9 Practical Applications and Speciality Crops

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9.1 Establishment of Grafted Transplants under Mediterranean Climate Conditions

Plantlet establishment is the part of horticultural sciences that focuses on the parameters and conditions enabling maximal throughput from propagation material, optimal yield from the crop and best horticultural performance under commercial growing conditions.

The major factors affecting plantlet establishment are seed health and vigour, plantlet quality and health, and the environmental conditions under which the transplantation is performed, namely abiotic and biotic stresses. Implementation of the best conditions at the transplanting stage and adjustment of agrotechniques enable the genetic potential of the seed to be realized (Grassbaugh and Bennett, 1998).

The Mediterranean climate is characterized by a long, hot summer with little precipitation, followed by a relatively short winter that is either dry with little rain or rich in precipitation from short rainstorms (Bolle, 2003; Alpert *et al.*, 2006). During most of the year, the level of radiation is high, which makes the summer very hot and confers moderate temperatures during most of the winter (Pardossi *et al.*, 2004). In the Mediterranean environment, the traditional planting dates start at the end of the warm summer season due to the unfavourable temperatures inside the vegetable growing greenhouses during the summer (up to 45–48°C), which are usually equipped with only rudimentary ventilation systems and no

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active cooling. The planting dates vary according to region and crop. In Italy and France, transplanting takes place mainly in winter time (November–March) for Cucurbitaceae (i.e. melon and watermelon), although in France there is a small area of melon transplanting in the summer. The main tomato transplanting in Sicily occurs in both the summer (July–August) and winter (December–January); in the centre and north of Italy, transplanting occurs from January until March/April. In France, tomato transplanting starts in December, mainly in rockwool soil-less substrate, and goes on until March/April in both soil-less substrate and in soil. In Israel, current planting dates have been achieved by extending the growing season, usually starting in the warm summer season (July/August), characterized by extremely hot air and soil temperatures (Arava valley and Jordan valley). As cropping progresses, the climatic conditions become moderate to cold with the transition to winter. The transition from winter to spring is rapid, with many warm days and high levels of radiation ranging between 15 and 30 MJ m^{-2} day^{-1} from March to June (Castilla and Baeza, 2013; Ityel *et al.*, 2014). In many Mediterranean habitats, there is a trend towards growing under insect-proof nets or in greenhouses to avoid aphids, other insects and virus vectors, such as *Bemisia tabaci* (Castilla, 2002). The general trend towards reduced pesticide application is promoting the use of physical barriers, such as dense screens, which contribute to higher temperatures and humidity in the greenhouse.

This section describes the factors involved in grafted transplant establishment in Mediterranean habitats, as is practised on a large scale in Israel, Turkey, Spain, Italy, France and Greece and on a smaller scale in many other countries in the region.

9.1.1 Factors affecting the establishment of grafted plants

Seeds

The seed is one of the most important components in the production of grafting. Unlike regular seedling production, which usually includes a single seed per seedling, grafted transplant production requires two seeds for each plantlet – one for the scion and the other for the rootstock. This does not necessarily increase demand for seeds because grafted compared with non-grafted crops are grown at lower planting densities, often with two main stems per rootstock (*see* Chapter 3, this volume). However, the grafting procedure requires vigorous rootstock seeds, which should include well defined structural features and high uniformity (Mavi *et al.*, 2006; Kubota and McClure, 2008). For example, for grafting cucurbitaceous plants using a diagonal cut, which is also known as one-cotyledon splice grafting (*see* Chapter 1, this volume), vigorous seedlings are needed with good cotyledon quality. In this method, the apical meristem and one cotyledon of the rootstock are removed by an approximate 65° cut; the scion is cut above the cotyledons at the same angle and then attached to the rootstock at the remaining cotyledon (Hassell *et al.*, 2008). Less vigorous seeds or cotyledon disorders will not suit this process. It should be noted that the transition to automatic grafting machinery requires uniformity and consistency of high-quality plant materials – both scion and rootstock seedlings (Chiu *et al.*, 2010). Seeds with high and uniform germination performance are a key factor for high throughputs (Kubota and McClure, 2008).

In recent years, seeds have been the main vector for several epidemic outbreaks in crops (de León *et al.*, 2011; Dutta *et al.*, 2014). Bacterial pathogens such as *Clavibacter michiganensis* and *Acidovorax citrulli* in vegetables, tobamoviruses such as cucumber green mottle mosaic virus (CGMMV), tobacco mosaic virus (TMV), tomato mottle virus and pepper mild mottle virus (PMMV) and viroids are easily contaminated via plant and soil by mechanical means, in addition to seedborne 'vertical' transmission. Their spread within the nursery and by the nursery product to the growers can be proliferated by the activities associated with grafting, such as sorting, cutting of the rootstock and the scion, and attaching them together. Seed health issues are intensified in grafting, and the required standard is higher than in normal production of non-grafted seedlings.

There is a vital need to improve standard tests for the detection of seedborne diseases (Shang *et al.*, 2011; Lecoq and Desbiez, 2012). For example, during 2013, a severe epidemic of CGMMV occurred in many of the watermelon plots in Israel. This was found to be because the seed inspections, which had been performed in the best seed-producing laboratories around the world, had used a kit that was not suitable for identifying the specific strain of the virus. The test results for virus infection in the seeds were negative, whereas in fact the seeds were infected. This situation led to a large-scale epidemic in the fields and greenhouses. Using serological detection of CGMMV in the inner parts of infected seeds may be more accurate for infected batch identification (Reingold *et al.*, 2015).

Development of more effective testing methods that are well suited to larger samples of seeds is essential to avoid epidemics such as that caused by CGMMV. This is particularly true in the case of tomatoes, which are highly sensitive to *C. michiganensis* (Mathis *et al.*, 2015). These bacteria are transmitted by the seeds both internally and on the seedcoat. Even extremely low rates of 25 colony-forming units in one seed in 10,000 might cause disease outbreaks in nurseries, especially in grafted transplants. The existing methods to identify the presence of bacteria in tomato seed lots, although sensitive (OEPP/EPPO, 2013), are still insufficient. This is because the representative sample size needed for a seed batch requires tens of thousands of seeds, placing economic difficulties in its implementation. Therefore, *C. michiganensis* epidemics are relatively common in many Mediterranean countries, mainly in grafted tomato production plots; detection in symptomless plantlets has not yet been fully validated.

Plantlets

Prior to grafting, seedlings should have the correct proportions among their components: rootstock size (i.e. height and diameter) and scion size (Hassell *et al.*, 2008). Seedlings that are too elongated are weak, exposed to burns during summer (heat, radiation) and might display further negative effects during cropping. However, components that are too short are difficult to graft correctly and their general development might be too slow during the winter.

The seedling should be healthy and free of diseases. To ensure disease-free seedlings, especially from viruses, which are transferred mainly by aphids and other insect vectors, a 50-mesh screen (50 openings per square inch) is essential for greenhouses in the Mediterranean region (Harel *et al.*, 2013). The hot season, when the insects are most active, creates a major challenge, as the heat load in the greenhouse is maximal, and professional skills are required to enable proper development of the grafted transplants.

Although good cotyledon quality is important for Cucurbitaceae, French growers absolutely require that plants of melon, grafted on to squash or melon, are provided without the cotyledon of the rootstock in order to avoid problems with *Oidium* spp. infection (powdery mildew). In Israel, in recent years, due to the threat of tobamoviruses transmitted by mechanical means, handling and direct touching of the plantlet after one-cotyledon grafting is minimal and therefore the cotyledon is not removed. Powdery mildew is instead treated by chemical and cultural methods.

The structure of the root system is important for plantlet establishment (*see* Plate 19). It is affected by nursery management as well as field practices such as irrigation methods (Sánchez-Rodríguez *et al.*, 2014). Root air pruning is common in the plug transplant production (Cantliffe, 2008). Root tips that are exposed to dry air by holes at the bottom of the trays become dried. This generates hormonal changes in the root system, and increases splitting and the production of lateral roots instead of taproots (Leskovar and Stoffella, 1995). Twisting roots adversely affect plantlet establishment, and enhance root vulnerability to soilborne pathogens such as *Macrophomina phaseolina*, as well as other pathogens. The nursery should avoid conditions that enhance root curling, especially in the Cucurbitaceae. Root architecture can also be adjusted by using pressed peat plugs or Ellepots (plugs made from degradable paper cylinders, filled with growth medium; http://ellepot.dk/ellepotsystem.html, accessed 24 November 2016), as an alternative method of air pruning. Pressed peat is used for watermelon in Italy and for melon in France; currently, more than 60% of these young plants are produced in pressed peat plugs. In Israel, the Ellepot system is more common for grafted Cucurbitaceae. The combination of a healthy root system and irrigation methods that are adjusted to the field conditions contributes to deep root systems and normal plant development.

The collapse of grafted transplants in the field shortly after planting may be related to nursery practices. Grafted watermelons may collapse shortly after transplanting if the scion and rootstock are not compatible by genotype, age, or stalk diameter. Low tolerance to environmental conditions and biotic stress may result from improper healing and/or hardening off process. Grafted plants may be infected by soilborne pathogens even though a resistant rootstock is being used because of the development of susceptible roots from the scion. For example, internal rooting in cucumber happens when the scion roots into an internal hole of the rootstock stem (*see* Plate 20). Usually, this problem appears in cucurbit plant species grafted by using the hole insertion method (Hassell *et al.*, 2008), but also when the one-cotyledon grafting method is used. This may lead to infection with soilborne pathogens that the rootstock is apparently resistant to, such as *Fusarium oxysporum* f. sp. *radices-cucumerinum*, which causes crown and root rot in cucumber and melon (Pavlou *et al.*, 2002). Similarly, a bypass may occur when the scion roots directly in the growth medium after transplanting. This phenomenon, which is quite common in tomato and other Solanaceae but less so in the Cucurbitaceae, occurs when the rootstock is too short for grafting or when the grafted position is too low on the rootstock.

