Can Double Graft Improve Affinity In Melon? Effects of Simple and Double Grafting Melon Plants on Mineral Absorption, Photosynthesis, and Biomass

Alberto San Bautista, a Angeles Calatayud, b Sergio Gonzalez-Nebauer, a Bernardo Pascual, a José Vicente Maroto, a Salvador López-Galarza, a*

a Departamento de Producción Vegetal, Universitat Politècnica de València, Camino de Vera 14, 46020 Valencia, Spain.
b Departamento de Horticultura, Instituto Valenciano de Investigaciones Agrarias, 46113 Moncada, Valencia, Spain.

*Corresponding author: Tel.: +34 963877337; fax: +34 963877339; email address: slopez@prv.upv.es
Abstract

The Spanish type cultivar ‘Piel de Sapo’ (*Cucumis melo* L. var. *saccharinus*), has less affinity with the *Cucurbita maxima* x *Cucurbita moschata* hybrids actually used as rootstocks. To improve affinity between rootstock and scion double grafting can be used, by means of an intermediate rootstock compatible with both of them. Non-grafted, single, and double grafted melon plants of the cultivar 'Piel de sapo' were evaluated for water and nutrient absorption to accurately evaluate if the double grafting response is related to the improvement in affinity when *Cucurbita maxima* x *Cucurbita moschata* hybrids are used as rootstocks. The melons were also evaluated for photosynthesis activity and biomass production in early phases. The hybrid ‘Shintoza’ (*Cucurbita maxima* x *Cucurbita moschata*) was used as rootstock, and the cantaloupe type melon cultivar ‘Sienne’ as an intermediate scion. Double grafted plants showed higher increased fresh and dry weights, and also showed a higher capacity for uptaking beneficial minerals (particularly NO$_3^-$, P, K, Ca, Mn, and Zn) with respect to non-grafted and simple grafted plants. Grafting did not affect net photosynthetic values, but significantly increased water use efficiency. Double grafted plants also revealed higher quantum efficiency PSII photochemistry values. Consequently, double grafting on a vigorous rootstock such as ‘Shintoza’ (with an intermediate scion that confers better affinity) results in improved mineral and water absorption and achieves an increase in ion influx to the scion – so enabling an increase in light photosynthetic reaction and biomass.

Keywords: biomass; *Cucurbita*; melon; mineral uptake; grafting; photosynthesis; water uptake.
1. Introduction

Cucurbit grafting is becoming a common practice worldwide, particularly in Japan, Korea, Spain, China, and Italy. In all these countries except Korea, grafting in watermelon is significantly more important than grafting in melon (Lee et al., 2010). Currently in Spain, 48.2 million watermelon plants and 2.5 million melon plants (90% and 1% of the total, respectively) are annually grafted on interspecific *Cucurbita maxima* x *Cucurbita moschata* hybrids (Hoyos, 2010). For watermelons, grafting helps control soil-borne pathogens and increases yields without affecting quality (Miguel et al., 2004; López-Galarza et al., 2004). These benefits compensate in part for the extra costs of grafting. Grafted melon plants have also proven effective in controlling soil-borne diseases and the *melon necrotic spot virus* (MNSV). This virus causes vine decline (Davis et al., 2008), although its appearance is less frequent and more erratic than the pathogens affecting watermelon (Cohen et al., 2004; Hassel et al., 2008). Melon plants grafted on *Cucurbita maxima* x *Cucurbita moschata* hybrids show poor compatibility, do not consistently increase yields, and show no improvement in vigour. As a result, this technique is used by few growers and only for cantaloup and Galia types. Melons grafted on melon-resistant cultivars have higher affinity but less resistance to soil-borne diseases, especially to MNSV (King et al., 2010).

The most common melon cultivars in Spain belong to the Spanish melon type ‘Piel de sapo’ (*Cucumis melo* var. *saccharinus*). These cultivars have little affinity with the *Cucurbita maxima* x *Cucurbita moschata* hybrids used as rootstocks (Miguel et al., 2007). These circumstances explain the different use of grafting in both species.
It is known that grafting directly affects plant physiology through the interaction of some or all of the biochemical processes. These processes include increases in water and mineral uptake, improvements in the synthesis of endogenous hormones, stimulated antioxidant systems, and greater resistance to abiotic and/or biotic stress. The result is a more vigorous root and shoot system (Martínez-Ballesta et al., 2010).

