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Grafting in Vegetable Crops: A Great Technique for Agriculture

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ABSTRACT

Grafting is a method employed to improve crop production. The first grafted vegetable seedlings used were for Watermelon (*Citrullus lanatus* L.) plants grafted onto *Lagenaria siceraria* L. rootstock to overcome *Fusarium* wilt. Since then, the use of grafted solanaceous and cucurbitaceous seedlings has spread, with the practice mainly used in Asia, Europe, and North America. The expansion of grafting is likely due to its ability to provide tolerance to biotic stress, such as soilborne pathogens, and to abiotic stresses, such as cold, salinity, drought, and heavy metal toxicity, due to the resistance found in the rootstock. Many aspects related to rootstock/scion interactions are poorly understood, which can cause loss of fruit quality, reduced production, shorter postharvest time, and, most commonly, incompatibility between rootstock and scion. The rootstock and scion cultivars must be chosen with care to avoid loss. This review discusses the possible loss, damage, and potential contribution of grafting and future perspectives of this technique toward improvement of vegetable production.

KEYWORDS

Cucurbitaceae; solanaceae;
abiotic stress; biotic stress;
rootstock; scion

Grafting is a tool normally used in vegetable crops to improve production. Grafting consists of the use of a vigorous plant to replace the root system of a cultivar of economic interest but that is susceptible to one or more stress factors. The new root system is called the rootstock, and the upper part or cultivar of interest is the scion. The first record of the use of vegetable grafting is from the late 1920s in Japan, when Watermelon (*Citrullus lanatus* L.) plants were grafted onto *Lagenaria siceraria* L. to prevent *Fusarium* wilt (Kawaide, 1985). Since then, use of grafting has spread around the world. In Japan and Korea, approximately 92% and 95% of the area cultivated with watermelon, respectively, use grafted seedlings (Lee et al., 2010).

In addition to preventing biotic stress from root-knot nematodes (Louws et al., 2010; Yin et al., 2015) and soilborne fungi (Cohen et al., 2007; Crinó et al., 2007), grafting can be an important practice to address many abiotic stresses,

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such as drought (Albacete et al., 2015; Schwarz et al., 2010; Yetisir et al., 2006), cold (Li et al., 2015), heat (Venema et al., 2008), heavy metal toxicity (Kumar et al., 2015; Savvas et al., 2010), salinity (Albacete et al., 2015; Colla et al., 2010), and nutrient deficiency or toxicity (Gao et al., 2015). Grafting is used to improve production and resource efficiency of vegetable crops, mainly in protected cultivation. Adoption of grafting depends, in part, on establishment of suitable grafting methods and vigorous rootstock development through breeding (King et al., 2010; Lee et al., 2010).

Despite benefits of using grafted seedlings, not all vegetable species are capable of being grafted, because grafting success is influenced by genetic background, growth characteristics, anatomy, and physiological and biochemical factors (Fan et al., 2015; Goldschmidt, 2014; Gratão et al., 2015; Martínez-Ballesta et al., 2010). Among vegetable crops, species of Solanaceae—Tomato (*Solanum lycopersicum* L.), Eggplant (*S. melongena* L.), and Sweet Pepper (*Capsicum annuum* L.)—and Cucurbitaceae—Watermelon [*Citrullus lanatus* (Thunb.) Matsum. and Nakai], Melon (*Cucumis melo* L.), and Cucumber (*C. sativus* L.)—families are commonly and economically grafted. Provided in this review is information on challenges and opportunities regarding species and methods and purpose of vegetable grafting for these vegetable crops.

Cucurbitaceae

Several cucurbit species, especially watermelon, melon, and cucumber, are grafted. There are many commercial applications of cucurbit grafting and numerous methods to join between scion and rootstock, with the majority done at young seedling stages; for example, hole insertion grafting, tongue approach grafting, splice grafting, and cleft grafting (Figure 1; for review, see Lee et al., 2010; Mohamed et al., 2014). Intra- and interspecific grafts are common among plants of the Cucurbitaceae family. The possibility of high-throughput methods using automation, with operator assistance or complete robotic control, can reduce the cost of grafted seedlings (Comba et al., 2016; Lee et al., 2010).