Logistics and transportation

Under the Mediterranean climate, transporting plantlets from the nursery to the field is a sensitive practice, and problems during planning, transport or at some other station along the way to the field might negatively affect plantlet establishment (Kubota and Kroggel, 2006). Insufficient irrigation before packing, transportation over long distances under non-cooled conditions or overheating immediately prior to transplanting can all impede plantlet establishment, and exposure to high temperatures, even for a few hours, may be deleterious to the plantlets. Vegetables, mainly cucumbers, accumulate ethylene under heat stress, which enhances plant ageing and inhibits establishment. Transplanting plantlets with low turgor or at high temperatures has similar negative effects. Long exposure of plants to low temperature may also reduce turgor, inhibit water absorption and decrease establishment success (Justus and Kubota, 2010). Because of the need to protect the plants from pests during transportation, different coverings are used, and these tend to intensify temperature build-up and heat stress. Shortened delivery times, maintaining a suitable temperature before planting and minimizing waiting times all facilitate the development of plantlets in the field.

Plot selection

The high management expense of greenhouses, net-houses and tunnels, and a scarcity of additional land suitable for agricultural use, have resulted in intensive use of available lands and continuous cropping on the same plots. The main limiting factor of this practice is the build-up of phytotoxic chemical residues and of soilborne pathogens, mainly fungi and nematodes but also viruses. The phase-out of methyl bromide for soil disinfection has led to applications of different soil fumigants and other pesticides and herbicides, some of which cause further residual build-up, requiring an awareness of the possibility that any residue might have a detrimental effect and verification of acceptable chemical levels before planting (Colla *et al.*, 2012).

Plot preparation

An area designated for planting grafted transplants should be totally cleared of weeds and previous crop residues (Katan, 2000). However, due to high costs, time investment and labour shortages, there has been a trend in recent years towards taking short cuts in plot preparation. Some farmers pulverize the previous crop's residues and spread them above the plots or incorporate them into the ground. Shallow and partial cultivation and no-till farming have also become popular agrotechnology practices. Although there are some benefits to these methods (Triplett and Dick, 2008), planting plantlets into residues of previous crops may inhibit plantlet establishment, mainly when the soil contains raw residues such as fibrous root systems, leaves and fruit, and may also increase the potential for hazards, such as pathogens that have remained in the previous crop's residues, as well as chemicals and salinity. For short periods, no-till cultivation may be used if sanitation, residue removal and washing are applied before planting. In the long term, any cultivation should be adjusted to soil type and season. In soils low in organic matter, compost amendments can improve soil structure (Mekki *et al.*, 2014). In heavy soils, high beds are recommended to improve drainage.

In warm areas and seasons, soil solarization is recommended wherever possible to control soilborne pests (Gamliel and Katan, 2012). Soil solarization consists of covering moist soil with a layer of transparent plastic and exposure to sunlight for a few weeks in the summer. Solarization can be used alone, or in combination with other chemical or biological agents as an integrated pest management programme in high-value horticultural crops grown in greenhouses and open fields. Successful solarization requires effective soil preparation and the use of suitable tarping and plastics technology (van Bruggen *et al*., 2016). Cold and moderate seasons limit soil heating and reduce heating deeper in the soil. Other limiting factors are the long period (30–60 days) required for an effective control process, although this can be shorter if combined with chemical soil disinfection, and the need for plastics disposal. Interactions with grafted transplants should be considered (Fallik *et al*., 2016): suitable plot preparation, consideration of the history of soilborne diseases, organic inputs and fertilizers, and reduction of soil salinity will support the grafted plant in its first stages in the field and enable successful cropping.

There exist some improved methods for coping with soilborne pathogens (Jarvis, 1989). For example, application of an intermediate medium before transplanting has been found to be effective against tobamovirus infection in infested soils (Antignus *et al*., 2005). This medium (clean soil, compost or inert medium) can be applied in pits or in strips along the plot and the plantlets are transplanted into it, thereby preventing infestation of the freshly injured roots by viruses. The new roots that break through the intermediate medium without transplanting injuries will be less sensitive to viral infection. This technique was successfully applied for grafted melons with a sensitive rootstock, which were transplanted in CGMMV-infested soil, and for grafted peppers that were sensitive to PMMV and were planted in infested soil (Antignus, 2012; Reingold *et al*., 2016).

The increased threat of soilborne pathogens, especially fungi and nematodes, in recent few years and depletion of permitted chemical soil disinfectants have contributed to increasing use of soil-less growth media such as rockwool and coco peat slabs. In Italy, increasing numbers of hectares of soil-less tomato are cultivated in coco peat slabs every year, and this system is also increasing in France, replacing soil cultivation. Soil-less growth on rockwool is also increasing but less rapidly. Soil-less substrates are usually highly conducive to soilborne diseases (Diara *et al*., 2012), mainly when used the first time; therefore, plantlets grafted on to resistant rootstocks are recommended. An additional advantage of the grafted transplants is enhanced vigour and improved establishment in soil-less growing systems (Patakioutas *et al*., 2015).

Planting

The grafted transplant should be transplanted carefully and with specific attention. As most the growth media include hydrophobic substrates, it should be confirmed that the plantlet has been well irrigated before transplanting. Otherwise, absorption of water from the soil will be less effective. It is recommended that the rootstock be squeezed gently before transplanting. If it discharges some water, then the irrigation is regarded as sufficient. If the rootstock is only damp or even dry, flooding the bottom of the trays (while keeping the foliage dry) in a cool water tank for a few minutes will wet the rootstock before transplanting. Deep planting and burial of the grafted point in wet soil creates a direct connection between the scion and the soil and encourages bypass of the rootstock by direct rooting. The size of the receiving hole for transplanting should be appropriate to the rootstock size to avoid air spaces, which lead to partial development of the new root system (*see* Plate 21). However, intensive compaction around the rootstock, twisted plantlet roots or insufficient wetting during transplanting causes significant delay in plantlet establishment. A certain distance between the ground and grafting point should be maintained, and covering the grafting point with soil, plastic mulch or other moisture-retaining materials is to be avoided. The grafted transplants should not be placed on the ground before planting, to avoid infection with pathogens such as tobamoviruses (Antignus *et al.*, 2005). These viruses can be present in plant residues, soil and organic particles, and any direct contact between them and the plantlet can lead to later infestation of the crop. Therefore, planting should be done directly from the tray into the transplanting holes, followed by gentle covering and pressing around the rootstock to avoid large air spaces.

9.1.2 Abiotic stress

Immediately after transplanting, the plantlet can be exposed to abiotic stresses, such as temperature (hot or cold ambient or soil temperature, high radiation), water availability (drought or salt) or flooding (lack of oxygen in the root zone) (Schwarz *et al.*, 2010). As a result, plantlet sensitivity to biotic stresses can also increase (Atkinson and Urwin, 2012). For example, exposure to hot or cold temperatures causes damage to the root membrane and leakage (Mahajan and Tuteja, 2005), thereby increasing plantlet sensitivity to pathogens such as *Pythium* spp. (Pivonia *et al.*, 2012).

Exposure to stresses at the establishment stage can affect the structure of the plant later on. For example, high radiation, either direct or reflected from the ground, increases plantlet height in a short time as an avoidance response to excess radiation (Takaichi *et al.*, 2000).

Heat and radiation

Heat stress is the most common abiotic stress during summer or autumn plantings in the Mediterranean region (Harel *et al.*, 2013). It is enhanced by high radiation and long days. Heat stress can be followed by osmotic stress due to water shortages and turgor loss. Plastic mulching of the soil and poor structural ventilation make the problem worse (*see* Plate 22). The mulching film colour also has a significant effect on stress potential (Lamont, 1995): black or transparent coverings absorb the radiation, increase soil and ambient temperatures around the plantlet, and may suppress new root development or even burn the plant where it is in direct contact with the covering (*see* Plate 23). Drip-irrigation pipes deployed under the mulch also absorb and emit heat and may harm the plantlets at points of direct contact.

Use of small planting holes in the mulch or covering of these holes with soil after planting can cause heat build-up in the rootstock, as soil cooling is limited under the mulch (*see* Plate 24). Heat is usually lost through evaporation, but if the soil is mulched, and the holes in the mulch are too narrow or covered, the high temperatures around the roots can become detrimental. If the ground is covered, large holes of more than 10 cm in diameter should be made to allow the soil around the plantlet to cool off by evaporation. Shading can also have a similar effect, but its combination with evaporation is most effective. Understanding the different stress factors in the different cropping sites and seasons will help in developing further techniques to reduce stress, such as additional plastic film mulching to avoid low temperatures, or application of non-woven fabric sheets or shading nets to reduce high radiation.