Poor vascular connections between rootstock and scion produce a deleterious effect on plant growth and create graft incompatibilities (Tiedemann, 1989).

Previous information shows that *Cucurbita* spp. rootstocks cause a deleterious graft on melon scion (Lee, 1994; Oda, 1995; Traka-Mavrona et al., 2000). These authors attribute this effect to the differences in stem diameter between *Cucurbita* and *Cucumis melo*, which reduces the sites with vascular and phloem connections due the large pith cavity of *Cucurbita* (Traka-Mavrona et al., 2000; Tiedemann, 1989).

To improve affinity between rootstock and scion, Hartman et al. (1997) indicated that double grafting by means of a mutually compatible intermediate rootstock is useful. Kwon et al. (2005) sought to improve quality and evaluated the performance of this technique in watermelon, using *Lagenaria* as an intermediate rootstock between ‘Shintoza’ (*Cucurbita maxima* x *Cucurbita moschata* hybrid) and the scion. Our group evaluated the performance of double grafting melon on ‘Shintoza’ during four years in field conditions using various intermediate rootstocks. We recorded an increase in yields compared with single grafting, particularly with the Galia-type cultivar ‘Sienne’.

Double grafting is not currently used in the ‘Piel de sapo’ type melon. In this study, we used a simple graft with *Cucurbita maxima* x *C. moschata* and double grafted *Cucurbita maxima* x *C. moschata* / melon ‘Sienne’ as rootstocks on scion melon
'Ricura' to identify metabolic and physiological factors that could be associated with the level of grafting compatibility. If double grafting improves compatibility in comparison with simple grafting, then double grafting could be used as a tool to improve the affinity of some melon cultivars such as 'Piel de sapo' and obtain a better yield and resistance to pathogens.

2. Materials and methods

2.1. Plant growth

Melon plants of the open pollinated 'Piel de sapo' type, cultivar ‘Ricura’ (Semillas Batlle) were directly grafted on squash (simple graft) (*Cucurbita maxima* x *Cucurbita moschata* cv. Shintoza, Intersemillas) or using an intermediate melon rootstock (double graft) (*Cucumis melo* sp. *cantalupensis* cv. Sienne, De Ruiter Seeds).

Melon seeds were sown on 14 March 2009 and squash on 29 March 2009 in 200 polystyrene trays filled with peat-based substrate that were kept under a Venlo-type glasshouse. Both types of grafting were made on 9 April using the tongue grafting method and the plants were transplanted to 54-cell trays. ‘Ricura’ variety plants without grafting were also transplanted to 54-cell trays and used as control plants.

Double, single, and non-grafted plants were placed in 2 L polyethylene pots covered with aluminium sheets on 29 April (the root system having been previously washed clean of substrate). Pots were filled with a nutrient solution containing (in mmol L⁻¹): 12.3 NO₃⁻; 1.02 H₂PO₄⁻; 2.45 SO₄²⁻; 3.24 Cl⁻; 5.05 K⁺; 4.23 Ca²⁺, 2.55 Mg²⁺ and 2.81 Na⁺ that had been artificially aerated. Micronutrients were also provided (15.8 µM Fe²⁺, 10.3 µM Mn²⁺, 4.2 µM Zn²⁺, 43.5 µM B⁵⁺, 1.4 µM Cu²⁺). The electrical
conductivity and pH of this nutrient solution were 2.2 dS m\(^{-1}\) and 6.5, respectively. Nutrient solution was added daily to compensate for absorption. The layout was in a completely randomised design of 15 plants per treatment.

After 13 days of plant acclimation to the pots, all plants were weighed and an exact volume of 2L of nutrient solution was added to each pot. An exact volume of nutrient solution was also added daily and annotated to compensate uptake. The system was watertight, so all volume losses were attributed to water and nutrient uptake.

The volume remaining in each pot was measured on 22 May, a 100 mL sample per pot was kept for analysis and each plant was separated in root and aerial parts to determine fresh and dry weights.

The environmental greenhouse range during the measurements was: temperature (21-24\(^\circ\)C); relative humidity (52-72%); and solar radiation (610-870 J s\(^{-1}\) m\(^{-2}\)).