Watermelon [*Citrullus lanatus* (Thunb.) Matsum. and Nakai]

The main purpose for grafting watermelon has been to induce resistance to soilborne pathogens, such as root-knot nematodes, *Fusarium oxysporum* f. sp. *niveum*, and *Verticillium* spp. (Davis et al., 2008; Lee et al., 2010; Louws et al., 2010). Watermelon has been grafted mainly onto Bottle Gourd (*L. siceraria*), Pumpkin (*Cucurbita pepo* L.), Squash (*C. moschata* Duch.), and interspecific hybrid Squash (*C. maxima* Duch. × *C. moschata* Duch.) (King et al., 2010; Lee et al., 2010). Watermelon exhibits high compatibility with related rootstocks (Khankhdani et al., 2012; Mohamed et al., 2014; Yassin

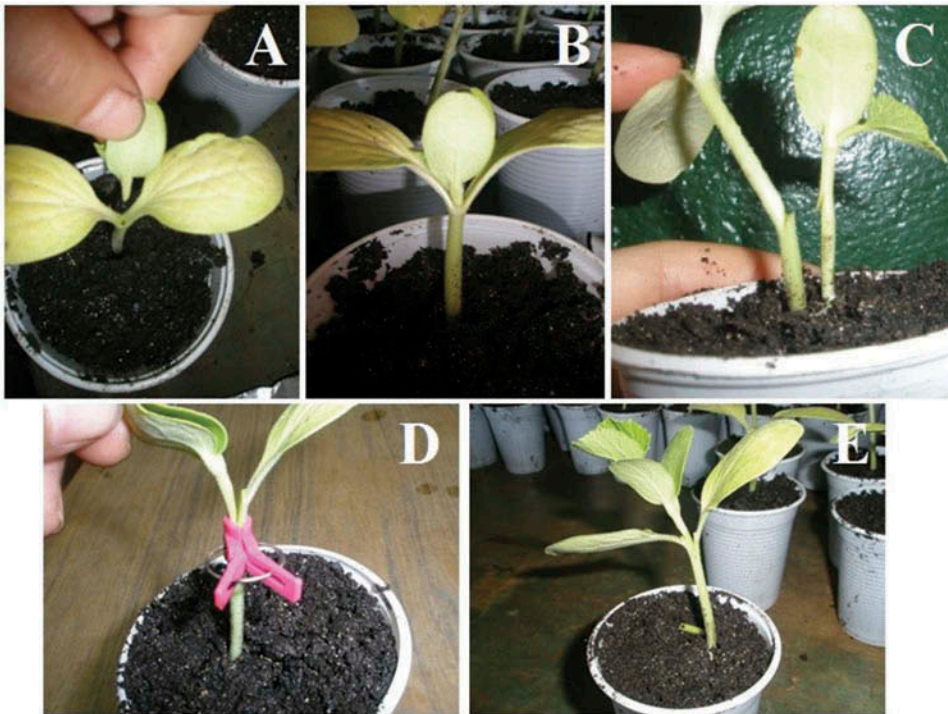


Figure 1. Grafting methods for vegetables. (A) and (B) Hole insertion grafting, (C) tongue approach grafting, (D) splice grafting, and (E) cleft grafting. Photographs courtesy of Dra. Leticia Akemi Ito.

and Hussen, 2015). Among these, squash and interspecific hybrids have been largely used for their vigorous root system and extreme temperature and *Fusarium* resistance (Lee et al., 2010; Ling et al., 2013; Miguel et al., 2004). The rootstock ‘Shintoza’ and ‘Super Shintoza’, a *C. maxima* × *C. moschata* hybrid, provided resistance to watermelon when cultivated in *Fusarium*-infested soils; the rootstocks increased fruit size and yield compared to those of nongrafted plants (Álvarez-Hernández et al., 2015; Miguel et al., 2004). Among these, the ‘Super Shintoza’ rootstocks also provide tolerance to *Verticillium* wilt, reducing the microsclerotia incidence, survival structure of *Verticillium* spp., and maintenance of fruit yield (Dabirian et al., 2017).

