The Potential of Enriched Fertilization in Overcoming Nutritional Deficiency in Grafted Melons

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Abstract. Melon plants grafted on *Cucurbita* rootstock may suffer from nutritional deficiencies due to reduced absorption and translocation of minerals to the foliage. Melon (*Cucumis melo* L.) cv. 6023 was grafted onto two interspecific *Cucurbita* rootstocks (*Cucurbita maxima* × *Cucurbita moschata*) 'TZ-148' and 'Gad'. Nongrafted melons were used as controls. Two fertilization field experiments were conducted in walk-in tunnels in the northern Arava valley of southern Israel. Two fertigation regimes were used: 1) standard and 2) enriched for magnesium (Mg; 150 mg·L⁻¹), manganese (Mn; 7.5 mg·L⁻¹), and zinc (Zn; 0.75 mg·L⁻¹) to increase the concentrations of the lacking elements. The enriched fertigation significantly increased Mn, Zn, and Mg contents in the leaf tissue. Concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sodium (Na), chloride (Cl), iron (Fe), and boron (B) were unaffected by the enriched fertilizer. There were no deficiency symptoms in grafted plants supplied with the enriched fertilizer.

Grafting as such is ancient but grafting vegetable plants is relatively recent innovation, used primarily to reduce damage from soilborne diseases. In recent years, this agrotechnology has undergone continuous expansion. For example in 2005, 1487 million grafted vegetable plants were used in Japan and Korea (Lee et al., 2010). Grafting in vegetable plants is becoming a common practice in some European countries, especially Spain, Italy, Turkey, and Greece (Cohen et al., 2007). The rootstock not only provides resistance to scion cultivar to biotic and abiotic stresses, but can also increase yield via utilization of the rootstock's vigorous root system. Grafting influences absorption and translocation of macro and micronutrients (Nie and Chen, 2000; Ruiz et al., 1997; Ruiz and Romero, 1999). Plants with vigorous root systems efficiently absorb water and inorganic nutrients (Heo, 1991), this being one of the motivations for the widespread use of grafted rootstocks (Lee, 1994). *Cucurbita* root systems are more efficient at nutrient uptake than melon root

systems. Moreover, there are differences in nutrient uptake among subspecies of *Cucurbita pepo* (Gent et al., 2005). Ruiz et al. (1997) showed that in grafted melon, N uptake is influenced more by the rootstock genotype than by the scion. Phosphorus is also increased by grafting in cucumber (Rouphael et al., 2008), watermelon (Colla et al., 2010; Uygur and Yetisir, 2009), and tomato (Fernandez-Garcia et al., 2004). Grafting also increases K⁺ content in different plants (Fernandez-Garcia et al., 2004; Goreta et al., 2008; Martinez-Rodriguez et al., 2008; Rouphael et al., 2008). On the other hand, many studies have shown that grafting can limit the uptake of certain elements, especially when they are present in excess in growth medium such as Na (Colla et al., 2006; Edelstein et al., 2011; Martinez-Rodriguez et al., 2008), B (Edelstein et al., 2005), copper (Cu) (Rouphael et al., 2008; Savvas et al., 2009), nickel, cadmium (Kumar et al., 2015a, 2015b; Savvas et al., 2013), and heavy metals (Edelstein and Ben-Hur, 2012). In effect, the selected rootstock acts like a biological filter that prevents the uptake of harmful elements. It seems, however, that the "biological filter effect" is not selective and may negatively affect absorption and uptake of necessary elements. Indeed, some studies have reported that the concentrations of Mg, Zn, and Mn are lower in grafted plants than in nongrafted ones. For example, tomato plants grafted on pepper rootstock exhibited lower concentrations of

Cu, Mn, and Zn compared with nongrafted plants (Kawaguchi et al., 2008). Grafting tomato onto three commercial rootstocks significantly reduced leaf Mg concentrations by 40%, resulting in Mg-deficiency symptoms 19 weeks after grafting (Savvas et al., 2009, 2011). In grafted melon, the concentrations of heavy metals and microelements, including Mn, Zn, Cu, and B, were substantially lower than those measured in their nongrafted counterparts (Edelstein and Ben-Hur, 2007). It is, however, noteworthy that reduced absorption of these elements does not always occur and it probably depends on the interaction between scion and rootstock, temperature, and soil type.

Today, grafted and nongrafted melons are fertilized similarly, but it seems that a new fertilization scheme should be developed that takes into consideration the differences in absorption and uptake between melon and *Cucurbita* root systems. Therefore, the aim of the present study was to examine whether the use of enriched fertilizer can overcome the lack of Mg, Mn, and Zn absorption of rootstock roots.