2.2. Water and nutrient absorption

At the end of the experiment water uptake, expressed as mL dry weight plant\(^{-1}\) day\(^{-1}\) for each hydroponic unit was calculated from the difference between the remains on the final day and the sum of all the exact volumes added daily. Nitrate concentration in the nutrient solution was determined by the Kjeldahl method at the end of the experiment (Bremner, 1965). Other nutrients were measured using simultaneous ICP emission spectrometry (iCAP 6000, Thermo Scientific. Cambridge, United Kingdom). Results were expressed as mg dry weight plant\(^{-1}\) day\(^{-1}\).
2.3. Photosynthetic activity and chlorophyll fluorescence

Net CO$_2$ fixation rate (A$_{max}$, µmol CO$_2$ m$^{-2}$ s$^{-1}$), stomatal conductance to water vapour (gs, mol H$_2$O m$^{-2}$ s$^{-1}$), transpiration rate (E, mmol H$_2$O m$^{-2}$ s$^{-1}$), and substomatal CO$_2$ concentration [Ci, µmol CO$_2$ mol$^{-1}$ (air)] were measured at steady-state under conditions of saturating light (1200 µmol m$^{-2}$ s$^{-1}$) and 400 ppm CO$_2$ with a LI-6400 (LI-COR, Nebraska, USA). The water use efficiency parameters (WUE, µmol CO$_2$/mol H$_2$O) were calculated from A$_{max}$/E. To evaluate the presence of chronic photoinhibitory processes, the maximum quantum yield of PSII (Fv/Fm: (Fm-Fo)/Fm) was measured on leaves after 30 minutes in darkness using a portable pulse amplitude modulation fluorometer (MINI PAM, Walz, Effeltrich, Germany). The background fluorescence signal for dark adapted leaves (Fo) was determined with a 0.5 µmol photon m$^{-2}$ s$^{-1}$ measuring light at a frequency of 600 Hz. The application of a saturating flash of 10000 µmol photon m$^{-2}$ s$^{-1}$ enabled estimations of the maximum fluorescence (Fm). The steady state fluorescence signal (Fs) and maximum fluorescence yield (F'm) were determined in the same leaves after adapting to light (1200 µmol m$^{-2}$ s$^{-1}$). The quantum efficiency of PSII photochemistry (Φ$_{PSII}$), closely associated with quantum yield of non-cyclic electron transport, was estimated from (F'm-Fs)/Fm` (Genty et al. 1989) and used for the calculation of the relative linear transport rate, ETR (µmol electron m$^{-2}$ s$^{-1}$)=(Φ$_{PSII}$ *PAR*α*β). PAR is the active photon flux density (1200 µmol m$^{-2}$ s$^{-1}$), α is the leaf absorbance (0.84), and β is the distribution of absorbed energy between photosystems (0.5).

Gas exchange and chlorophyll fluorescence measurements were performed on 21 May from 9:00 am to 11:00 am (GMT). One measurement per plant was performed
on a fully expanded mature leaf (third or fourth leaf from the shoot apex). Ten plants were measured for each treatment.

3. Results

3.1. Biomass production

Total number of leaves by plant, aerial dry weight (DWa), and the aerial and root part dry weight ratio (DWa/DWr) (Table 1) were significantly influenced by grafting. However, at the end of experiment no significant differences were observed for fresh weights (FW), DWr, nor the aerial and root fresh weight (FWa/FWr) ratio between control and graft plants. Nevertheless, double grafted plants showed increased values for these parameters. The number of leaves was higher in double and simple grafted than non-grafted plants (51% and 30% respectively). The aerial fresh weight (FWa) showed no significant differences but the higher value was in double grafting. As a result of grafting, the plants showed a higher aerial dry weight (DWa). These changes meant a higher DWa/DWr ratio for simple and double graft (Table 1).