The grafted transplant is sensitive to high ambient and soil temperatures (Garibaldi and Minuto, 2003; Cohen *et al.*, 2007). As the grafted transplant is undergoing graft healing during the days before planting, the water-transport system between the scion and the rootstock is still incomplete and hence highly sensitive. For example, certain botanical varieties of *Cucumis melo* (melon), grafted on to *Cucurbita* (pumpkin) rootstocks, are sensitive to high soil temperature, which may cause physiological incompatibility at an early stage (Aloni *et al.*, 2008) or a late stage, during fruit ripening (Soteriou *et al.*, 2016). This phenomenon might be reflected by poor root development, early flowering and inhibited vegetative growth. Reduction of soil temperature by adequate mulch or shading successfully prevents the negative effects of heat on these grafted transplants. However, shading should be used properly and for a limited time during plantlet establishment. A constant and continuous reduction in radiation may decrease plant functioning, fitness, vigour and root-system development. Hence, any action taken after transplanting should be adjusted according to accumulated experience throughout the growing season and according to the developmental stage of the plant.

Cold temperature

Low temperature causes a delay in the development and growth of the plantlets (Korkmaz and Dufault, 2001). Temperatures that are too low will delay the appearance of the first inflorescence. In general, vegetable transplants are very sensitive to low temperatures (Jouyban *et al.*, 2013), and this is particularly noticeable in grafted cucumber and grafted melon (Ahn *et al.*, 1999). During the winter, it is recommended that the plantlets be protected using a plastic cover or non-woven fabric sheets, even if the plantlets are planted indoors. In temperate regions in the Mediterranean area, these non-woven fabric sheets are used mainly during the cold season as row covers. They have different purposes, such as to conserve warmth, stimulate germination and early growth, protect plants from frost injury and improve the quality of the crops.

The date of planting is critical in terms of plantlet development. In Israel, planting in the middle of winter – late November to mid-December – inhibits plantlet establishment and slows down plantlet development. Before or after midwinter, moderate stress is expected, and plantlets will become established and develop faster than those planted in the middle of winter. Hence, one means of avoiding plantlet growth retardation is transplanting before or after the lowest winter temperatures.

Low oxygen

Poorly drained soil or suboptimal irrigation-management strategies can cause a temporary excess of water; this situation may result in low-oxygen stress in the roots, followed by toxicity and death (Patel *et al.*, 2014). In sensitive crops such as cucumber, growth and development are retarded, but toxicity will only become apparent in the shoots at a later stage (van Dongen and Licausi, 2014). Therefore, it is important to identify the various abiotic stress factors and avoid them in order to prevent consequent damage by biotic stresses.

Salinization

Salinization is often associated with irrigated areas that are characterized by low rainfall and high evapotranspiration (Postiglione, 2003; Rengasamy, 2006). Excessive fertilization and irrigation with water containing high levels of salt dramatically aggravate the problem (Balliu *et al.*, 2012). Although grafted plants are relatively tolerant to high salinity (Edelstein *et al.*, 2005), it can influence normal functioning. High salinity levels, as well as high concentrations of specific ions in the irrigation water, reduce the yield potential in melon plants (Edelstein *et al.*, 2005); however, grafting on to a suitable rootstock can improve fruit quality under stress conditions (Colla *et al.*, 2006). Water shortages and high management costs have led many farmers to stop soil washing by sprinklers to remove salts until after tillage. The alternative of washing through conventional drip-irrigation systems with dripper intervals of 20–50 cm is not sufficient, as the salts accumulate at the margins of the wetting area and in the upper layer, instead of being flushed into the deeper soil layers. Soil tillage increases salt accumulation and fertilizer residues in the root zone from deeper layers. Ineffective or partial implementation of washing can result in high salt concentrations in the plantlet root zone, reduced water availability and increased ion toxicity, mainly from sodium and chloride ions (Shalhevet, 2004). It is therefore recommended to wash the soil with sprinklers, but if drip irrigation is used, it should include short dripper spacing or double the rate of dripping into a bed. Transplanting should only be performed in the washed zone, and planting at the bed margins where the salts concentrate to their highest level should be avoided.

The combination of salinization and high temperature has a weakening effect on grafted transplants such as cucumber or melon, which are particularly sensitive crops (Al-Sadi *et al.*, 2010); this combination makes them highly vulnerable to pathogens, mainly *Pythium* spp. If transplanting is carried out indoors and under hot climatic conditions, it is recommended that the ground at the bottom of the rootstock is well packed while leaving its upper part uncovered, that is, the hypocotyl and the adjacent roots at the crown (roots at the top of the plug) should left exposed. This will help avoid salt damage to the lower part of the stem, which is the most salt-sensitive part of the grafted transplant. This method should be performed carefully and only in the hot season, and is not be intended for application during the winter.

9.1.3 Biotic stress

Weeds and self-seeding

Self-seeded plants or residues from the prior crop, as well as weeds, can become hosts for pests such as mites, thrips, mealybugs and whiteflies (Jarvis, 1989; Wisler and Norris, 2005). In some cases, they could be a source of acquired virus, or other inoculum of plant pathogens. Sanitation and removal of previous crop residues are effective for reducing these hazards (Ucko and Dayan, 1986; Katan, 2004; Louws *et al.*, 2010). Chopping and rototilling of crop residues into the plot may allow pathogenic microorganisms to survive, with consequent risk for the next crop.

Viruses

The major viral risk factors in intensive crops include viruses from the family *Tobamovirus* such as CGMMV, TMV and ToMV (Loebenstein and Lecoq, 2012). In recent years, these seedborne viruses, which are spread by crop residues and agricultural equipment, have been found to significantly infest and survive in agricultural land. As already mentioned, an effective method for preventing root infection by viruses is application of a physical buffer before transplanting. Other groups of viruses, transmitted by vectors such as whiteflies or aphids, can damage plantlets after planting (Tomlinsone, 1987). Physical barriers, mainly nets or screens (minimum 50-mesh) prevent pest invasion or enable insect confusion, based on wavelength-dependent insect vision. Such barriers reduce the proliferation and direct damage from these potential viral vectors (Antignus and Ben-Yakir, 2004). UV-absorbing films that significantly reduce transmission of UV-A and UV-B natural solar radiation can interfere with the vision of pests. The exclusion of UV from natural sunlight hampers flight initiation, dispersal, host finding and establishment, hence affecting the population build-up (Gulidov and Poehling, 2013). For example, UV-absorbing plastic roofs showed a pronounced deterrent effect for movement of thrips towards greenhouses, and the UV-absorbing net effectively reduced the number of thrips crossing the net barrier into the greenhouse (Nguyen *et al.*, 2009).

Bacteria

Exclusion of pathogenic inoculum sources before transplanting is essential to decrease bacterial infestation after transplanting (van der Wolf and de Boer, 2015). For example, one of the major sources of *Clavibacter* survival in tomatoes is fruit residues from the previous crop. Keeping the plot clean of residues effectively decreases inoculum density and possible sources for epidemics. Guttation should be considered as an additional source for the secondary spread of *C. michiganensis* (Sharabani *et al.*, 2013). Avoiding touching tomato plants bearing guttation droplets significantly decreased the occurrence of severe bacterial canker epidemics (Shtienberg *et al.*, 2015). Some pathogenic bacteria are encouraged by abiotic stress conditions such as excess water or extreme temperatures. Avoiding these conditions shortly after transplanting decreased the presence of *Erwinia* and other bacteria with the potential to cause diseases (Albajes, 1999; Gnanamanickam, 2007).

Fungal diseases

The primary purpose of grafting vegetables worldwide has been to provide resistance to soilborne diseases (Louws *et al*., 2010), and its use dramatically increased after the phase-out of the soil disinfectant methyl bromide (King *et al*., 2008). However, under the hot Mediterranean climate conditions, crop sensitivity to certain pathogens may increase. Breakdown of rootstock resistance (Abdul-Baki and Haroon, 1996), or favoured conditions for disease expression during plantlet establishment, will negatively affect plant health. For example, oomycetes such as *Pythium* spp. are considered to have a broad host range. *Pythium aphanidermatum* favours the very warm conditions (Ben-Yephet and Nelson, 1999) that are unfavourable for proper plantlet establishment, making the latter more sensitive to *Pythium* infection. Grafting cucumber on to different *Cucurbita* rootstocks indeed improved its tolerance to *P. aphanidermatum* infection, but infected plantlet survival was reduced when the temperature and humidity were higher (Al-Mawaali *et al*., 2012). Insufficient soilborne disease management may result in suppression of growth after transplanting.

Macrophomina phaseolina, which causes vine decline and yield losses in muskmelon, and *Monosporascus cannonballus*, which causes sudden wilt of muskmelon, are both enhanced by hot environmental conditions (Cohen *et al*., 2000). Verticillium wilt of watermelon was successfully managed by grafting, although disease incidence, fruit yield and quality were affected by soil inoculum density and environmental conditions (Wimer *et al*., 2015). Soil and water salinity may increase transplant sensitivity to soilborne pathogens (Al-Sadi *et al*., 2010). Irrigation with saline water significantly increased disease severity in tomato transplants inoculated with *F. oxysporum* f. sp. *radicis-lycopersici*, and mineral fertilization further increased it (Triky-Dotan *et al*., 2005). In certain cases, grafting improved tomato salinity tolerance (Martorana *et al*., 2007; di Gioia *et al*., 2013), but possible interactions with soilborne diseases should be considered.

9.2 Recommendations for the Use of Grafted Plants in Greenhouses: the Case of The Netherlands

Annual fruit crops such as tomato, pepper, cucumber and aubergine are commonly grown in soil-less culture in The Netherlands. Almost 100% of the year-round cultivation of tomato and aubergine is grafted, whereas rootstocks are hardly used in the cultivation of pepper and cucumber. In the latter crops, grafting is economically not feasible due to the lack of production increase. In pepper and cucumber, rootstocks are only used in organic cultivation in soil, in order to prevent problems with soilborne diseases.