Grafting provides tolerance to abiotic stress, including drought (Rouphael et al., 2008) and nutrient deficiency (Huang et al., 2013). Under drought, a common condition in many watermelon-producing regions of the world, grafting of mini-watermelon cv. Ingrid onto ‘PS 1313’ rootstock (*C. maxima* × *C. moschata*) resulted in greater yield and yield water use efficiency (calculated by dividing fruit yield by seasonal crop evapotranspiration) compared to nongrafted plants (Rouphael et al., 2008). When watermelon plants were exposed to low potassium (K), use of ‘Hongdun’ (*C. lanatus*) and ‘Jinxinzhen No. 4’ (*C. moschata*) as rootstocks reduced shoot dry weight losses due to increased K

uptake (Huang et al., 2013). An adequate rootstock–scion combination can improve uptake and transport of N, K, and Mg, reducing the amount of chemical fertilizer applied (Pulgar et al., 2000; Roupael et al., 2008).

Several reports indicate that squash and interspecific rootstocks can decrease fruit flesh quality (Davis et al., 2008; King et al., 2010; Soteriou et al., 2014), although this decrease in quality has been associated with enhanced nutritional uptake (King et al., 2010; Özmen et al., 2015; Shinbori et al., 1981). Soteriou et al. (2014) found that loss of quality is related to changes in flesh maturity and delayed fruit ripening. Because grafting slows ripening by 5–10 days compared to nongrafted plants, if producers harvest fruit from grafted plants at the same time as they would harvest nongrafted plants, fruit from grafted plants usually exhibit a lower pH and a “squash-like” flavor (King et al., 2010; Soteriou et al., 2014). Nevertheless, Kyriacou et al. (2016) verified that, despite the potential suppression of sugar content, fruits of plants grafted onto interspecific hybrid rootstocks showed improved pulp texture and lycopene, and detrimental effects of grafting are minimized at full commercial maturity. In fact, when harvested later, grafting can benefit fruit quality by improving physical attributes and increasing bioactive compounds, such as lycopene (King et al., 2010; Soteriou et al., 2014). Watermelon growers use rootstock of bottle gourd and pumpkin to improve fruit quality and sensory parameters such as taste and pulp texture, although these rootstocks have less resistance to soilborne pathogens (Fallik et al., 2016; King et al., 2010; Kyriacou et al., 2016; Villocino and Quevedo, 2015).

Melon (*Cucumis melo* L.)

Melon has been grafted onto the same species as watermelon (squash; interspecific hybrids; pumpkin; bottle gourd) and onto *C. melo* rootstocks (King et al., 2010; Lee et al., 2010). Melons have also been grafted onto the related species cucumber and wax gourd (*Benincasa hispida* Thunb.). The main purpose of using grafted melon seedlings is to provide resistance to soilborne pathogens *Monosporascus cannonballus*, *Fusarium oxysporum* f. sp. *melonis* (*Fom*), and *Stagonosporopsis* spp. and root-knot nematodes (Cohen et al., 2000; Dhall, 2015; Ito et al., 2009; Zhou et al., 2014). Wax gourd and squash, used as rootstocks, induce resistance to nematodes (*Meloidogyne incognita* and *M. javanica*) and the fungus *Stagonosporopsis* spp., respectively (Galatti et al., 2013; Ito et al., 2009).

King et al. (2010) stated that during rootstock development, two types of diseases must be considered: wilts, caused mainly by *Fom*, and root and stem rot diseases, including that caused by *M. cannonballus*, *Macrophomina phaseolina*, and *Stagonosporopsis* spp. However, it has been difficult to develop melon cultivars that are completely resistant to *Fom*, because the pathogen has

four distinct races (0, 1, 2, and 1,2; Dhall, 2015; Zink and Thomas, 1990). Three dominant genes confer resistance to different *Fom* races: *Fom-1* and *Fom-3* confer resistance to races 0 and 2 and *Fom-2* confers resistance to races 0 and 1 (Zink and Gubler, 1985; Zink et al., 1983). A set of recessive genes was discovered (*Fom-4*) that controls resistance to *Fom* race 1,2 (Oumouloud et al., 2010, 2013). Due to the unavailability of resistant melon cultivars, farmers use rootstocks that can provide better growth and production in fields infested with *Fom*, because rootstocks tolerant to all races have been discovered (Oumouloud et al., 2013). Other cucurbitaceous species are resistant to *Fusarium* wilt and can be used as rootstocks for melon. For instance, inter-specific hybrid rootstocks ('SYTZ' and 'NZ1') were demonstrated to be resistant to all four races of *Fom*, and rootstock use increased yield compared to nongrafted melon cv. Liyu (Zhou et al., 2014).