3.2. Water and nutrient absorption

Table 2 shows the water and nutrient absorption versus influence of grafting after ten days in the hydroponic system. Water absorption was statistically higher in double grafted plants with an increase of 40% compared to non-grafted plants. The N-NO$_3^-$, P, K, Ca, Mn and Zn uptakes were statistically higher in double grafted plants than in simple grafted and control plants. The opposite occurs with Na, Cu, Fe
and B uptakes, in these cases a large decrease was observed in double grafted plants (p values between 0.045 and 0.024). The ratio K/Na quantification is a major ionic parameter relation with salt tolerance. The ratio was higher in the double graft plant, lower in control plants, and intermediate in simple graft. There were significant differences between control and grafted plants (3.41, 6.18 and 10.05 respectively, data not shown in the Table 2). Sulphur and Mg absorption showed similar values in the three types of plants (Table 2).

3.3. Relation between nutrient absorption and biomass

To understand the variations in the plant nutrient content in grafted (simple and double) plants, we compared the nutrient concentration (calculated from absorption) in the DW plants with non-grafted plants as a reference (Table 3). The use of graft induces differences in the mineral content of all plants. With respect to N-NO₃, P, Fe, Mn, Zn, B, Cu and Na the double graft shows a lower value and significant differences with control plants, due to a higher dry weight in double graft plant. The response of some nutrients such as K, Ca, S, and Mg, was mainly homogenous in all plants.

3.4. Graft effect on photosynthetic activity and chlorophyll fluorescence

CO₂ assimilation rates (Table 4) at light saturation level (Amax) were similar in the three types of plants without significant differences; however, the grafted plants had lower values of intercellular CO₂ concentration (Ci) with significant differences for double grafted plants. Leaves of shoots grafted on the simple or double rootstocks
had lower values of stomatal conductance (gs) and transpiration rate (E). Changes in E but with similar A values in graft plants were associated with statistically significant increases in WUE by about 35% (Table 4).

Chlorophyll fluorescence parameters for dark-adaptation for mature leaves subjected to graft and non-graft are shown in Table 4. The maximum quantum yield of PSII photochemistry estimated using the Fv/Fm ratio is similar in all plants. An apparently steady-state was examined after four minutes of actinic illumination for the quantum yield of PSII ($\phi_{PSII}$) electron transport rates in all the leaves on the control and graft plants. The highest values for $\phi_{PSII}$ were obtained by double graft plants with an increase of 12% (with significant differences) compared to control plants.

4. Discussion

In this study, we describe how simple and double graft affects water and nutrient uptakes and the photosynthetic processes in order to identify metabolic and physiological factors that may be associated with the level of grafting compatibility in plants in early development (when grafting incompatibilities usually occur). The aim is to evaluate the possibility of using double graft in ‘Piel de sapo’ type melons.

Grafting did not affect net photosynthetic values, and similar results were obtained by Salehi et al. (2010) with ‘Khatooni’ melon (Cucumis melo var inodorus) grafted on three Cucurbita rootstocks. However, grafted plants had more net CO$_2$ assimilation due to an increase in gs and Ci parameters. Consequently, the WUE values were lower in ‘Khatooni’ melon grafted plants. In our experimental conditions and with other melon scion and rootstocks, the gs and E values for scion leaves with simple and double grafts are lower. This effect implies that minor gs values are responsible
for the diminishing intercellular CO$_2$ concentration when compared with non-grafted plants assayed under the same conditions. This can be explained by the fact that only very critically low levels of gs affect photosynthesis, which is in agreement with Flexas et al. (2004); and/or decreasing stomatal conductance can be compensated by higher photosynthetic capacity ($\phi_{PSII}$). The parameter $\phi_{PSII}$ closely correlates with the quantum yield of non-cyclic electron transport (Genty et al., 1989) being increased by double graft; and therefore indicates a stimulation of electron flow around PSII when compared to simple graft and control plants. Considering the beneficial double grafted effect on the electron transport rate (ETR), the similar values of CO$_2$ fixation obtained with grafted and non-grafted plants could be a result, at least to some extent, of an increase of ATP and reduced power in graft plants, mainly in double grafted plants with lower gs values. An increase in $\phi_{PSII}$ can help CO$_2$ fixation in double grafted plants. These facts occur without signs of photoinhibition in leaves, as indicated by the unchanged Fv/Fm ratio (Calatayud and Barreno, 2001). The Fv/Fm ratio has often appeared as a sensitive parameter in tomatoes grafted under saline conditions (Albacete et al., 2009); in grafted cucumber leaves at low root temperatures (Ahn et al., 1999); and for the water temperature effects on the graft union of tomato and eggplant (Shibuya et al., 2007).

