Grafting Manual:
How to Produce Grafted Vegetable Plants

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Synopsis:
Discusses rootstock selection and other important aspects of grafted melon and watermelon production for improving disease management, fruit yield, and crop performance.

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USDA United States Department of Agriculture National Institute of Food and Agriculture

Rootstock selections and important considerations in melon and watermelon grafting

General information

Chapter 3.22 in this grafting manual discusses the major methods used for melon (*Cucumis melo*) and watermelon (*Citrullus lanatus*) grafting, specific advantages and disadvantages of each method, the graft healing process, as well as preparation for field transplanting and maintenance of grafted plants. This chapter addresses rootstock selection and other important aspects of grafted melon and watermelon production towards improving disease management, fruit yield, and crop performance.

Major rootstocks used for grafted melon and watermelon production

Grafting is used primarily for managing soil-borne diseases including Fusarium wilt (caused by *Fusarium oxysporum*) and Verticillium wilt (caused by *Verticillium dahliae*) in melon and watermelon production. Moreover, improved cold tolerance of grafted cucurbits by using selected rootstocks also makes grafting a viable tool for early planting and harvest especially under protected culture. Currently, *Lagenaria siceraria* bottle gourd, *Cucurbita moschata* squash, and *C. maxima* × *C. moschata* interspecific hybrid squash are the most commonly used commercial rootstocks for melons and watermelons. *Lagenaria siceraria* is among the early generation of cucurbit rootstocks, and its popularity declined over the years due to broken resistance to Fusarium, as well as shallow root system. More interspecific *Cucurbita* hybrids with vigorous root systems are now being developed for watermelon for their high resistance to Fusarium wilt, tolerance to heat and drought conditions, and for cold tolerance.

The early work of rootstock evaluation among cucurbit species also confirmed the grafting compatibility of *C. maxima*, *C. pepo*, *Benincasa hispida*, and *Luffa cylindrica* with melons (Zhao et al., 2016), while commercial use of these rootstocks is rather limited. However, *C. maxima* rootstocks are sometimes used to manage Monosporascus vine decline (caused by *Monosporascus cannonballus*) in infested fields (Davis et al., 2008). The lack of resistance/tolerance to root-knot nematodes (*Meloidogyne* spp.) in interspecific hybrid squash rootstocks (Fig. 1) also stimulated the selection of *Cucumis metulifer* as an effective rootstock to control root-knot nematodes in melon production (Guan et al., 2014). However, given the weaker growth vigor of *C. metulifer* compared with squash rootstocks, more breeding work is needed to develop more vigorous *C. metulifer* rootstocks with greater potential for improving melon yield.

Although *C. moschata* rootstocks may possess a certain level of tolerance to nematodes, the relatively high susceptibility of *Cucurbita* rootstocks, particularly the interspecific hybrids, has led to the search for wild watermelon (*C. lanatus* var. *citroides*) as a new source of rootstocks for managing both Fusarium wilt and root-knot nematodes in watermelon production.

Despite their effectiveness in dealing with biotic and abiotic stresses, interspecific squash hybrid rootstocks have been found to negatively affect melon fruit quality of certain genotypes, especially specialty cultivars with aromatic flavors (Guan et al., 2015b). Such decline of fruit quality as a result of rootstock-scion interactions associated with use of interspecific hybrid squash rootstocks resulted in breeding effort to seek promising rootstock candidates in *Cucumis* species. *Cucumis melo* rootstock cultivars are commercially available, and most recently interspecific *Cucumis* hybrid rootstocks including *C. ficifolius* × *C. myriocarpus* 'UPV-FMy' and *C. ficifolius* × *C. anguria* 'UPV-FA' were developed in Spain (Caceres et al., 2017).

Figure 1. Root-knot nematode infestation in the roots of a melon plant grafted with an interspecific hybrid squash rootstock. (*Photo by Yufan Tang*)

Table 1 lists the major types of rootstock species used for grafted melon and watermelon production and their key characteristics. If the melon fruit are targeted to a premium market, the rootstock-scion combination needs to be tested to determine potential rootstock effects on fruit quality attributes such as soluble solids content before large-scale adoption occurs.

Important considerations for using grafted plants to improve disease management

By using resistant/tolerant rootstocks, soilborne fungal diseases including Fusarium wilt, Verticillium wilt, and Monosporascus root rot and vine decline can be successfully controlled in grafted melon and watermelon production (Guan et al., 2012; Louws et al., 2010). Both bottle gourd and interspecific hybrid squash rootstocks for watermelon grafting are considered susceptible to gummy stem blight (caused by *Didymella bryoniae*), and managing gummy stem blight on watermelon and rootstock seedlings with fungicides during transplant production may be necessary to ensure grafted watermelon health and quality prior to field planting (Keinath, 2013). On the other hand, grafting with certain *C. maxima* × *C. moschata* rootstocks has been shown to effectively manage gummy stem blight that survives in crop residues and initiates infection in the lower crown

Table 1. Major types of rootstocks used for melon and watermelon grafting and their key characteristics.