Closely related species used as rootstocks can cause deleterious effects on yield and/or fruit quality, and these species can exhibit low compatibility with melon in a cultivar-dependent way (Calatayud et al., 2013; Lee et al., 2010; Nisini et al., 2002; Salar et al., 2015). Nevertheless, regarding incompatibility between rootstock and scion, an alternative was demonstrated by Bautista et al. (2011). They used double grafting to improve compatibility between the scion and rootstock using an intermediate compatible with both. A scion from cv. Piel de Sapo was grafted onto a portion of the melon cv. Sienne, which was an intermediate and which was grafted to the rootstock 'Shintoza' (*C. maxima* × *C. moschata*). 'Shintoza', a vigorous rootstock, provided higher uptake of minerals and water, which increased shoot biomass and fruit yield without affecting fruit quality (Bautista et al., 2011). However, double grafting may not be cost effective because of the increased labor required.

Beyond tolerance to biotic stress, grafting can be used to improve tolerance to nutrient deficiency (Edelstein et al., 2011; Neocleous, 2015; Orsini et al., 2013). The pumpkin cv. TZ-148 has a strong ability to accumulate Na ions within its roots but a limited ability to transport them to the scion. Grafted melon plants have low Na content in the shoot and in exudates from the cut stem compared to self-grafted and nongrafted melon plants (Edelstein et al., 2011). Orsini et al. (2013) observed that 'RD841' rootstock increased Na exclusion and K uptake. The authors attributed increased salt stress tolerance to a greater control of stomatal functions, explained by a possible alteration of hormonal signaling between the root and shoot caused by grafting. Further, when the cv. Dikti was grafted onto 'RS 841', an inter-specific hybrid, it exhibited higher nitrate uptake and improvement of photosynthesis and biomass production (Neocleous, 2015).

Cucumber (*Cucumis sativus* L.)

The main objective for grafting cucumber is to provide tolerance to cold and *Fusarium* wilt and improve fruit appearance. Cucumber has typically been grafted onto Figleaf Gourd (*C. ficifolia* Bouché), Squash, interspecific hybrid Squash, and Pumpkin (Dhall, 2015; Lee et al., 2010; Velkov and Pevicharova, 2016). Intensive cultivation, mainly in the greenhouse, has increased environmental stress, among which salinity seems to be most limiting to cucumber production (Colla et al., 2010). Studies have provided breakthroughs concerning use of grafting to increase salt tolerance in cucumber (Xu et al., 2017). Grafting cucumber cv. Jinchun No. 2 onto ‘Chaojiqianwang’ rootstock (*C. moschata*) resulted in lower Na content in the scion. This rootstock has a higher capacity than cucumber for Na exclusion and Na retention in roots, which reduces Na transport to the scion and increases cucumber tolerance to salinity (Huang et al., 2013). Similarly, pumpkin rootstocks can confer tolerance to both saline and cold stresses (Xu et al., 2017). Furthermore, *C. moschata* rootstocks are used by growers because they enable production of wax-free (bloomless) cucumber fruit. This fruit is preferred by consumers for its appearance and longer shelf-life (King et al., 2010).