Higher water use efficiency is a desired plant characteristic (Ruiz et al., 1997). The WUE parameter in scion leaves is highest in graft plants as a result of lower transpiration and stomatal conductance. The minor E value in grafted plants can be compensated by a higher number of leaves: increasing the transpiration stream (mainly in double graft); and/or by an enhancement of vigour in the rootstock root system (Rouphael et al., 2008a) that encourages water and mineral uptake (Ruiz and Romero, 1999; Davis et al., 2008; Salehi et al., 2010). The higher water absorption
obtained in double graft shows that a sufficient connection of vascular bundles between scion and the *Cucurbita-Cucumis* rootstocks is obtained. Alterations in growth scion are observed when water absorption by roots is suppressed at the graft interface (Torii et al., 1992; Atkinson and Else, 2001; Oda et al., 2005). Double graft plants produced the highest increase in fresh and dry weight. Dry mass is an important factor when determining how the environment is affecting the growth rate (Justus and Kubota, 2010) and is related to nutrient uptake capacity (Colla et al., 2010a).

Double graft plants show a higher capacity for uptaking beneficial minerals compared to non-graft and simple graft plants. Nitrogen is considered a limiting factor to growth, and the development and production of amino acids and proteins in plants (Ruiz and Romero, 1999; Calatayud et al., 2008). In melon, N uptake was more influenced by the rootstock genotype than by the scion (Ruiz et al., 1997). In earlier studies, the influence of rootstocks on N uptake was described (Castle and Krezdorn, 1975; Heo, 1991; Jang, 1992). More recently, Salehi et al. (2010) showed that mineral concentration of NO$_3^-$ in the xylem exudates in *Curcurbita* rootstocks on 'Iranian' melon was higher than in the non-grafted melons. Plants of *Cucumis melo* grafted on three *Cucurbita maxima* x *C. moschata* cultivars contained higher amounts of organic N than the controls (Ruiz and Romero, 1999); and a higher N uptake efficiency were observed in melon (cv. Proteo) grafted on *Cucumis melo* (Colla et al., 2010a).

The characteristics of the rootstocks and a good rootstock-scion interaction can determine increased uptake, as well as the subsequent transport and accumulation of NO$_3^-$ in scion leaves (Ruiz et al., 1996-1997-1999; Martínez-Ballesta et al., 2010). One of the major metabolic check-points coordinating nitrogen assimilation in leaves
is nitrate reductase (NR). NR activity is governed by multiple factors, the most important being light, nitrates, and carbohydrates (Sitt et al., 2002; Calatayud et al., 2007). The regulatory effect of light on leaf NR is closely linked to light photosynthesis reaction (Iglesias-Bartolomé et al., 2004): NR located in the cytosol of a leaf catalyses the NADPH-dependent reduction of NO$_3^-$ to NO$_2^-$. Nitrite is converted into ammonium by nitrite reductase in the chloroplast and accounts for the ability of nitrite to support non-cyclic electron transport ($\phi_{\text{PSII}}$) in the chloroplast (Heber et al., 1995). A higher $\phi_{\text{PSII}}$ in double graft can also explain the higher NO$_3^-$ uptake and we assume that nitrate in scion leaves is incorporated in the biomass (superior growth of melon on double rootstocks).

It has been reported that grafted plants increase the absorption of phosphorus in melon (Ruiz et al., 1996) for compatible grafts with Solanaceous plants (Kawaguchi et al., 2008), in watermelon (Colla et al., 2010b), in tomato (Fernandez-Garcia et al., 2004), in eggplants (Leonardi and Guiffrida, 2006), or cucumber (Rouphael et al., 2008b). Due to the low mobility of P, a more vigorous root system characterised by a higher density of root hair and/or increase in exudation of organic acid by the roots can be responsible for increasing the P uptake (Gent et al., 2005; Savvas et al., 2010; Colla et al., 2010b). Higher P depletion in a nutrient solution was obtained with double grafted melon plants. A positive effect has been seen between the foliar level of total P and greater shoot vigour (Lee, 1994; Ruiz et al., 1996) as reflected in the double graft melon plants.