Materials and Methods

Two experiments were conducted in the field in walk-in tunnels at the Zohar Experiment Station, 'En Tamar (87% sand, 8% silt, and 5% clay), northern 'Arava, Israel (lat. 30°94' N, long. 35°37' E), during 2013/2014 and 2014/2015. Melon (*Cucumis melo*) '6023' (Galia market type; Hazera Seeds, Mivhor, Israel) was grafted onto two commercial rootstocks of interspecific *Cucurbita* (*C. maxima* Duchesne × *C. moschata* Duchesne rootstocks), 'TZ-148' (Tezier, now HM. Clause, Portes-lès-Valence, France) and 'Gad' (Hazera Seeds), were used in this experiment. Nongrafted and grafted seedlings were produced by a commercial nursery (Hishtil, Ashqelon, Israel). The seedlings were transplanted on 16 Dec. 2013 and on 15 Dec. 2014. Each treatment plot consisted of one row of 20 plants spaced 40 cm apart within the row. The bed centers were 190 cm apart. The two experiments were designed as randomized blocks with four replicates per treatment. During the experimental period of 2013/2014, greenhouse temperature range was 1.1–34.8 °C and for 2014/2015 the range was 5.0–36.7 °C. Relative humidity averaged 49.3% for 2013/2014 and 58.8% for 2014/2015. Fertigation was applied by a surface drip irrigation system that consisted of one irrigation line per plot. From planting to fruit set, the plants were fertigated every 3 d with 20 m³·ha⁻¹·d⁻¹. From fruit set to harvest, the plants were fertigated each day with 403 m³·ha⁻¹·d⁻¹. The chemical composition of the irrigation water was: electrical conductivity = 3.0 dS·m⁻¹; pH = 7.1; N-NH₄ = 30 ppm; N-NO₃ = 50 ppm; P = 8 ppm; K = 55 ppm; Ca = 180 ppm; Na = 320 ppm; Cl = 700 ppm; B = 0.57; Mg = 100 ppm; Mn = 5 ppm; and Zn = 0.5 ppm. In the enriched treatment, Mg, Mn, and Zn levels were 150, 7.5,

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and 0.75 ppm, respectively (Table 1). Three full-sized leaves from the top of the plant were sampled during fruit set. Leaf macro and microelements were determined according to Edelstein et al. (2005). Data from all experiments were subjected to one-way analysis of variance by Tukey honestly significant difference to determine statistical differences between treatments ($P = 0.05$) using JMP software (SAS Institute Inc., Cary, NC).

Results and Discussion

In a previous similar experiment conducted in 2013, grafted melons exhibited significant deficiency symptoms due to lack of Mg, Zn, and Mn (Table 2). These results led us to test the possibility of correcting the deficiencies using enriched fertilizer. Reports on the uptake of microelements by rootstocks are inconsistent. For instance, grafting of tomato cv. Moneymaker (*Solanum lycopersicum* L.) on the rootstock 'Maxifort' had no effect on the micronutrients uptake (Borgognone et al., 2013). On the other hand, some rootstocks of *Lycopersicon esculentum* and *Cucurbita* increased the grafted plants' uptake and translocation efficiency of Fe and/or Mn to the scion

shoots compared with nongrafted plants (Colla et al., 2010; Huang et al., 2010; Rivero et al., 2004).

In the first year of the experiment (2014), leaf Mn concentration was significantly lower in grafted plants (–34% in 'Gad' and –34% in 'TZ-148') than in nongrafted ones. In the 2nd year (2015), no significant differences in Mn concentration were found between the grafted and nongrafted plants (Fig. 1). Increasing Mn concentration in the root zone had been shown to result in similar increases in the Mn concentration in both roots and leaves of tomato (Le Bot et al., 1990). Accordingly, in our experiment, the enriched fertilizer caused a significant increase of $\approx 100\%$ in leaf Mn concentration for all plants in both years (Fig. 1).

Zn concentration followed a pattern similar to that of Mn. In both years, use of the enriched fertilizer significantly increased Zn concentration in the leaves of grafted and nongrafted plants (Fig. 2). Zn in the leaves of melon grafted onto 'TZ-148' and 'Gad' rootstocks treated with the enriched fertilizer reached similar (2014) or higher (2015) concentrations than those in the nongrafted melon treated with the standard fertilizer. In the 2nd year (2015), the increase in leaf Zn concentration with the enriched fertilizer treatment was more pronounced than that in 2014. In general, the increase in Zn was $\approx 50\%$, i.e., lower than that of Mn.