Type of rootstock	Rootstock cultivar example	Major beneficial characteristic	Limitation
Lagenaria siceraria (bottle gourd)	'Emphasis' (Syngenta), 'Macis' (Nunhems)	Resistant to Fusarium wilt; tolerant to low temperature	Possible susceptibility to new Fusarium races; shallow root system
Cucurbita moschata (squash)	'Marvel' (American Takii)	Resistant to Fusarium wilt; possibly tolerant to root-knot nematodes; tolerant to low temperature	Possible susceptibility to *Phytophthora*; possible adverse effect on fruit quality
Cucubita maxima × *C. moschata* (interspecific hybrid squash)	'Carnivor', 'Super Shintosa' (Syngenta); 'Cobalt' (Rijk Zwaan); 'RST-04-109- MW' (DP Seeds); 'Flexifort' (Enza Zaden)	Resistant to Fusarium wilt; possibly resistant to melon necrotic spot virus; tolerant to low and high temperatures; vigorous growth	Susceptibility to root-knot nematodes; possible susceptibility to *Phytophthora*; possible delay in fruit set and reduction in fruit quality
Citrullus lanatus var. citroides (wild watermelon)	'Ojakkyo' (Syngenta)	Resistant to Fusarium wilt and root-knot nematodes	For watermelon grafting. Lack of good tolerance to low temperature
Cucumis melo (melon)	'Dinero' (Syngenta)	Resistant or tolerant to Fusarium wilt; maintaining fruit quality	For melon grafting. Possible susceptibility to *Phytophthora*; less vigorous compared to *Cucurbita* rootstocks
Cucumis metuliferus (African horned cucumber)	No commercial rootstocks available	Resistant to Fusarium wilt; resistant to root-knot nematodes	For melon grafting. Less vigorous compared to *Cucurbita* rootstocks; lack of good tolerance to low temperature

Adapted from Davis et al. (2008) and Louws et al. (2010).

of melon plants (Crinò et al., 2007). In addition, some *C. maxima* × *C. moschata* rootstocks bred for resistance to melon necrotic spot virus, a soil-borne virus, can be employed to limit virus infection. When virus disease is prevalent, growers need to be well aware of possible virus resistance or susceptibility of rootstocks, because if the rootstock is more susceptible than the scion, the virus issue can become worse with grafted plants.

It needs to be noted that most of the current rootstocks used for melon and watermelon grafting may be susceptible to *Phytophthora*. Growers are advised to identify the production constraints on site, including soil-borne disease problems and environmental stress conditions, in order to choose the appropriate rootstocks to best suit their needs. Few commercial rootstock cultivars with high resistance to root-knot nematodes are currently available, although *C. moschata* rootstocks may show tolerance to root-knot nematodes under intermediate levels of field infestation.

While their capability of coping with low temperatures and other abiotic stress is yet to be fully determined, wild watermelon rootstocks can be used as an effective management tool for both Fusarium wilt and root-knot nematodes. It is important to understand the complete disease resistance package of the rootstock for successful use of grafted plants in addressing specific soil-borne disease problems. Rotation of rootstocks is also recommended to

Figure 2. Commercial greenhouse operations of grafted melon production in Italy. (*Photos by Xin Zhao*)

minimize new pathogen emergence and possible shifts in the host specificity of the pathogen population (Louws et al., 2010).

Optimizing improvement of crop performance of grafted plants beyond disease resistance

In addition to soil-borne disease management, resistant rootstocks, especially the squash rootstocks, often possess good to excellent tolerance to abiotic stress particularly low temperature conditions. Almost all the melons and watermelon grown in South Korea are grafted. For watermelon, disease resistance is the main consideration in Korea as well as other countries. In contrast, for melons, cold tolerance is the main consideration because melons are primarily cultivated under winter greenhouse production conditions.

Grafting melon onto low-temperature-tolerant rootstocks reduces the risk of severe growth inhibition caused by low soil temperatures in winter greenhouses (Lee et al., 2010). Using

Figure 3. Commercial production of grafted melon in low-cost tunnel systems in Sicily, Italy for improved earliness. (*Photos by Xin Zhao*)

grafted plants under protected culture for enhancing earliness of melon fruit is also widely practiced in Italy (Fig. 2 and 3). Research trials are taking place in the southeastern U.S. and other regions to explore the use of grafted plants for early spring planting of seedless watermelons in open field systems. Selected *C. maxima* × *C. moschata* rootstocks may also hold promise for improving plant tolerance to soil salinity (Rouphael et al., 2012).