The main objectives of using grafted transplants are: (i) to increase production (Rouphael *et al*., 2010; Flores *et al*., 2010); (ii) to improve the physiology of the plants, making them more robust to tolerate biotic and abiotic environmental stresses (Lee *et al*., 2010); and (iii) to impart resistance against a number of soilborne diseases and nematodes (Louws *et al*., 2010). In order to realize these advantages, the grafted plantlets from the nurseries have to meet the highest quality standards and the cultivation practice has to be adapted to the demands of grafted plants. In this section, a number of recommendations on the cultivation of grafted vegetable plants in high-tech greenhouse systems are presented.

9.2.1 The grafting process

Before grafting takes place, the grower has to decide on the genotypes of the rootstock and scion that will best fit their cultivation strategy. This decision is usually taken based on discussions with a consultant and a seed company, who will have an array of rootstock genotypes available ranging from high to moderate vigour and with resistances to viruses, fungi and nematodes.

For commercial cultivation of grafted plants in large-scale greenhouses, the grafting process usually takes place at specialized nurseries. For a successful graft union formation, the cambium of the rootstock and scion must be well aligned and in close contact. The scion and rootstock plants must therefore have similar stem diameters at the moment of grafting. To realize this, tomato rootstock seeds are sown approximately 1 week earlier than the scion cultivar. Compared with the cultivation of non-grafted plants, seeds of the scion have to be sown approximately 5 days earlier to obtain plants of the desired size on the date of planting, as grafting results in a delay in plant growth and development (Peet and Welles, 2005). Currently, the most commonly used grafting technique is splice grafting in which the rootstock and the scion are cut at matching 45° angles and fixed together with a silicone grafting clip (*see* Chapter 1, this volume) (Lee *et al.*, 2010).

After grafting and a healing schedule in which the vascular connections are established under high humidity conditions at the nursery, the grafted plants are transferred to commercial greenhouses. For successful cultivation in which high production levels and high product quality are realized, the quality of the grafted plantlet is a key factor. High-quality plantlets should be uniform in size and traits, of proper size or height and with a well developed root system and an aboveground plant appearance as agreed with the grower (in terms of thickness of the stem, plant height, developmental stage and leaf area). The grafted plantlets should be completely free of bacterial and viral diseases, although this may not always be easily recognized at the time of transplanting (Lee *et al.*, 2010).

9.2.2 Cultivation system of grafted plants

One of the issues in the use of grafted plants is their price. Grafted plants are 50–100% more expensive than non-grafted plants, which is caused by the fact that two seeds are required per plantlet (one for the rootstock and the other for the scion) and that there are additional labour costs in the production of grafted plants (Morra, 2004), a problem that could be mitigated by the development of automated grafting robots (Kurata, 1994). To reduce the expenses for the grafted plant material per m^2 for the grower, often two stems per plant are kept. Multiple strategies can be used to obtain two stems. The first is to allow the main stem to grow normally, and let a side shoot below the first or second truss become the second stem. Depending on the plant density in the greenhouse, additional shoots may be allowed on all plants at the same time, or in a number of steps, to realize the final stem density. Another strategy to obtain two stems per plant is to decapitate the plant and allow two buds to grow and form the two stems per plant. This decapitation can be done above the cotyledons (*see* Plate 25) so that two equal-sized shoots will be produced from the buds at the base of the cotyledons. However, at the moment of decapitation, the plants are relatively small with little capacity for light interception. Therefore, this is a strategy that is applied mainly in countries with higher light intensities at the moment of planting (e.g. France, Italy), or at sites where artificial light is used. The most commonly used method in countries with lower light intensities in winter, such as The Netherlands and Belgium, is to decapitate above the second leaf (*see* Plate 26) so that the plants have a larger leaf area for light interception after decapitation than when decapitated above the cotyledons. In this case, the buds belonging to the first and second leaf will grow out to form the shoots. Both decapitation methods will set back the plant growth, delaying the shoot appearance by 14 days (decapitation above the cotyledons) to 1 week (decapitation above the second leaf).

9.2.3 Start of cultivation

In general, the start of cultivation of grafted plants requires more skills of the grower than non-grafted plants. Cultivation starts with plants that tend to be more vegetative (larger leaves), with one or more leaves below the first truss, than in non-grafted plants (Peet and Welles, 2005), and with two stems that differ in vigour. The high vigour of the plants demands a high rate of cultivation, which implies that they should be cultivated at a higher average 24 h temperatures. Other measures that can be taken are a higher electrical conductivity level or less irrigation than non-grafted plants to stimulate flowering and fruit set. In general, the early fruit production of grafted plants is equal to or lower than that of the non-grafted plants (Wittemans, 2012). To prevent too great a difference in early production, the growth pattern of grafted plants should be controlled accurately at the beginning of the cultivation.

The rootstocks that are currently used are highly vigorous, and so would produce much leaf mass at the expense of fruit production if their growth pattern was not adjusted by the grower. The grower therefore has to take 'generative' actions, that is, measures that will stimulate the assimilate distribution to the fruits rather than to the leaves. The measures that can be taken are as follows:

- Maintain two stems per plant. This generates a larger aboveground 'sink' compared with the root volume, which suppresses the vegetative growth of the plant.
- Maintain a large difference between the temperature during the day and the temperature at the beginning of the night (Zhang *et al.*, 2010). This is common practice in tomato cultivation, although there is limited evidence that this stimulates assimilate partitioning to the fruits.
- Prevent the plants from using a large part of their assimilates for root growth. This means that the root volume should be restricted during the first (2) weeks of cultivation when the plantlet is not placed on the rock wool slab and is only

allowed to form the root system in a rock wool cube of 10 × 10 cm. In the first weeks after planting on the rockwool slab, restricted root growth and water transport to the leaves is realized by increasing the electrical conductivity of the nutrient solution, and by not watering the plants during the day so that the amount of available water will be less then.

- Leaf removal: during cultivation, young leaves are removed from the top of the shoot to reduce the partitioning of assimilates to the leaves in favour of partitioning of assimilates to the fruits.

9.2.4 Later phases in cultivation

One of the objectives of grafting vegetables is to obtain a yield increase. In general, in crops that are planted in December, early production levels of non-grafted plants are equal to or higher than those of grafted plants (Wittemans, 2012). The advantages of grafting are seen only in the second part of the cropping cycle (after June). Especially in periods when the climate is unfavourable, grafted plants have proven to be able to deal with these conditions better, due to better uptake of water and nutrients (Tachibana, 1982; Ahn *et al.*, 1999). This is the case both in the winter months when light conditions are unfavourable, and in summer when greenhouse temperatures are high. Grafted plants also have the ability to recover better after infection with diseases like pepino mosaic virus. In summer, grafted plants were able to maintain fruit set and fruit quality, whereas non-grafted plants had problems with these processes (Kell and Jaksch, 1998). The production increase is due to the higher mean fruit mass, as well as the rate of truss initiation, which is higher from June onwards for grafted plants compared with non-grafted plants (Wittemans, 2012).

The consequence is that a grafted crop can be cultivated for a longer period than a non-grafted crop (Lee, 1994), which is convenient in western European cultivation where the cropping cycle of a tomato or aubergine crop is 11 months. The advantages of rootstocks are even more pronounced in high-tech greenhouses that have high light transmission, CO_2 supply and light assimilation.

9.3 Role of Grafting in Speciality Crops

9.3.1 Globe artichoke

Cynara cardunculus L., a Mediterranean perennial species within the *Asteraceae* (Compositaeae) family, includes the two cultivated taxa globe artichoke (*C. cardunculus* var. *scolymus* L.) and cardoon (*C. cardunculus* var. *altilis* DC), along with their ancestor the wild cardoon, also called artichoke thistle (*C. cardunculus* var. *sylvestris* (Lam.) Fiori) (Rouphael *et al.*, 2012; Colla *et al.*, 2013). Currently, most commercial grafting is practised in annual fruit crops belonging to the Solanaceae, such as aubergine, pepper and tomato, and the Cucurbitaceae, such as cucumber, melon and watermelon. However, in recent years, grafting has been adopted in other vegetables, in particular artichoke (Ciccarese *et al.*, 2012; Temperini *et al.*, 2013; Trinchera *et al.*, 2013). Reports mentioning Verticillium wilt tolerance in artichoke being affected by grafting began in 2012. Verticillium wilt, caused by the soilborne fungus *Verticillium dahliae*, is spreading in artichoke-growing areas worldwide and is becoming a threat to artichoke production (Cirulli *et al.*, 2010). Ciccarese *et al.* (2012) tested a collection of wild and cultivated cardoons under controlled conditions for resistance to *V. dahliae* by artificial inoculation with a conidial suspension of the fungus. Of 44 populations obtained by open pollination in the field, nine showed a high level of resistance to Verticillium wilt without any symptoms. The authors concluded that the use of artichoke plants grafted on to rootstocks resistant to Verticillium wilt can be an efficient agronomical tool, mainly in areas where the soil is significantly infested (Ciccarese *et al.*, 2012). Similarly, Temperini *et al.* (2013) evaluated the crop performance of seed-propagated artichoke selection 'T3' either non-grafted or grafted on to the cultivated cardoon 'Bianco gigante inerme a foglia intera' in soil infested with *Verticillium* spp. over 3 years. Selection 'T3' was used due to the susceptibility to Verticillium wilt. The total yield was on average higher by 44–53% over the 3 years in grafted compared with non-grafted artichoke plants (Temperini *et al.*, 2013). The increase in total yield in grafted plants was attributed to an increase in both head mean mass and numbers. Moreover, the Verticillium wilt incidence in grafted plants was significantly lower in comparison with non-grafted plants (10 versus 43%). The higher yield and yield components of grafted artichoke plants in infested soils were also recorded in non-infested soil conditions when the seed-propagated artichoke hybrid 'Concerto' was grafted on to the cultivated cardoon variety 'Belgio' (Temperini *et al.*, 2013). In the same work, the authors evaluated the compatibility of the two seed artichoke cultivars 'Romolo' and 'Istar' grafted on to the cultivated cardoon 'Bianco avorio' and wild cardoon, and also identified the most accurate grafting method (splice versus cleft grafting) (*see* Plate 27). Temperini *et al.* (2013) demonstrated that the higher grafting survival rate (82–92%) was recorded when the two cultivars were self-grafted, cross-grafted and grafted on to 'Bianco avorio', whereas a lower affinity rate (39–49%) was found when the wild cardoon was used as rootstock. The grafting technique affected the survival rate, with higher values observed with the splice grafting (78%) compared with cleft grafting (73%) method, indicating that splice grafting is the most suitable method for globe artichoke.

