (Rouphael *et al.*, 2010). On the other hand the cost of a grafted seedling is surely one of the main concerns of growers, especially since grafted seedling costs from three to five times more than non-grafted seedling (Leonardi and Romano, 2004). However, investigation proved that, on-farm grafted tomato transplant production can be successful and the results of the economic analysis indicate that grafting tomatoes onto hybrid grafting rootstocks can increase on-farm net returns by approximately $50,000 when soil borne disease pressure is high (O'Connell, 2009).

One of the tough works in producing grafted seedlings of fruit vegetable is healing the graft junctions. After the grafts are clipped back together they need to be placed in a high humidity environment known as a healing chamber. A healing chamber can be constructed in various ways using wooden or metal frames and a plastic covering. The goal is to create a closed environment in which the humidity can increase and the temperature can be controlled (Wilson *et al.*, 2012).

Besides, limited researches on vegetable grafting obstruct from exploiting the importance of grafting and further investigation on it. Generally, the incomplete resistance of grafted seedlings, high number of scion/rootstock combinations, the need for skilled workers, cost of grafted seedlings and limited research works are some of the challenges observed in fruit vegetable grafting.

b) Prospects

Grafting techniques in fruit vegetables will be further known and used in the world because it has at least two distinct functions. First, resistant rootstock can be deployed to limit risk of crop losses from soil borne pathogens. Second, rootstock hybrid lines could be identified for increased plant vigor and crop yield, even in the absence of disease pressure. In addition the technique is an effective integrated pest management tool for growers that face heavy disease pressure from soil borne pathogens (Rivard and Louws, 2008).

The proved positive effect of grafting on yield and quality of tomato, cucumber, watermelon and eggplant results in the increment of the status of using grafting for fruit vegetables (Pogonyi *et al.*, 2005). Though grafting is extremely laborious and time-consuming, and growers are trying to reduce the labour input required and currently robots are invented and make it possible for eight plugs of tomato, eggplant, or pepper to be grafted simultaneously. Robotic grafting is about ten times faster than conventional hand grafting (Bekhradi *et al.*, 2011).

Until recently, grafted seedling production and its use were not common in Ethiopia. The exception is the trial practice in Jittu Farm. But it has encouraging prospects due to the expansion of private farms those intended to sell the produces to local and export market. Yet the continuous cropping in greenhouse and open field condition results in nutrient depletion and development of soil borne diseases that lower the productivity of the crops ultimately, producers forced to use chemicals which are expensive and persistent pollutants. Hence, grafting can be used as alternative way to tackle the biotic and abiotic stress. Furthermore, grafting is an environmentally friendly technique that can be used in organic farming. Even though the process is costly partly due to the high input for labor, but this is not as such a problem in our country. So that the cost of making grafted seedlings might be lowered that boost using of this technique.

Overall, vegetable grafting can be considered a powerful technique. Nonetheless, different "actors" have to be involved in order to allow grafting to become further widespread (Leonardi and Romano, 2004). Though, application of grafting has mentioned problems, breeding programs for production of multipurpose rootstocks, developing efficient grafting machines and improved grafting techniques will undoubtedly encourage use of grafted seedlings all over the world.

V. Summary and Conclusion

Due to problems related to biotic and abiotic stress in vegetable production, the use of grafting as alternative means becoming the known technique in different parts of the world. There are different grafting methods however the most common methods for grafting vegetables are the splice or tube, tongue and cleft method.

Primarily, grafting solves problems related to infections by soil-borne pathogens and to enhance the tolerance against abiotic stresses. The grafting technique could help in the solution of many problems. Therefore, the advantages of grafted plants which offer increased yield and consequently higher profit, to be of value for farmers. In addition, the use of grafting is a simple step for more developed cultivation forms.

Grafting of fruit vegetables represents an effective tool not only for overcoming the salinity problem but also for enhancing fruit quality. Moreover, it may reduce or eliminate the use of certain pesticides (especially soil fumigants) because the rootstocks will provide tolerance to many soil insect and disease pests.

Grafting is not associated with the input of agrochemicals to the crops and is therefore considered to be an environment-friendly operation of substantial and sustainable relevance to integrated and organic crop management systems. It is a promising tool to enhance plant performance under growth conditions in which plants (roots) have to deal with suboptimal and/or super optimal temperatures, water stress and organic pollutants.

Overall, it can conclude that grafting is an effective agricultural approach to improve fruit quality under both adequate growth conditions and salinity, and results indicated that, the fruit quality of the shoot, at least partially, depends on the root system. The fact that the positive effect of the rootstock on fruit quality may be dependent on both, the shoot and root genotypes, as well as the growth conditions, with or without stress, makes the selection of optimum rootstocks a difficult task. Yet, selection of the best combination of rootstock and scion is necessary to get best result.

As a result of its benefits and value, demand for high-quality grafted seedlings by growers and is expected to rapidly increase. Researchers, extension specialists, and industries need to work together to integrate this modernized technology as an effective tool for sustainable horticultural production in Ethiopia.