The cv. Jinchun No. 2, grafted onto figleaf gourd rootstock, exhibited higher scion dry weight under salinity compared to self-grafted and non-grafted plants by maintaining high activities of the antioxidant enzymes superoxide dismutase (SOD) and peroxidase, which led to reduced electrical leakage (EL) and levels of malondialdehyde (Huang et al., 2010, 2015). X.E. Li et al. (2015) reported that rootstocks originating from figleaf gourd were more tolerant to salt. It has been demonstrated that the use of interspecific hybrids (*C. maxima* × *C. moschata*) provides tolerance to cadmium, nickel, and nitrate (Gao et al., 2015; Savvas et al., 2013), indicating a promising opportunity to be explored. Scientists have explored the ability of rootstocks to induce temperature stress tolerance in cucumber plants (Ahn et al., 1999; H. Li et al., 2014; Y. Li et al., 2015a, 2015b).

Cucumber, cv. Xintaimici, grafted onto the rootstocks ‘Kilameki’, ‘Tielizhen’, and figleaf gourd, grown under low temperature exhibited reduced electrolyte leakage and malondialdehyde content compared to ungrafted seedlings. The figleaf gourd rootstock had greater proline accumulation and enhanced activity of SOD, catalase, and ascorbate peroxidase (Y. Li et al., 2015a). H. Li et al. (2014) verified figleaf gourd-induced low temperature (18/13°C; day/night) tolerance in cucumber plants; luffa [*Luffa cylindrica* (L.) M. Roem] rootstock induced heat stress (36/31°C) tolerance. In response to stress, both rootstocks induced upregulation of the genes *MAPK1*, *MYC*, *MYB*, and *Cu/Zn-SOD*. These results demonstrate the potential influence of the rootstock on the scion through unknown signals transported to the shoot by the roots, mainly in plants under stress.

In addition to heat stress tolerance, luffa rootstock could provide drought tolerance via induction of abscisic acid biosynthesis (Liu et al., 2016). The luffa root system seems to have an enhanced ability to detect changes in root-zone moisture and can induce a more rapid response to water deprivation by accumulating abscisic acid in roots, xylem sap, and leaves compared to self-grafted cucumber plants. Cucumber plants, cv. Jinyan No. 4, grafted onto luffa rootstock exhibit greater water use efficiency and lower transpiration rate.

Solanaceae

Species of tomato, eggplant, and sweet pepper appear particularly amenable to grafting, which is likely related to their regenerative abilities. Although almost all greenhouse-produced tomatoes are grafted and eggplant is also widely grafted, the use of sweet pepper grafting by producers is less widespread. Actually, sweet pepper has limitations regarding compatibility with other solanaceous species. Therefore, the development of rootstocks with resistance to a wide range of diseases, good root vigor, high compatibility, and adoption of suitable grafting methods are the main constraints to increase yield of solanaceous crops through grafting.

Tomato (Solanum lycopersicum L.)

Despite the wide array of closely related *Solanum* species that could be used as rootstocks, tomato has been grafted mainly onto tomato genotypes and inter-specific hybrids. Traditionally, the main reason for grafting tomato has been to provide resistance against soilborne pathogens, such as *Fusarium* spp., *Verticillium* spp., *Ralstonia solanacearum*, and *Meloidogyne* spp. (Hamdi et al., 2009; Owusu et al., 2016; Polizzi et al., 2015; Yin et al., 2015). More recently, rootstocks are being used to provide abiotic stress tolerance and greater nutrient and water uptake (Albacete et al., 2015; Asins et al., 2015; Ntatsi et al., 2013; Savvas et al., 2017; Semiz and Suarez, 2015). Among abiotic stresses, salinity has received the most attention due to intensive greenhouse production, use of fertigation, and the high evaporation demands of tomato.

Different rootstocks provide salt stress tolerance (Fernández-García et al., 2002, 2004; Voutsela et al., 2012). Tomato, cvs. Fanny and Goldmar, grafted onto the tomato rootstock 'AR-9704' had a lower accumulation of chloride and sodium in saline conditions (Fernández-García et al., 2002, 2004). An experimental rootstock conferred salt tolerance and higher yield with to tomato, cv. Despina, than did self-grafted or nongrafted plants (Voutsela et al., 2012). Semiz and Suarez (2015) reported that cv. Big Dena grafted onto 'Maxifort' tomato rootstock exhibited increased yield under control and saline conditions compared to nongrafted plants.