Rootstock–scion compatibility is a key factor in grafted vegetables depending on anatomical, physiological and genetic variables (Edelstein *et al.*, 2004). The mechanism of graft compatibility/incompatibility in artichoke was studied by Trinchera *et al.* (2013), who reported that the degree of affinity between different artichoke scion and cardoon rootstocks was associated with the healing time of the two bionts. Scanning electron microscopy images of longitudinal sections of graft junctions, just 3 days after grafting, revealed the appearance of many interconnection structures between the two grafting components, followed by a vascular rearrangement and callus development during graft union formation. The 'Romolo'–'Sardo' affinity has been associated with the higher capacity of wild cardoon 'Sardo' to produce pectic and carbohydrate materials at the graft interface (Trinchera *et al.*, 2013). The authors also demonstrated that the duration of the early-stage grafting process could be affected not only by the scion–rootstock compatibility, but also by the different growing seasons, being favoured by lower temperatures and a reduced light/dark photoperiod.

9.3.2 Green bean

Grafting of green beans (*Phaseolus vulgaris* L.) has been used in Portugal to prevent biotic and abiotic stresses since 2010 and is currently an important strategy for the production of this crop in greenhouses, in both hydroponic and soil-based production systems. Keen interest in green bean grafting has also arisen because of its environmental sustainability and ease of management, which make it ideal for organic production.

Historically, protected crops of green beans grown in soil have been cultivated under intensive conditions, frequently twice a year, with high application rates of mineral synthetic fertilizers and pesticides and without crop rotation. These practices led to a significant increase in soil salinity and to a higher incidence of soilborne diseases such as those caused by *Fusarium* spp. and by root-knot nematodes (*Meloidogyne* spp.), which have impaired the production of this crop in the main vegetable production areas in Portugal (Rodrigues, 2010). Therefore, grafting became a promising technique to improve nutrient uptake, increase crop tolerance to salinity and suppress soilborne diseases through natural resistance/tolerance of some rootstocks of *Phaseolus coccineus* L. and *P. vulgaris* species.

P. coccineus was cultivated for several thousand years in Mesoamerica and was introduced to Europe in the 17th century (Hernández-Bermejo and León, 1992). Its centre of origin is the Mexican highlands where it grows wild and sometimes at the edge of cultivated bean plots (Delgado-Salinas, 1988). This species has a high degree of allogamy, shown, for example, by different seed colours produced from a single-coloured seed sown (Giurcă, 2009). The wild forms show great phenotypic variation and are currently under active speciation, although crosses between wild and domesticated forms have changed the speciation patterns. However, this species still shows great potential for breeding, and it is recognized that rustic forms of *P. coccineus* are resistant to some viruses (e.g. bean golden mosaic virus), bacteria (e.g. *Pseudomonas syringae* Van Mall; *Xanthomonas phaseoli*) and fungi (e.g. *Colletotrichum lindemuthianum*) (CATIE, 2014). For example, Giurcă (2009) showed that *P. vulgaris* plants had a lower vigour and were more susceptible to attack by *Xanthomonas campestris*, compared with *P. coccineus* species, which showed high vigour and greater resistance to attack by this pathogen.

P. coccineus has a well developed root system with a tuberized taproot, which is rich in starch, and numerous large and fleshy secondary roots (Delgado-Salinas, 1988; Giurcă, 2009; Labuda, 2010; CATIE, 2014), while *P. vulgaris* has a fusiform, weakly developed root system (Giurcă, 2009). *P. coccineus* plants have smaller numbers of stem ramifications but greater growth vigour compared with *P. vulgaris* plants (Giurcă, 2009). There are only a few distinguishable cultivars of *P. coccineus* for the determinate or the indeterminate plant growth habit types (Hernández-Bermejo and León, 1992). In Portugal, the indeterminate type is cultivated traditionally in the north of the country and is called *feijão de 7 anos* or

'7-year bean', due to the vegetative buds in the root crown of this species, allowing regrowth for several consecutive years.

The traits of *P. coccineus* and its botanical proximity to the common bean *P. vulgaris* match the green bean rootstock requirements for both plant breeding programmes (Gurusamy *et al.*, 2010) and crop production. Trials developed in Portugal with the *P. coccineus* cultivars 'Aintree' (P1) and 'White Emergo' (P2) (TozerSeeds) and the '7-year bean' landrace 'Ponte de Lima' (P3) as rootstocks (*see* Plate 28), were conducted in two different locations in north-west Portugal to evaluate the effect of root/shoot genotype combinations on yield and pod quality of two commercial cultivars, 'Oriente' (Vreeken's Zaden) and the standard Portuguese traditional 'Vagem rajada' (Anseme) (I. Mourão, M.L. Moura, L.M. Brito, J. Coutinho and S.R. Costa, 2016, unpublished results). The splice grafted plants could withstand two sets of stems along two training supports but the self- and non-grafted plants only one. In order to maintain the same stem density, self- and non-grafted plants were planted in pairs. Planting densities were equivalent to 3.3 and 2.1 stems m^{-2}, respectively, for the first and second experimental sites.

At the first site, the experiment was conducted with low input of soil mineral nutrients and the crop showed symptoms of vascular wilt caused by the soilborne fungus *F. oxysporum* f. sp. *phaseoli*. At this site, the highest yield was obtained with 'Oriente' shoot grafted on to '7-year bean' root (P3), followed by the scion–rootstock combinations 'Oriente'–P2 and 'Vagem rajada'–P2 and –P3. A similar lower yield was found in the graft combinations of both cultivars grafted on to rootstock P1, in the self-grafted and in the non-grafted plants of both green bean cultivars. At the second site, with absence of disease symptoms, increased mineral nutrient availability and lower crop density, a comparable yield was obtained from plants of both cultivars in self-grafted and non-grafted plants and where they were grafted on to P1 and P3 rootstocks, which was higher than the yield from plants of both cultivars grafted on to rootstock P2. Symptoms of root-knot nematodes were not observed in either site, which agreed with the non-detection of this disease through nematological soil analysis done at planting.

Grafting green beans showed no advantages at the second experimental site, but in the first site, with low nutrient input, the root/shoot genotype affected crop growth and development. 'Oriente' grafted on to rootstock of the '7-year bean' landrace (P3) appeared to be an appropriate strategy for increasing crop tolerance to vascular wilt disease (*F. oxysporum* f. sp. *phaseoli*) and to allow greater absorption of nutrients in the soil, probably due to the better developed root system, compared with the *P. vulgaris* cultivars (Giurcă, 2009). The rootstock 'Aintree' (P1) may have been more sensitive to this soilborne pathogen. Different root/shoot genotype responses to *F. oxysporum* f. sp. *phaseoli* were also reported for the root-rot disease caused by *Fusarium solani* f. sp. *phaseoli*, whose severity in *P. vulgaris* crops has been shown to increase with the environmental factors that stressed the plants (Cichy *et al.*, 2007). Two quantitative trait loci associated with *F. solani* f. sp. *phaseoli* resistance have been identified in the *P. vulgaris* genome (Schneider *et al.*, 2001; Hagerty *et al.*, 2015) and accounted for 9 and 22% of the total genetic variation in the studies described by Hagerty *et al.* (2015). Although these findings improved bean resistance selection and breeding towards a more efficient marker-assisted selection, different mechanisms of resistance were apparently at work under different environmental conditions. Cichy *et al*. (2007), working with different *P. vulgaris* graft combinations, reported that root genotype controlled the expression of root-rot incidence in the absence of soil compaction, but with the addition of a compacted soil layer, the interaction of the root/shoot genotype dictated *F. solani* f. sp. *phaseoli* severity. In addition, quantitative trait loci for root vigour were correlated with *F. solani* f. sp. *phaseoli* resistance, indicating that selection for vigorous root systems can be especially valuable in uncompacted soils. Therefore, crop management and plant breeding efforts that effectively improve root growth can play a critical role in mitigating this disease.