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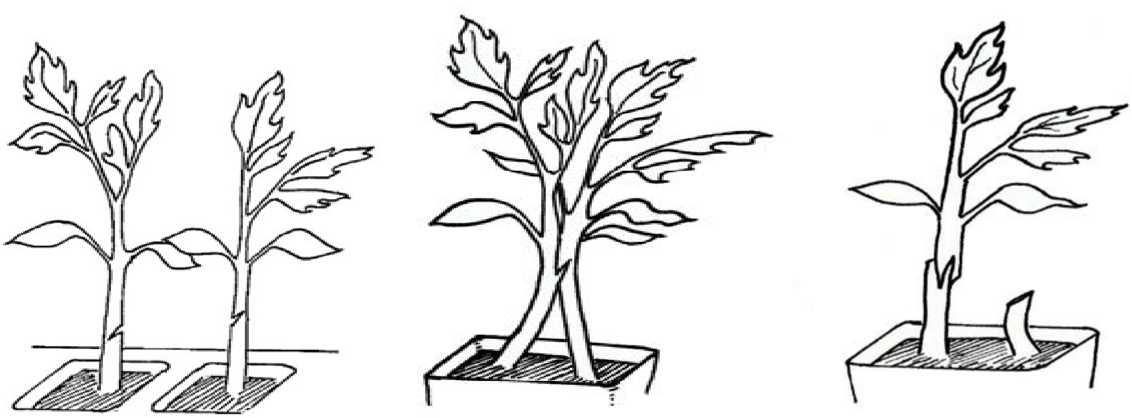
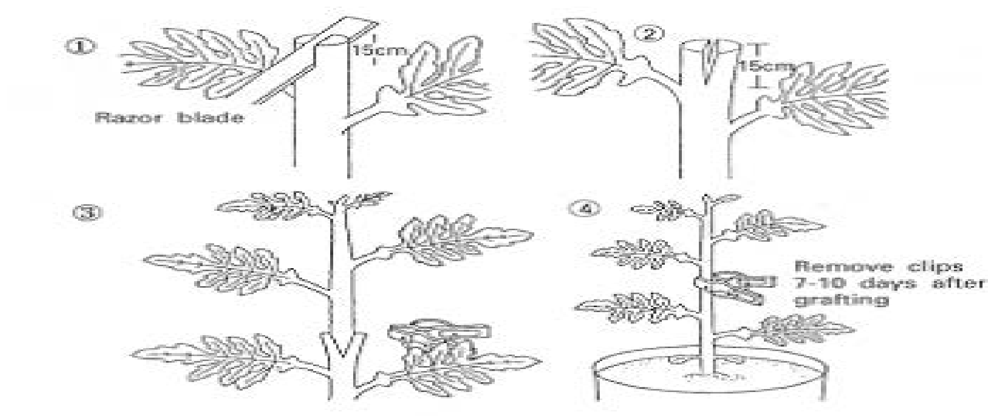
VI. Appendices

Appendix A

Appendix Figure 1 Splice grafting of tomato plants. Cutting tomato stem at a 45° angle (A) and using a clip to secure the scion to the rootstock (B). Source: (Johnson *et al.*, 2011).



Appendix Figure 2 Tongue-approach grafting. Source: (Johnson *et al.*, 2011).



Appendix Figure 3 Cleft grafting. Source: Johnson *et al.*, 2011).

Appendix B

Appendix Table 1 Lists of crops and diseases reported to be controlled by grafting

Crop	Disease	Organism
Cucumber	Fusarium wilt	*Fusarium oxysporum*
	Phytopthora blight	*Phytopthora capsici*
	Root-not nematodes	*Meloidogyne spp.*
	Verticillium wilt	*Verticillium dahlia*
	Target leaf spot	*Corynespora cassicola*
	Black root rot	*Phomopsis sclerotiodes*
Melon	Fusarium wilt	*Fusarium oxysporum*
	Vine decline	*Monosporascus cannonballus*
	Root-not nematodes	*Meloidogyne spp.*
	Gummy stem blight	*Didymela bryoniae*
	Verticillium wilt	*Verticillium dahlia*
	Black root rot	*Phomopsis sclerotiodes*
Cucurbita sp. Watermelon	Spider mites	*Tetranychus cinnabarinus*
	Fusarium wilt	*Fusarium oxysporum*
	Root-not nematodes	*Meloidogyne spp.*
	Verticillium wilt	*Verticillium dahlia*
	Virus complexes	CMV, ZYMV, PRSV,WMV-II
Eggplant	Verticillium wilt	*Verticillium dahlia*
	Corky root	*pyrenochaeta lycopersici*
	Root-not nematodes	*Meloidogyne spp.*
Tomato	Bacterial wilt	*Ralstonia solanacearum*
	Fusarium wilt	*Fusarium oxysporum*
	Corky root	*pyrenochaeta lycopersici*
	Root-not nematodes	*Meloidogyne spp.*
	Verticillium wilt	*Verticillium dahlia*
	Tomato yellow leaf curl	ToYLCV

CMV, Cucumber Mosaic Virus; ZYMV, Zucchini Yellows Mosaic Virus: PRSV, Papaya Ring spot Virus; WMV-II, Watermelon Mosaic Virus II. Source: (King et al., 2008).

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