Contradictory results have been obtained in graft plants in relation with Ca acquisition (see Martínez-Ballesta, 2010; Savvas et al., 2010). Increased Ca uptake has been observed in watermelon grafted on Cucurbita maxima (Ruiz et al., 1997); in tomato grafted on the rootstock of tomato (Fernandez-Garcia et al., 2004); or in
eggplant and tomato plants grafted on interspecific rootstock ‘Beaufort’ (Leonardi and Guiffrida, 2006). However, melon grafted on *Cucurbita* rootstocks showed no significant differences in comparison with non-grafted plants (Edelstein et al., 2005) or in cucumber grafted on *Cucurbita maxima* x *C. moschata* (Rouphael et al., 2008b). In our results, a significant increase in Ca uptake was obtained in double grafted plants; but not in simple grafted plants. Many reports indicate that Ca absorption can be significantly influenced by rootstocks, but the scion generally has no effect on uptake (Martínez-Balleta et al., 2010).

The uptake of micronutrients does not usually decrease in grafted plants (Huang et al., 2010). The Mn and Zn uptake increases in double grafted melon. The Zn is directly involved in the synthesis of heavy nitrogenous compounds (Cakmak, 1988). Pulgar et al. (1998) indicated that grafted watermelon plants have a higher efficiency in integrating Zn into nitrogenous compounds that form chelates with Zn, thereby also explaining the greater foliar biomass in grafted plants. In our results, a higher Zn uptake is correlated with higher NO$_3^-$ depletion in a nutrient solution. As a catalytically active metal, manganese has an important function and plays an activating role on enzymes and with Fe-involved chlorophyll synthesis. Under saline conditions, cucumber plants grafted on figleaf gourd enhances tolerance by maintaining higher Mn concentrations that promote higher antioxidant enzyme activity (Huang et al., 2010). A stimulated Mn uptake observed in double grafted melon possibly compensates for the lower Fe uptake.

Many results suggest that grafted plants can limit Cu and B transport from root to leaves reducing their toxic effect (Martínez-Ballesta et al., 2010; Savvas et al., 2010). Graft can partly mitigate Cu toxicity in environments with Cu concentrations that are too high. This is due to the ability of the rootstock to restrict Cu accumulation in the
shoots, for example, in cucumber graft on *C. maxima* x *C. moschata* (Rouphael et al., 2008b); or in tomato grafted on *Solanum lycopersicum* x *S. habrochaites* rootstock (Savvas et al., 2009). Excessive boron can be a problem in dry Mediterranean soils.

Many results in melon suggest that grafting may alleviate or even prevent growth and yield decrease due to B toxicity (Edelstein et al., 2005, 2007). Double grafted melon shows lower uptake of Cu and B – indicating that these plants could be more effective in excluding both elements.

K concentration in the plant and the K/Na ratio have been the most studied parameters related to salt tolerance, and these parameters are positively correlated with leaf biomass and chlorophyll fluorescence (Cuartero and Fernandez-Muñoz, 1999; Foolad, 2004; Albacete et al., 2009). There are conflicting results when determining the beneficial graft effect of salinity resistance in melon (Romero et al., 1997; Rivero et al., 2003; Edelstein et al., 2005; Colla et al., 2006). The diversity of outcomes may be due to the different effects of the *Cucurbita* rootstocks that were used in these studies (see Colla et al., 2010c). A higher Na exclusion is observed in double graft melon plants compared to simple graft – given that the root system is the same. The bibliography places great importance on the role of rootstocks in conferring resistance to abiotic and biotic stress.

In general, we observed that double graft achieved higher beneficial nutrient uptakes. This superiority in nutrient and water uptake was found in growth plants. In this experiment, we used *Cucurbita maxima* x *Cucurbita moschata* ‘Shintoza’ as rootstock grafted directly on melon (simple graft), or we used an intermediate rootstock (*Cucumis melo* in double graft). In both cases, the root system developed by *Cucurbita* rootstock was the same. So then why did double graft show the better physiological conditions? Our results confirm that grafted plants on vigorous root
systems can improve mineral and water absorption – but good graft compatibility is also important. In our case, an intermediate graft achieved an increase in ion influx to the scion that enabled increased light photosynthetic reaction and biomass. More studies should be undertaken to understand the mechanism underlying the rootstock/scion interaction.