A pot experiment in controlled conditions was conducted to evaluate the resistance/tolerance to *Meloidogyne javanica* of five cultivars of *P. vulgaris* and four cultivars *P. coccineus* (I. Mourão, M.L. Moura, L.M. Brito, J. Coutinho and S.R. Costa, 2016, unpublished results). Plants were inoculated with 5000 eggs and second-stage juveniles of *M. javanica*, with non-inoculated plants serving as a negative control and susceptible tomato 'Tiny Tim' being used as a positive control. Sixty days after inoculation, roots were observed to determine the number of galls and egg masses. None of the tested cultivars was completely resistant to the nematode, but a potential for resistance was detected in two *P. vulgaris* cultivars out of the nine cultivars tested. These two cultivars showed levels of nematode-induced galls and egg masses comparable to cultivars classified as resistant. Soils with nematode problems could benefit from these non-grafted cultivars if they were used as rootstocks because resistance factors to the root-knot nematodes *Meloidogyne incognita* were either localized within roots or not translocated basipetally through the stem graft union in studies conducted by Mullin *et al*. (1991). These authors, using graft combinations between resistant and susceptible *P. vulgaris* cultivars, reported that a resistant rootstock resulted in a resistant response to the root-knot nematodes, and that those combinations in which the rootstock was susceptible had a susceptible response, regardless of the scion component.

Green bean pod quality can also be influenced by the rootstock genotype. In the above-mentioned field experiments in Portugal (I. Mourão, M.L. Moura, L.M. Brito, J. Coutinho and S.R. Costa, 2016, unpublished results), grafting with 'White Emergo' (P2) and the '7-year bean' landrace (P3) rootstocks resulted in an increased phosphorus content of the pods for both cultivars ('Oriente' and 'Vagem rajada') at both experimental sites, as well as increased magnesium content at the first site and calcium content at the second site, compared with self-grafted and non-grafted plants. These higher nutrient contents of the pods indicated increased nutrient uptake and better utilization of these nutrients by grafted plants with P2 and P3 rootstocks. In addition to these nutritional quality attributes, the green pods of both cultivars grafted on to rootstock P3 at the first site showed a 15% increase in mean length per pod compared with self-grafted and non-grafted plants.

Recently, green bean crop production has begun to benefit from grafting, and we believe that improved rootstocks will be able to overcome the main production constraints for both conventional and organic protected crops. Green bean grafting appears to be an appropriate strategy to increase crop tolerance to important soilborne diseases and to increase nutrient uptake, which will allow crop yield increases and reduced use of synthetic chemical solutions. Selection and breeding efforts, together with a better understanding of scion–rootstock combinations and crop management effects on plant growth and development, need further study.

9.4 Conclusions and Future Perspectives on Vegetable Grafting

Vegetable grafting has the potential to improve resistance to biotic and abiotic stresses, as well as to increase yield biomass and quality. As a result of its benefits and value, demand for high-quality grafted transplants by vegetable growers and interest by specialist propagators are expected to increase in the years to come. However, care must be taken to ensure sanitation, Good Manufacturing Practice and appropriate conditions during transport and transplanting to ensure proper establishment of the grafted transplant. Investing effort in sufficient plot preparation before transplanting and elimination of stress factors after transplanting will improve plantlet establishment and enable expression of the proper benefits of grafting. As grafted plants have different behaviours and requirements from non-grafted ones, special cultivation practices (plant density, length of the growing cycle, irrigation and fertilization) have to be adapted to the demands of grafted plants. New frontiers in vegetable grafting have been reached in recent years as specialty crops such as globe artichoke and green bean have been successfully grafted on to specific rootstocks with very promising results. Scientists, extension specialists, propagators and vegetable growers need to work together in the future to integrate this environmentally friendly technology as a key factor for sustainable horticultural production.

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References

Abdul-Baki, A.A. and Haroon, S.A. (1996) Temperature effects on resistance to *Meloidogyne* spp. in excised tomato roots. *HortScience* 31, 147–149.

Ahn, S.J., Im, Y.J., Chung, G.C., Cho, B.H. and Suh, S.R. (1999) Physiological responses of grafted-cucumber leaves and rootstock roots affected by low root temperature. *Scientia Horticulturae* 81, 397–408.

Albajes, R. (ed.) (1999) *Integrated Pest and Disease Management in Greenhouse Crops*. Springer Science & Business Media, New York.

Al-Mawaali, Q.S., Al-Sadi, A.M., Khan, A.J., Al-Hasani, H.D. and Deadman, M.L. (2012) Response of cucurbit rootstocks to *Pythium aphanidermatum*. *Crop Protection* 42, 64–68.

Aloni, B., Karni, L., Deventurero, G., Levin, Z., Cohen, R., Katzir, N., Lotan-Pompan, M., Edelstein, M., Aktas, H., Turhan, E., Joel, D.M., Horev, C. and Kapulnik, Y. (2008) Possible

mechanisms for graft incompatibility between melon scions and pumpkin rootstocks. *Acta Horticulturae* 782, 313–324.
Alpert, P., Baldi, M., Ilani, R., Krichak, S., Price, C., Rodó, X., Saaroni, H., Ziv, B., Kishcha, P., Barkan, J., Mariotti, A. and Xoplaki, E. (2006) Relations between climate variability in the Mediterranean region and the tropics: ENSO, South Asian and African monsoons, hurricanes and Saharan dust. In: Lionello, P., Malanotte-Rizzoli, P. and Boscolo, R. (eds) In: *Mediterranean Climate Variability. Developments in Earth and Environmental* Sciences, Vol. 4. Elsevier, Amsterdam, The Netherlands, pp. 149–177.
Al-Sadi, A.M., Al-Masoudi, R.S., Al-Habsi, N., Al-Said, F.A., Al-Rawahy, S.A., Ahmed, M. and Deadman, M.L. (2010) Effect of salinity on pythium damping-off of cucumber and on the tolerance of *Pythium aphanidermatum*. *Plant Pathology* 59, 112–120.
Antignus, Y. (2012) Control methods of virus diseases in the Mediterranean basin. *Advances in Virus Research* 84, 533–553.
Antignus, Y. and Ben-Yakir, D. (2004) Ultraviolet-absorbing barriers, an efficient integrated pest management tool to protect greenhouses from insects and virus diseases. In: Horowitz, A.R. and Ishaaya, I. (eds) *Insect Pest Management*. Springer, Berlin/Heidelberg, pp. 319–335.
Antignus, Y., Lachman, O., Pearlsman, M. and Koren, A. (2005) Containment of cucumber fruit mottle mosaic virus (CFMMV) infection through roots by planting into a virus-free intermediating medium. *Phytoparasitica* 33, 85–87.
Atkinson, N.J. and Urwin, P.E. (2012) The interaction of plant biotic and abiotic stresses: from genes to the field. *Journal of Experimental Botany* 63, 695–709.
Balliu, A., Sallaku, G. and Babaj, I. (2012) The effect of watermelon (*Citrullus aedulis*) grafting methods on seedling's growth rate and plant stand establishment rate under saline conditions. *Acta Horticulturae* 927, 393–398.
Ben-Yephet, Y. and Nelson, E.B. (1999) Differential suppression of damping-off caused by *Pythium aphanidermatum*, *P. irregulare*, and *P. myriotylum* in composts at different temperatures. *Plant Disease* 83, 356–360.
Bolle, H.J. (ed.) (2003) *Mediterranean Climate: Variability and Trends*. Springer Science & Business Media, New York.
Cantliffe, D.J. (2008) Plug technology: horticultural revolution. *Chronica Horticulturae* 4, 7–10.
Castilla, N. (2002) Current situation and future prospects of protected crops in the Mediterranean region. *Acta Horticulturae* 582, 135–147.
Castilla, N. and Baeza, E. (2013) Greenhouse site selection. In: *Good Agricultural Practices for Greenhouse Vegetable Crops*. FAO Plant Production and Protection Paper 217. UN Food and Agriculture Organization, Rome, pp. 21–34.
CATIE (2014) *Phaseolus coccineus*. Banco de Germoplasma de semillas ortodoxas del Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Costa Rica. Available at: http://bancodegermoplasma.catie.ac.cr/phaseolus_coccineus.php (accessed 6 July 2015).
Chiu, Y.C., Chen, S. and Chang, Y.C. (2010) Development of a circular grafting robotic system for watermelon seedlings. *Applied Engineering in Agriculture* 26, 1077–1084.
Ciccarese, F., Crinò, P., Raccuia, S.A., Temperini, A. (2012) Use of resistant cardoons as rootstocks for the control of verticillium wilt in globe artichoke. *Acta Horticulturae* 942, 201–206.
Cichy, K.A., Snapp, S.S. and Kirk, W.W. (2007) Fusarium root rot incidence and root system architecture in grafted common bean lines. *Plant Soil* 300, 233–244.
Cirulli, M., Bubici, G., Amenduni, M., Armengol, J., Berbegal, M., Jiménez-Gasco, M.M. and Jiménez-Díaz, R.M. (2010) Verticillium wilt: a threat to artichoke production. *Plant Disease Feature Article*, 94, 1176–1187.
Cohen, R., Pivonia, S., Burger, Y., Edelstein, M., Gamliel, A. and Katan, J. (2000) Towards integrated management of *Monosporascus* wilt of melons in Israel. *Plant Disease* 84, 496–505.
Cohen, R., Burger, Y., Horev, C., Koren, A. and Edelstein, M. (2007) Introducing grafted cucurbits to modern agriculture: the Israeli experience. *Plant Disease* 91, 916–923.

Colla, G., Roupahel, Y., Cardarelli, M. and Rea, E. (2006) Effect of salinity on yield, fruit quality, leaf gas exchange, and mineral composition of grafted watermelon plants. *HortScience* 41, 622–627.