In addition to salinity tolerance, grafting can provide adaptations to other stresses, such as suboptimal temperature (Ntatsi et al., 2013), continuous light (Velez-Ramirez et al., 2015), heavy metal toxicity (Kumar et al., 2015; Savvas et al., 2010), drought (Nilsen et al., 2014), flooding (Black et al., 2003), and low nutrient supply (Albacete et al., 2015). The drought-susceptible cv. Josefina grafted onto cv. Zarina, which is more tolerant to drought, improved shoot growth and maintenance of the relative water content of leaves (Sánchez-Rodríguez et al., 2011). Further, when the cv. BHN 602 was grafted with the 'Jjak Kkung' rootstock and exposed to mild drought conditions, it was observed that grafted plants exhibited a smaller reduction of the leaf water potential and the photosynthetic rate compared to nongrafted plants (Nilsen et al., 2014).

The economic importance and large cultivated area of tomato (in field and greenhouse) have stimulated development of improved rootstocks (King et al., 2010). These rootstocks, normally interspecific hybrid (e.g., *S. lycopersicum* × *S. habrochaites*), can induce productivity gains even under conditions without stressors factors. For example, tomato cv. Florida 47 grafted on 'Beaufort' and 'Multifort' rootstocks, both interspecific hybrid, was compared with non- and self-grafted plants (Djidonou et al., 2016). In this assay, it was found that grafted plants increased the marketable fruit yield by up to 41%. Similarly, the 'El Cid' tomato grafted onto interspecific hybrid rootstock 'Multifort' obtained a 12.9% increase in fruit yield (Velasco-Alvarado et al., 2016). Moreover, the use of interspecific hybrids as rootstock can improve fruit quality, with higher macro- and microelements, phenolic compounds, vitamin C, lycopene, and flavonoids accumulation in fruit of grafted plants (Riga et al., 2016).

Eggplant (*Solanum melongena* L.)

Eggplant has been grafted traditionally on wild species such as *S. integrifolium* or on tomato hybrid rootstocks. The former is used to provide resistance to soilborne pathogens, such as bacterial and *Fusarium* wilt, although tomato hybrid rootstocks are more popular among producers who use them for tomato grafting (King et al., 2010). There are reports of loss of tolerance and deleterious effects of grafting on yield from traditional rootstocks (Honna 1977; Kawaguchi et al., 2008). This led to a search for alternative rootstocks, such as interspecific hybrids, and more closely related wild species. Wild species, such as *S. torvum* and *S. sisymbriifolium*, have shown promise as a rootstock for eggplant, because they provide a high level of resistance to bacterial wilt, *Fusarium* wilt, *Verticillium* wilt, and root-knot nematode.

The eggplant cv. Tsakoniki grafted onto rootstocks of *S. torvum* and *S. sisymbriifolium* grown in infected or noninfected soil had increased yield

and resistance to *Verticillium* wilt (Bletsos et al., 2003). In addition to improvement in fruit production, cv. Sciacca grafted onto *S. torvum* exhibited higher phenolic antioxidant contents, important compounds for human metabolism and health (Sabatino et al., 2016). Some eggplant cultivars grafted onto *S. torvum* had darker fruit and fruit with less vivid color, which can result in loss of commercial value, although this rootstock has induced enhanced yield (Moncada et al., 2013; Sabatino et al., 2016). An alternative to wild rootstock, such as *S. torvum*, is interspecific hybrids. Eggplant grafted onto the interspecific hybrid rootstocks *S. melongena* × *S. incanum* L. and *S. melongena* × *S. aethiopicum* L. have obtained good compatibility, high plant vigor, increased yield, and moderate tolerance to root-knot nematodes without negative effects on fruit quality (Gisbert et al., 2011a, 2011b).

Regarding abiotic stress, Giuffrida et al. (2015) studied performance of eggplant ('Black Bell') grafted onto tomato interspecific hybrids 'Beaufort' F₁ and 'He-Man' F₁ (*S. lycopersicon* × *S. habrochaites*) and on *S. torvum* grown in saline and nonsaline conditions. They found that 'Beaufort' F₁ and 'He-Man' F₁ rootstocks improved plant development under nonsaline conditions, but the grafted plants did not tolerate of salinity. Eggplant cultivars grafted onto 'Beaufort' F₁ exhibited improved yield and fruit quality, which was attributed to greater vigor of grafted plants (Maršić et al., 2014). 'Beaufort' F₁ rootstock also induces resistance to *Verticillium* wilt in the grafted eggplant cv. Epic (Johnson et al., 2014; Miles et al., 2015).