Acknowledgements

The authors gratefully acknowledge Conselleria de Agricultura, Pesca y Alimentación (Generalitat Valenciana, Spain) for its financial support especially for the contract for A. Calatayud. The translation of this paper was founded by the Universitat Politècnica de València, Spain.
References


Calatayud, A., Roca, D., Gorbe, E., Martinez, P.F., 2008. Effect of two nutrient


Heo, Y.C., 1991. Effects of rootstocks on exudation and mineral elements contents in different parts of oriental melon and cucumber. MS thesis, Kyung Hee University, Seoul, South Corea, pp. 53.


The grafting of triploid watermelon is an advantageous alternative to soil fumigation by methyl bromide for control of *Fusarium* wilt. Sci. Hortic. 103, 9-17.


Table 1. Vegetative parameters: number of leaves per plant (n° plant⁻¹), aerial and root fresh weight (FWa and FWr respectively in g plant⁻¹), aerial and root dry weight (DWa, DWr in g plant⁻¹), and aerial and root fresh and dry ratios (FWa/FWr and DWa/DWr respectively) of single grafted, double grafted, and non-grafted plants at the end of the experiment.

<table>
<thead>
<tr>
<th></th>
<th>Leaves</th>
<th>FWa</th>
<th>FWr</th>
<th>DWa</th>
<th>Dw</th>
<th>FWa/FWr</th>
<th>DWa/DWr</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>35.80</td>
<td>166.54</td>
<td>31.82</td>
<td>12.09</td>
<td>1.69</td>
<td>5.60</td>
<td>7.19 b</td>
</tr>
<tr>
<td>S</td>
<td>46.07</td>
<td>165.19</td>
<td>22.33</td>
<td>15.31</td>
<td>1.59</td>
<td>7.56</td>
<td>9.61 a</td>
</tr>
<tr>
<td>D</td>
<td>54.27</td>
<td>226.41</td>
<td>34.77</td>
<td>20.09</td>
<td>2.13</td>
<td>6.83</td>
<td>9.54 a</td>
</tr>
</tbody>
</table>

Significance F(values) 0.001  0.210  0.402  0.020  0.230  0.445  0.008

Different letters in columns indicate significant differences at P<0.05 using the LSD test.

N: Non-grafted plants; S: Simple grafted plants; D: Double grafted plants.
Table 2. Water absorption (WA) (mL plant\(^{-1}\) d\(^{-1}\)) and nutrient uptake (mg plant\(^{-1}\) d\(^{-1}\)) of single grafted, doubled grafted, and non-grafted plants during the experiment.

<table>
<thead>
<tr>
<th></th>
<th>WA</th>
<th>N-NO(_3)</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>S</th>
<th>Mg</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>B</th>
<th>Cu</th>
<th>Na</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>324.2 b</td>
<td>210.2 b</td>
<td>11.4 b</td>
<td>491.9 b</td>
<td>47.5 b</td>
<td>12.0 - 15.1 -</td>
<td>0.157 ab</td>
<td>1.36 b</td>
<td>0.13 c</td>
<td>0.12 a</td>
<td>0.034 a</td>
<td>14.4 a</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>374.4 ab</td>
<td>213.0 b</td>
<td>9.6 b</td>
<td>531.4 ab</td>
<td>47.4 b</td>
<td>15.8 - 13.3 -</td>
<td>0.258 a</td>
<td>1.54 b</td>
<td>0.15 b</td>
<td>0.10 ab</td>
<td>0.029 a</td>
<td>8.6 ab</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>453.6 a</td>
<td>266.4 a</td>
<td>15.5 a</td>
<td>630.5 a</td>
<td>66.0 a</td>
<td>12.6 - 17.6 -</td>
<td>0.049 b</td>
<td>1.83 a</td>
<td>0.17 a</td>
<td>0.05 b</td>
<td>0.006 b</td>
<td>6.3 b</td>
<td></td>
</tr>
</tbody>
</table>

Significance F(values) | 0.047 | 0.044 | 0.013 | 0.049 | 0.045 | 0.844 | 0.609 | 0.024 | 0.007 | 0.005 | 0.033 | 0.033 | 0.045 |

Different letters in columns indicate significant differences at \(P < 0.05\) using the LSD test.