Even though the yield improvement potential varies with the genotype of rootstock, modification of nutrient and water management as well as plant spacing is suggested to maximize the benefits of using grafted transplants. Without appropriate management programs, the excessive vegetative growth resulting from the use of vigorous interspecific rootstocks could cause delayed appearance of female flowers and fruit set. Meanwhile, more vegetative growth observed in grafted watermelons could potentially create a microclimate condition that is more favorable for foliar disease development.

Typically, nitrogen application needs to be reduced during the vegetative phase to minimize the potential adverse impact of vigorous rootstocks on flowering and fruit set. Wider plant spacings can also be considered to better utilize the rootstock vigor. Such management considerations will not only assist with optimizing crop performance of grafted plants but also help justify the high price of grafted transplants by reducing production input costs.

Dealing with fruit quality concerns

As described earlier, especially in melon, fruit off-flavor was noticed when vigorous hybrid squash rootstocks are used (Davis et al., 2008). This may be a reason that introduction of grafting is more advanced in watermelon than in melon worldwide. Melons (including muskmelon and honeydew type) belong to four groups of two subspecies of *Cucumis melo*, including the groups of cantalupensis, reticulatus, and inodorus within the subspecies *melo*, and the group of makuwa within the subspecies *agrestis* (Guan, et al., 2013). The complexity of various melon cultivars makes melon a good crop to study rootstock-scion interaction effects in terms of physiological and biochemical changes in grafted plants, but also results in complicated scenarios for examining fruit quality.

For example, some interspecific hybrid squash rootstocks could reduce soluble solids content of aromatic galia melons and sensory attributes perceived by consumers (Guan et al., 2015a). The delay in fruit set together with accelerated ripening by grafting with the vigorous interspecific squash rootstock contributed to the fruit quality decline at harvest. Because of the fruit quality concerns, Fusarium wilt-susceptible melon cultivars are grafted onto Fusarium wilt-resistant *C. melo* rootstocks in Japan to maintain fruit quality while accomplishing disease management (King et al., 2010).

As honeydew melons in the inodorus group tended to be less influenced by squash rootstocks in contrast to melons in the reticulatus and cantalupensis groups (Guan et al., 2015b; Traka-Mavrona et al., 2000), it has been speculated that melon cultivars producing climacteric fruit with aromatic flavors might be more likely to respond to grafting in terms of fruit quality attribute changes as opposed to nonclimacteric, less aromatic melons.

Interspecific hybrid squash rootstocks generally have good grafting compatibility with melons and watermelons. Nevertheless, a non-pathological vine decline specifically associated with certain combinations of melon scion and interspecific hybrid squash rootstock has been reported in Israel, U.S. (Fig. 4) and Cyprus (Aloni et al., 2008; Guan et al., 2015a; Soteriou et al., 2016). The crop failure observed later during the melon planting season is likely caused by increased water stress as a result of heavy fruit load and high temperature, while more in-depth investigations are expected to shed light on the fundamental mechanisms at plant physiological and hormonal levels.

Since fruit size increase is often found in grafted melon and watermelon plants when interspecific squash rootstocks are used, growers are advised to consider market acceptability of certain fruit size categories to avoid unexpected loss of marketable yield. In general, the adverse impact of grafting with squash rootstocks on watermelon fruit quality appears to be less extensive in contrast to the situation with melon grafting. Fruit soluble solids content, pH, titratable acidity, lycopene content, and consumer perceived sensory attributes may be well maintained in grafted watermelon (Liu et al., 2017). The *C. lanatus* var. *citroides* wild watermelon rootstock has been found to have rather limited influence on watermelon fruit quality and aroma profile besides yielding larger fruit with thicker rind (Fredes et al., 2016). On the other hand, increase in watermelon flesh firmness, reduction in hollow heart incidence and severity, and higher level of lycopene observed in certain rootstock-scion combinations could be the added value of using grafted plants.

As more studies are needed to fully understand the intrinsic impacts of rootstock and rootstock-scion interaction on fruit quality modification, environmental conditions during crop production and fruit maturity at harvest also deserve attention in assessing fruit quality of grafted plants (Rouphael et al., 2010). Rootstock breeding and development for melon and watermelon production will continue to address the fruit quality concerns. Ultimately, grower's decision of integrating grafting with selected rootstocks into melon and watermelon production will be driven by their needs to overcome production challenges towards longer-term environmental and economic sustainability.

Figure 4. Grafted muskmelon plants (with an interspecific hybrid squash rootstock) collapse during fruit maturation stage later in the spring production season in north Florida. This non-pathological disorder might be caused by increased water stress as a result of heavy fruit load and high temperature; however, this physiological disorder is not well understood. (*Photo by Wenjing Guan*)

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