Sweet pepper (*Capsicum annuum* L.)

Among solanaceous crops, grafting sweet pepper has received less attention than grafting tomato and eggplant. This could be because sweet pepper is not typically grafted commercially due to its limited compatibility with other species (Kwon et al., 2006). There are reports of successful sweet pepper grafts on rootstocks of *Capsicum annuum*, indicating that grafting may be a potential tool for controlling disease, mainly caused by root-knot nematodes (Oka et al., 2004). The cv. Celica, grafted onto accession 'AR-96023' (*C. annuum*), which is resistant to *M. incognita* and *M. javanica*, performed better than nongrafted plants when grown in infested soil (Oka et al., 2004). Sweet pepper cvs. Rubia R, Margarita, and Maximos grafted onto the commercial rootstock 'Snooker' had improved tolerance to *M. incognita* (Oliveira et al., 2009). Rootstocks of the *C. annuum* hybrids 'AF-2638' and 'AF-2640' were compatible with cvs. Elisa, Margarita, and Magali-R, and these rootstocks provided resistance to *Phytophthora capsici* (Santos and Goto, 2004). Furthermore, Madeira et al. (2016) observed compatibility among cvs. Margarita,

Rubia R, Magali R, and Maximos and the rootstocks Snooker, BRS Mari (*Capsicum baccatum* var. *pendulum*), CNPH 143, and an experimental simple hybrid (HSE) of sweet pepper. Although all combinations have shown compatibility, the ‘Snooker’ and HSE rootstocks provide higher yield when compared to nongrafted plants (Madeira et al., 2016). In addition, when the sweet pepper cv. Herminio was grafted onto three rootstocks (Atlante, Creonte, and Terrano) and exposed to drought stress, it was verified that rootstocks, especially Creonte, induced an increase in total and marketable yield under both control and deficit irrigation as well as improved water use efficiency (López-Marín et al., 2017).

Special care should be taken in the choice of the rootstock–scion combination, because the rootstock can influence fruit shape on the scion (Tsaballa et al., 2013). The authors demonstrated that this phenotypic change in sweet pepper can be inherited for up to two generations of seed derived from these progenies, indicating that signals from the rootstock are able to modulate gene expression and fruit development of the scion.

Future prospects

Grafting can provide beneficial contributions to crop production. Advances have been made to expand adoption of the technique, such as the development of more efficient grafting robots able to perform a large number of operations in a short time, reducing the price of grafted seedlings (Comba et al., 2016; Kubota et al., 2017). Another advancement includes development of rootstocks that provide a robust root system, resistance to soilborne pathogens, capability to induce increased shoot vigor due to higher absorption of water and nutrients, and maintenance of plant health, which would contribute to productivity (Table 1). These advances support the growing interest by producers in this technique. Beyond its current use in horticulture, grafting has become an important research tool in plant science. The use of grafting in physiological, biochemical, and molecular research is due to the combination of the use of plant models such as *Arabidopsis thaliana*, Pea (*Pisum sativum* L.), and dwarf tomato, cv. Micro-Tom, and the establishment of appropriate grafting and micrografting protocols (Harada, 2010; Turnbull, 2010; Turnbull et al., 2002). Grafting allows the combination in the same plant of different root system and shoot and even two root systems or two shoots in the same plant (Turnbull et al., 2002). Therefore, it is possible to investigate the reciprocal influence of scion and rootstock as well as long-distance transport of molecules throughout the plant. There are examples of grafting uses in plant studies, mainly those that seek to discover the existence of transport of molecules, including hormones (Kiba et al., 2013; Regnault et al., 2015), RNAs (Notaguchi et al., 2015),

Table 1. Relation of some rootstocks for Cucurbitaceae and Solanaceae crops and use of rootstock to improve characteristic.