Tzerakis et al. (2012) showed that increasing the supply of Mn (160 μmol) and Zn (64 μmol) to cucumber through the nutrient solution results in corresponding increases in the leaf Mn and Zn concentrations. However, excessively high Mn and/or

Zn caused toxicity symptoms and a decrease in plant growth and fruit yield.

Grafting onto 'Gad' and 'TZ-148' decreased the leaf Mg concentration by an average 37% in the first year and 50% in the 2nd year, compared with the nongrafted plants. The enriched fertilizer did not affect its concentration in the 2014 experiment, but in the 2015 experiment, it caused a 22% increase in Mg in the leaves of nongrafted plants and a 40% increase in plants grafted onto 'Gad' and 'TZ-148' (Fig. 3). Despite the high concentration of Mg in the irrigation water, Mg concentration in the grafted plants was low. Similarly, Edelstein and Ben-Hur (2007) (in melons) and Savvas et al. (2011) (in tomato) found that Mg concentration in grafted plants is lower than in their counterpart nongrafted.

The concentrations of N, P, K, Ca, Na, Cl, Fe, and B were unaffected by the enriched fertilizer (data not presented). However, Tzerakis et al. (2012) found that high Mn and Zn levels (although in excess) in the irrigation water decrease uptake of Mg, Ca, Fe, and Cu, whereas K and P concentrations are unaffected. They suggested that excess Mn and Zn may restrict the leaf Ca and Mg concentrations, but not to levels resulting in nutrient deficiency.

The differences in the absorption of minerals between 2014 and 2015 could be due to different temperatures: in 2014, the temperature was an average 5 °C lower, especially early in the season, than in 2015. For example, the average minimum in Dec. 2014 was 4.5 °C (the lowest temperatures were 1.1, 2.4, and 2.5 °C) compared with an average minimum of 9.43 °C in Dec. 2015 (the lowest temperatures were 5.6, 6.0, and 7.0 °C). This is consistent with Schwarz et al. (2010), who found that low temperatures inhibit the absorption of water and minerals. However, we cannot say for certain that the temperature difference in 1 month (December) caused these differences. The reasons for the inconsistent results between the 2 years remain somewhat unclear. On the other hand, the differences in nutrient uptake among studies might be due to

Table 1. Elemental content ($\text{mg}\cdot\text{L}^{-1}$) in fertigation treatments.

Element	Standard ($\text{mg}\cdot\text{L}^{-1}$)	Enriched ($\text{mg}\cdot\text{L}^{-1}$)
Mg	100	150
Mn	5	7.5
Zn	0.5	0.75

Mg = magnesium; Mn = manganese; Zn = zinc.

Table 2. Concentration of Mg, Zn, and Mn in leaves of grafted and nongrafted melons (2013).

Element	Nongrafted melon ($\text{mg}\cdot\text{kg}^{-1}$)	Grafted melon ($\text{mg}\cdot\text{kg}^{-1}$)	% Reduction
Mg	1.60 a	0.81 b	40.4
Zn	52.46 a	27.92 b	46.8
Mn	49.63 a	28.25 b	43.1

Mg = magnesium; Mn = manganese; Zn = zinc.

Values followed by different letters in a row are significantly different at $P < 0.05$.

Fig. 1. Concentration of manganese (Mn) in leaves of nongrafted (NG) and grafted (Gad, TZ) melons fertigated with standard or enriched fertilizer (2014 and 2015). Different letters indicate significant differences between treatments at $P < 0.05$.

Fig. 2. Concentration of zinc (Zn) in leaves of nongrafted (NG) and grafted (Gad, TZ) melons fertiligated with standard or enriched fertilizer (2014 and 2015). Different letters indicate significant differences between treatments at $P < 0.05$.

Fig. 3. Concentration of magnesium (Mg) in leaves of nongrafted (NG) and grafted (Gad, TZ) melons fertiligated with standard or enriched fertilizer (2014 and 2015). Different letters indicate significant differences between treatments at $P < 0.05$.

different rootstocks, scions, temperature, or other environmental conditions.

It seems that for grafted melons, we need to create an enriched fertilizer that will improve uptake of the deficient elements. Moreover, it is necessary to determine the adequate balance between excess fertilizer that may leak into the groundwater and the sufficient amounts that will prevent deficiency in grafted plants.

In conclusion, the use of enriched fertilizer increased the concentrations of Mn, Zn, and Mg in grafted melons. To be on the safe side, we recommend using enriched fertilizer in grafted melons to avoid shortages of Mn, Zn, and Mg. At the same time, rootstocks with higher efficiency of Mn, Zn, and Mg uptake should be sought.

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