Colla, P., Gilardi, G. and Gullino, M.L. (2012) A review and critical analysis of the European situation of soilborne disease management in the vegetable sector. *Phytoparasitica* 40, 515–523.

Colla, G., Rouphael, Y., Cardarelli, M., Svecova, E., Rea, E. and Lucini, L. (2013) Effects of saline stress on mineral composition, phenolics acids and flavonoids in leaves of artichoke and cardoon genotypes grown in floating system. *Journal of the Science of Food and Agriculture* 93, 1119–1127.

de León, L., Siverio, F., López, M.M. and Rodríguez, A. (2011) *Clavibacter michiganensis* subsp. *michiganensis*, a seedborne tomato pathogen: healthy seeds are still the goal. *Plant Disease* 95, 1328–1338.

Delgado-Salinas, A. (1988) Variation, taxonomy, domestication, and germplasm potentialities in *Phaseolus coccineus*. In: Gepts, P. (ed.) *Genetic Resources of Phaseolus Beans*. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 441–463.

Diara, C., Incrocci, L., Pardossi, A. and Minuto, A. (2012) Reusing greenhouse growing media. *Acta Horticulturae* 927, 793–800.

di Gioia, F., Signore, A., Serio, F. and Santamaria, P. (2013) Grafting improves tomato salinity tolerance through sodium partitioning within the shoot. *HortScience* 48, 855–862.

Dutta, B., Gitaitis, R., Smith, S., Langston, D. Jr (2014) Interactions of seedborne bacterial pathogens with host and non-host plants in relation to seed infestation and seedling transmission. *PLoS ONE* 9, e99215.

Edelstein, M., Burger, Y., Horev, C., Porat, A., Meir, A. and Cohen, R. (2004) Assessing the effect of genetic and anatomic variation of *Cucurbita* rootstocks on vigour, survival and yield of grafted melons. *Journal of Horticultural Science and Biotechnology* 79, 370–374.

Edelstein, M., Ben-Hur, M., Cohen, R., Burger, Y. and Ravina, I. (2005) Boron and salinity effects on grafted and non-grafted melon plants. *Plant and Soil* 269, 273–284.

Fallik, E., Alkalai-Tuvia, S., Chalupowicz, D., Zutahy, Y., Zaaroor, M., Beniches, M. and Gamliel, A. (2016) Effects of rootstock and soil disinfection on quality of grafted watermelon fruit (*Citrullus lanatus* L.): a two-year study. *Israel Journal of Plant Sciences* 63, 38–44.

Flores, F.B., Sanchez-Bel, P., Estan, M.T., Martinez-Rodriguez, M.M., Moyano, E., Morales, B., Campos, J.F., Garcia-Abellán, J.O., Egea, M.I., Fernández-Garcia, N., Romojaro, F. and Bolarín, M.C. (2010) The effectiveness of grafting to improve tomato fruit quality. *Scientia Horticulturae* 125, 211–217.

Gamliel, A. and Katan, J. (eds) (2012) *Soil Solarization: Theory and Practice*. American Phytopathological Society, St Paul, Minnesota.

Garibaldi, A. and Minuto, A. (2003) The application of grafting against soilborne pests and diseases of tomato in Italy: present situation and perspectives. In: *Proceedings of International Congress 'Greenhouse tomato – Integrated Crop Production – Organic Production*, Avignon, France, pp. 55–59.

Giurcă, D.M. (2009) Morphological and phenological differences between the two species of the *Phaseolus* genus (*Phaseolus vulgaris* and *Phaseolus coccineus*). *Cercetări Agronomice în Moldova* 42, 39–45.

Gnanamanickam, S.S. (ed.) (2007) *Plant-associated Bacteria.* Springer Science & Business Media, New York.

Grassbaugh, E.M. and Bennett, M.A. (1998) Factors affecting vegetable stand establishment. *Scientia Agricola* 55, 116–120.

Gulidov, S. and Poehling, H.M. (2013) Control of aphids and whiteflies on Brussels sprouts by means of UV-absorbing plastic films. *Journal of Plant Diseases and Protection* 120, 122–130.

Gurusamy, V., Bett, K.E. and Vandenberg, A. (2010) Grafting as a tool in common bean breeding. *Canadian Journal of Plant Science* 90, 299–304.

Hagerty, C.H., Cuesta-Marcos, A., Cregan, P.B., Song, Q., McClean, P., Noffsinger, S. and Myers, J.R. (2015) Mapping *Fusarium solani* and *Aphanomyces euteiches*. Root rot resistance and root architecture quantitative trait loci in common bean. *Crop Science* 55, 1969–1977.

Harel, D., Fadida, H., Gantz, S., Shilo, K. and Yasuor, H. (2013) Evaluation of low pressure fogging system for improving crop yield of tomato (*Lycopersicon esculentum* Mill.): grown under heat stress conditions. *Agronomy* 3, 497–507.

Hassell, R.L., Memmott, F. and Liere, D.G. (2008) Grafting methods for watermelon production. *HortScience* 43, 1677–1679.

Hernández-Bermejo, J.E. and León, J. (1992) Cultivos marginados, otra perspectiva de 1492. *Colleción FAO – Producción y Protección Vegetal* 26, 46–49.

Ityel, E., Avraham, L., Alon, H. and Offenbach, R. (2014) Predicting pepper fruit yield based on temperature and solar radiation. *Journal of Agricultural Science and Technology* 4, 360–367.

Jarvis, W.R. (1989) Managing diseases in greenhouse crops. *Plant Disease* 73, 190–194.

Jouyban, Z., Hasanzade, R. and Sharafi, S. (2013) Chilling stress in plants. *International Journal of Agriculture and Crop Sciences* 5, 2961–2968.

Justus, I. and Kubota, C. (2010) Effects of low temperature storage on growth and transplant quality of non-grafted and grafted cantaloupe-type muskmelon seedlings. *Scientia Horticulturae* 125, 47–54.

Katan, J. (2000) Physical and cultural methods for the management of soil-borne pathogens. *Crop Protection* 19, 725–731.

Katan, J. (2004) Role of cultural practices for the management of soilborne pathogens in intensive horticultural systems. *Acta Horticulturae* 635, 11–18.

Kell, K. and Jaksch, T. (1998) Veredlungsunterlagen bei Tomaten im Vergleich. *Gemüse* 12, 700–704.

King, S.R., Davis, A.R., Liu, W. and Levi, A. (2008) Grafting for disease resistance. *HortScience* 43, 1673–1676.

Korkmaz, A. and Dufault, R.J. (2001) Developmental consequences of cold temperature stress at transplanting on seedling and field growth and yield. I. Watermelon. *Journal of the American Society for Horticultural Science* 126, 404–409.

Kubota, C. and Kroggel, M. (2006) Air temperature and illumination during transportation affect quality of mature tomato seedlings. *HortScience* 41, 1640–1644.

Kubota, C. and McClure, M.A. (2008) Vegetable grafting: history, use, and current technology status in North America. *HortScience* 43, 1664–1669.

Kurata, K. (1994) Cultivation of grafted vegetables II. Development of grafting robots in Japan. *HortScience* 29, 240–244.

Labuda, H. (2010) Runner bean (*Phaseolus coccineus* L.) – biology and use. *Acta Scientiarum Polonorum – Hortorum Cultus* 9, 117–132.

Lamont, W.J. Jr (1995) Plastics: modifying the microclimate for the production of vegetable crops. *HortTechnology* 15, 477–481.

Lee, J.M. (1994) Cultivation of grafted vegetables I. Current status, grafting methods, and benefits. *HortScience* 29, 235–239.

Lee, J.M., Kubota, C., Tsao, S.J., Bie, Z., Hoyos Echevarria, P., Morra, L. and Oda, M. (2010) Current status of vegetable grafting: diffusing, grafting techniques, automation. *Scientia Horticulturae* 127, 93–105.

Lecoq, H. and Desbiez, C. (2012) Virus of cucurbit crops in the Mediterranean region: an ever-changing picture. In: Loebenstein, G. and Lecoq, H. (eds) *Viruses and Virus Diseases of the Vegetables in the Mediterranean Basin*. Academic Press, Norwich, UK, pp. 67–126.

Leskovar, D.I. and Stoffella, P.J. (1995) Vegetable seedling root systems: morphology, development, and importance. *HortScience* 30, 1153–1159.

Loebenstein, G. and Lecoq, H. (eds) (2012) *Viruses and Virus Diseases of the Vegetables in the Mediterranean Basin.* Academic Press, San Diego.

Louws, F.J., Rivard, C.A. and Kubota, C. (2010) Grafting fruiting vegetables to manage soilborne pathogens, foliar pathogens, arthropods and weeds. *Scientia Horticulturae* 127, 127–146.

Mahajan, S. and Tuteja, N. (2005) Cold, salinity and drought stresses: an overview. *Archives of Biochemistry and Biophysics* 444, 139–158.

Martorana, M., Giuffrida, F., Leonardi, C., and Kaya, S. (2007) Influence of rootstock on tomato response to salinity. *Acta Horticulturae* 747, 555–561.

Mathis, R., Fricot, C., Larenaudie, M., Quillévéré, A., Rolland, M., Grimault, V., Olivier, V., Dousset, C., Gentit, P., Germain, R. and Baldwin, T. (2015) *Clavibacter michiganensis* subsp. *michiganensis*: optimization of detection in seed and effect of seed treatment on efficiency of detection methods. *Acta Horticulturae* 1069, 113–118.