N: Non-grafted plants; S: Simple grafted plants; D: Double grafted plants.
Table 3. Nutrient uptake per dry weight (mg g⁻¹) of single grafted, doubled grafted, and non-grafted plants at the end of the experiment.

<table>
<thead>
<tr>
<th></th>
<th>N-NO₃</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>S</th>
<th>Mg</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>B</th>
<th>Cu</th>
<th>Na</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>153.88 a</td>
<td>8.37 a</td>
<td>36.31</td>
<td>34.35</td>
<td>8.76</td>
<td>10.80</td>
<td>0.113 a</td>
<td>0.997 a</td>
<td>0.094 a</td>
<td>0.089 a</td>
<td>0.025 a</td>
<td>10.50 a</td>
</tr>
<tr>
<td>S</td>
<td>127.13 ab</td>
<td>5.76 ab</td>
<td>31.61</td>
<td>28.35</td>
<td>9.33</td>
<td>7.94</td>
<td>0.150 a</td>
<td>0.917 ab</td>
<td>0.088 ab</td>
<td>0.056 ab</td>
<td>0.017 a</td>
<td>5.09 b</td>
</tr>
<tr>
<td>D</td>
<td>119.77 b</td>
<td>6.96 b</td>
<td>28.41</td>
<td>29.64</td>
<td>5.70</td>
<td>7.93</td>
<td>0.022 b</td>
<td>0.822 b</td>
<td>0.075 b</td>
<td>0.023 b</td>
<td>0.003 b</td>
<td>2.89 b</td>
</tr>
</tbody>
</table>

Significance F(values) | 0.045 | 0.058 | 0.156 | 0.182 | 0.762 | 0.552 | 0.015 | 0.041 | 0.040 | 0.010 | 0.007 | 0.013 |

Different letters in columns indicate significant differences at $P<0.05$ using the LSD test.

N: Non-grafted plants; S: Simple grafted plants; D: Double grafted plants.
Table 4. Influence of grafting (simple and double) on photosynthetic activity and chlorophyll fluorescence parameters.

<table>
<thead>
<tr>
<th></th>
<th>Amax</th>
<th>gs</th>
<th>Ci</th>
<th>E</th>
<th>WUE</th>
<th>(\phi_{\text{PSII}})</th>
<th>ETR</th>
<th>Fv/Fm</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>24.4</td>
<td>0.62 a</td>
<td>302 a</td>
<td>13.0 a</td>
<td>2.0 b</td>
<td>0.336 b</td>
<td>171 b</td>
<td>0.77</td>
</tr>
<tr>
<td>S</td>
<td>21.8</td>
<td>0.34 b</td>
<td>241 ab</td>
<td>9.0 b</td>
<td>2.7 a</td>
<td>0.343 ab</td>
<td>182 ab</td>
<td>0.79</td>
</tr>
<tr>
<td>D</td>
<td>23.3</td>
<td>0.39 b</td>
<td>239 b</td>
<td>9.7 b</td>
<td>2.7 a</td>
<td>0.376 a</td>
<td>192 a</td>
<td>0.78</td>
</tr>
</tbody>
</table>

Significance F(values) 0.710 0.040 0.010 0.040 0.020 0.010 0.010 0.590

Different letters in columns indicate significant differences at \(P<0.05\) using the LSD test.

N: Non-grafted plants; S: Simple grafted plants; D: Double grafted plants.

\(A_{\text{max}}\): net CO\(_2\) fixation rate (\(\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}\)); gs: stomatal conductance to water vapour (mol H\(_2\)O m\(^{-2}\) s\(^{-1}\)); Ci: substomatal CO\(_2\) concentration [\(\mu\text{mol CO}_2 \text{ mol}^{-1} \text{ (air)}\)];

\(E\): transpiration rate (mol H\(_2\)O m\(^{-2}\) s\(^{-1}\)) WUE: water use efficiency (\(\mu\text{mol CO}_2 \text{ mol}^{-1} \text{ H}_2\text{O}\)); \(\phi_{\text{PSII}}\): quantum efficiency of PSII photochemistry [(\(F_{\text{m}}-F_{\text{s}}\))/\(F_{\text{m}}\)]; ETR: relative linear transport rate (\(\mu\text{mol electron m}^{-2} \text{ s}^{-1}\)); Fv/Fm: maximum quantum yield of PSII.