Crop	Rootstock (specie)	Improved feature	Reference	
Watermelon	'Shintoza' (<i>Cucurbita maxima</i> × <i>C. moschata</i>)	<i>Fusarium</i> wilt	Miguel et al. (2004)	
	<i>Cucurbita</i> spp.	<i>Verticillium</i> wilt	Papomatias et al. (2002)	
	'Shintoza' (<i>C. maxima</i> × <i>C. moschata</i>)	Root-knot nematode	Miguel et al. (2006)	
	'PS 1313' (<i>C. maxima</i> × <i>C. moschata</i>)	Water use efficiency	Rouphael et al. (2008)	
	'Jinxinzhen' (<i>C. moschata</i>)	K uptake and metabolism	Huang et al. (2013)	
	'Brava' (<i>C. pepo</i> L.)	N metabolism	Pulgar et al. (2000)	
	TZ 148' (<i>C. maxima</i> × <i>C. moschata</i>)	Salinity	Edelstein et al. (2005)	
	TZ 148' (<i>C. maxima</i> × <i>C. moschata</i>)	<i>Fusarium</i> wilt	Cohen et al. (2007)	
	'Shintoza' (<i>C. maxima</i> × <i>C. moschata</i>)	Root rot diseases	Nisini et al. (2002)	
	'Shintoza' (<i>C. maxima</i> × <i>C. moschata</i>)	Mineral and water uptake	Bautista et al. (2011)	
Melon	'Shintoza' (<i>C. maxima</i> × <i>C. moschata</i>)	Salinity	Edelstein et al. (2011)	
	TZ 148' (<i>C. maxima</i> × <i>C. moschata</i>)	K uptake	Orsini et al. (2013)	
	'RD 841' (<i>C. maxima</i> × <i>C. moschata</i>)	<i>Fusarium</i> wilt	Marukawa and Takatsu (1969)	
	Figleaf gourd (<i>C. ficifolia</i>)	High temperature	Lee et al. (2010)	
	'Shintoza' (<i>C. maxima</i> × <i>C. moschata</i>)	Salinity	Huang et al. (2013)	
	'Chaojiuanwang' (<i>C. moschata</i>)	Cold	Y. Li et al. (2015a, 2015b)	
	'Shintoza' (<i>C. maxima</i> × <i>C. moschata</i>)	Wax-free fruit	Sakata et al. (2008)	
	Squash (<i>C. moschata</i>)	Salinity	Fernández-García et al. (2004)	
	'AR-9707' (<i>Solanum lycopersicum</i>)	Productivity	Semiz and Suarez (2015)	
	'Maxifort' (<i>S. lycopersicum</i> × <i>S. habrochaites</i>)	Heavy metal	Kumar et al. (2015)	
Tomato	'Maxifort' (<i>S. lycopersicum</i> × <i>S. habrochaites</i>)	Soilborne pathogens	Hamdi et al. (2009)	
	'Beaufort' (<i>S. lycopersicum</i> × <i>S. habrochaites</i>)	Mineral uptake and metabolism	Savvas et al. (2010); Djidonou et al. (2015)	
	'Beaufort' (<i>S. lycopersicum</i> × <i>S. habrochaites</i>)	Root-knot nematode	Gisbert et al. (2011a)	
	<i>S. integrifolium</i>	Salinity	Giuffrida et al. (2015)	
	<i>S. torvum</i>	<i>Verticillium</i> wilt	Milles et al. (2015)	
	<i>S. incanum</i> × <i>S. melongena</i>	Productivity	Gisbert et al. (2011a, 2011b)	
	'AR-96023' (<i>Capsicum annuum</i>)	Root-knot nematode	Oka et al. (2004)	
	'AF-2638' (<i>C. annuum</i>)	<i>Phytophthora capsici</i>	Santos and Goto (2004)	
	Eggplant			
Sweet pepper				

proteins (Notaguchi et al., 2008; Spiegelman et al., 2015), and enzymatic antioxidant molecules (Gratão et al., 2015), in plant organs (Ali et al., 2015; Jin et al., 2015). For these reasons, grafting has become increasingly popular in agricultural and academic communities due to the numerous possibilities that it offers.

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