Mavi, K., Ermis, S. and Demir, I. (2006) The effect of tomato rootstock seeds in relation to seedling growth. *Asian Journal of Plant Sciences* 5, 940–947.

Mekki, A., Mdhaffar, M. and Sayadi, S. (2014) Advance in Mediterranean soil properties following compost amendment. *International Journal of Agricultural Policy and Research* 2, 373–379.

Morra, L. (2004) Grafting in vegetable crops. In: *International Workshop on the Production in the Greenhouse After the Era of the methyl bromide*. Comiso, Italy, pp. 147–154.

Mullin, B.A., Abawi, G.S., Pastor-Corrales, M.A. and Kornegay, J.L. (1991) Contribution of root and shoot tissues of *Phaseolus vulgaris* to *Meloidogyne incognita* resistance. *Hortscience* 26, 1503–1504.

Nguyen, H.N., Borgemeister, C., Max, J. and Poehling, H.-M. (2009) Manipulation of ultraviolet light affects immigration behavior of *Ceratothripoides claratris* (Thysanoptera: Thripidae). *Journal of Economic Entomology* 102, 1559–1566.

Pardossi, A. Tognoni, F. and Incrocci, L. (2004) Mediterranean greenhouse technology. *Chronica Horticulturae* 44, 28–34.

Patakioutas, G., Dimou, D., Kostoula, O., Yfanti, P., Paraskevopoulos, A., Ntatsi, G. and Savvas, D. (2015) Inoculation of tomato roots with beneficial micro-organisms as a means to control *Fusarium oxysporum* f. sp. *lycopersici* and improve nutrient uptake and yield. *Acta Horticulturae* 1107, 141–148.

Patel, P.K., Singh, A.K., Tripathi, N., Yadav, D. and Hemantaranjan, A. (2014) Flooding: abiotic constraint limiting vegetable productivity. *Advances in Plants and Agriculture Research* 1, 00016.

Pavlou, G.C., Vakalounakis, D.J. and Ligoxigakis, E.K. (2002) Control of root and stem rot of cucumber, caused by *Fusarium oxysporum* f. sp. *radicis-cucumerinum*, by grafting onto resistant rootstocks. *Plant Disease* 86, 379–382.

Peet, M.M. and Welles, G. (2005) Greenhouse tomato production. In: Heuvelink, E. (ed.) *Tomatoes. Crop Production Science in Horticulture*, Vol. 13. CABI Publishing, Wallingford, UK, pp. 257–304.

Pivonia, S., de Cock, A.W.A.M., Levita, R., Etiel, E. and Cohen, R. (2012) Low temperatures enhance winter wilt of pepper plants caused by *Pythium* sp. *Phytoparasitica* 40, 525–531.

OEPP/EPPO (2013) PM 7/42 (2) *Clavibacter michiganensis* subsp. *michiganensis*. *OEPP/EPPO Bulletin* 43, 46–67.

Postiglione, L. (2003) Soil salinization in the Mediterranean. In: Geeson, N.A., Brandt, C.J. and Thorne, J.B. (eds) *Mediterranean Desertification: a Mosaic of Processes and Responses*. Wiley, Chichester, UK, pp. 163–173.

Reingold, V., Lachman, O., Blaosov, E. and Dombrovsky, A. (2015) Seed disinfection treatments do not sufficiently eliminate the infectivity of *Cucumber green mottle mosaic virus* (CGMMV) on cucurbit seeds. *Plant Pathology* 64, 245–255.

Reingold, V., Lachman, O., Belausov, E., Koren, A., Mor, N. and Dombrovsky, A. (2016) Epidemiological study of *Cucumber green mottle mosaic virus* in greenhouses enables reduction of disease damage in cucurbit production. *Annals of Applied Biology* 168, 29–40.

Rengasamy, P. (2006) World salinization with emphasis on Australia. *Journal of Experimental Botany* 57, 1017–1023.

Rodrigues, C. (2010) Plantas enxertadas conquistam portugueses. *Frutas Legumes e Flores* 110, 40–41.

Rouphael, Y., Schwarz, D., Krumbein, A. and Colla, G. (2010) Impact of grafting on product quality of fruit vegetables. *Scientia Horticulturae* 127, 172–179.

Rouphael, Y., Cardarelli, M., Lucini, L., Rea, E. and Colla, G. (2012) Nutrient solution concentration affects growth, mineral composition, phenolic acids and flavonoids in leaves of artichoke and cardoon. *HortScience* 47, 1424–1429.

Sánchez-Rodríguez, E., Leyva, R., Constán-Aguilar, C., Romero, L. and Ruiz, J.M. (2014) How does grafting affect the ionome of cherry tomato plants under water stress? *Soil Science and Plant Nutrition* 60, 145–155.

Schneider, K.A., Grafton, K.F. and Kelly, J.D. (2001) QTL analysis of resistance to Fusarium root rot in bean. *Crop Science* 41, 535–542.

Schwarz, D., Rouphael, Y., Colla, G. and Venema, J.H. (2010) Grafting as a tool to improve tolerance of vegetables to abiotic stresses: thermal stress, water stress and organic pollutants. *Scientia Horticulturae* 127, 162–171.

Shalhevet, J. (2004) Using water of marginal quality for crop production: major issues. *Agricultural Water Management* 25, 233–269.

Shang, H., Xie, Y., Zhou, X., Qian, Y. and Wu, J. (2011) Monoclonal antibody-based serological methods for detection of Cucumber green mottle mosaic virus. *Virology Journal* 8, 228.

Sharabani, G., Manulis-Sasson, S., Borenstein, M., Shulhani, R., Lofthouse, M., Chalupowicz, L. and Shtienberg, D. (2013) The significance of guttation in the secondary spread of *Clavibacter michiganensis* subsp. *michiganensis* in tomato greenhouses. *Plant Pathology* 62, 578–586.

Shtienberg, D., Sharabani, G., Bornstein, M., Shulhani, R., Frenkel, O., Manulis-Sasson, S., Lofthouse, M. and Sofer, M. (2015) Management of bacterial canker of tomatoes: an attainable goal. *Acta Horticulturae* 1069, 151–158.

Soteriou, G.A., Papayiannis, L.C. and Kyriacou, M.C. (2016) Indexing melon physiological decline to fruit quality and vine morphometric parameters. *Scientia Horticulturae* 203, 207–215.

Tachibana, S. (1982) Comparison of effects of root temperature on the growth and mineral nutrition of cucumber cultivars and figleaf gourd. *Journal of the Japanese Society for Horticultural Science* 51, 299–308.

Takaichi, M., Shimaji, H. and Higashide, T. (2000) Effect of red/far-red photon flux ratio of solar radiation on growth of fruit vegetable seedlings. *Acta Horticulturae* 514, 147–156.

Temperini, O., Calabrese, N., Temperini, A., Rouphael, Y., Tesi, R., Lenzi, A., Carito, A. and Colla, G. (2013) Grafting artichoke onto cardoon rootstocks: graft compatibility, yield and Verticillium wilt incidence. *Scientia Horticulturae* 149, 22–27.

Tomlinsone, J.A. (1987) Epidemiology and control of virus diseases of vegetables. *Annals of Applied Biology* 110, 661–681.

Triky-Dotan, S., Yermiyahu, U., Katan, J. and Gamliel, A. (2005) Development of crown and root rot disease of tomato under irrigation with saline water. *Phytopathology* 95, 1438–1444.

Trinchera, A., Pandozy, G., Rinaldi, S., Crinò, P., Temperini, O. and Rea, E. (2013) Graft union formation in artichoke grafting onto wild and cultivated cardoon: an anatomical study. *Journal of Plant Physiology* 170, 1569–1578.

Triplett, G.B. and Dick, W.A. (2008) No-tillage crop production: a revolution in agriculture! *Agronomy Journal* 100, 153–165.

Ucko, O. and Dayan, R. (1986) Prevention of virus diseases in vegetables by sanitation in the Arava Valley. *Phytoparasitica* 14, 159 (abstract).
van Bruggen, A.H.C., Gamliel, A. and Finck, M.R. (2016) Plant disease management in organic farming systems. *Pest Management Science* 72, 30–44.
van Dongen, J.T. and Licausi, F. (eds) (2014) *Low-oxygen Stress in Plants: Oxygen Sensing and Adaptive Responses to Hypoxia.* Plant Cell Monographs 21. Springer, Wien, Austria.
van der Wolf, J. and de Boer, S.H. (2015) Phytopathogenic bacteria. In: Lugtenberg, B. (ed.) *Principles of Plant–Microbe Interactions: Microbes for Sustainable Agriculture*. Springer International Publishing, Cham, Switzerland, pp. 65–77.
Wimer, J., Inglis, D. and Miles, C. (2015) Evaluating grafted watermelon for Verticillium wilt severity, yield, and fruit quality in Washington State. *HortScience* 50, 1625–1630.
Wisler, G.C. and Norris, R.F. (2005) Interactions between weeds and cultivated plants as related to management of plant pathogens. *Weed Science* 53, 914–917.
Wittemans, L. (2012) Kunnen ongeënte planten even rendabel zijn als geënte planten? *ProeftuinNieuws* 17, 38–39.
Zhang, L., Hao, X., Li, Y. and Jiang, G. (2010) Response of greenhouse tomato to varied low pre-night temperatures at the same daily integrated temperature. *HortScience* 45, 1654–1661.