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Effect of newly developed interspecific hybrid rootstocks on mineral nutrient composition and fruit quality in tomato (*Solanum lycopersicum* L.)

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is one of the important vegetables in the world due to large production area and consumer interest. Biotic and abiotic stresses have negative effect on tomato production. Utilisation of rootstocks conferring resistance to biotic stresses can be considered as the most effective and environment friendly solution in tomato production to overcome this problem. Although wild tomato species is a good rootstock candidate due to its resistance to multiple plant diseases, effects of wild tomato species as rootstock on mineral nutrient composition and fruit quality are not clear. In the present study, effects of interspecific hybrids derived from two wild tomato species (*Solanum habrochaites* and *Solanum penellii*) as rootstock on tomato fruit mineral nutrient composition (phosphor (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), manganese (Mn), and copper (Cu)) and fruit quality traits (soluble solids content (SSC), pH, percent titratable acidity (TA), and lycopene content) were evaluated. In the study, Amaron, Armstrong, and Arazi commercial rootstocks were used as control and AK0004 F1 (candidate tomato hybrid) was used as a source of scion. As result, only lycopene content was affected by different rootstocks. *S. penellii* was found to be with more potential for lycopene content. For mineral nutrient composition, all hybrids and controls had similar contents of potassium, phosphor, calcium, and magnesium. Manganese and copper contents decreased in all plants. *S. habrochaites* had more potential regarding nitrogen, iron, and zinc contens than *S. penellii*. This is the first study to evaluate two interspecific hybrids derived from *S. habrochaites* and *S. penellii*, and the results might be useful to understand effects of rootstocks derived from wild tomato species on mineral nutrient content and fruit quality.

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KEYWORDS

interspecific hybrid, nutrient composition, lycopene

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is considered a major vegetable cultivated worldwide due to its high adaptation capacity (Djidonou et al., 2016). China, the EU, India, the USA, and Turkey are the major tomato producers in the world (FAO, 2018). Although tomato breeding programs aim to develop cultivars resistant to biotic and abiotic stresses, such a breeding is difficult due to complex inheritance mechanism of stress related traits. Utilisation of suitable rootstocks in tomato production can also reduce the adverse effects of such stresses (Singh et al. 2017). Thus, rootstocks are commonly used in tomato production. The use of rootstock applications in vegetable growing dates back to the 1920s (Ashita, 1927), and now it is the most popular technique in many parts of the world to control soil borne diseases (Rivard, 2006, Bletsos 2006; Lopez-Perez et al., 2006), to improve many traits of the scion such as fruit yield and quality (Oda et al., 1996; King et al., 2010), and to increase water usage efficiency (Urlić et al., 2020). In addition, use of rootstock provided tolerance to abiotic stresses such as low and high temperatures, drought, floods, heavy metals, and trace elements (Colla et al., 2006; Yetisir et al., 2006; Otani and Seike, 2007; Martínez-Rodriguez et al., 2008; Schwarz et al., 2010; Edelstein et al., 2011). Despite the importance of rootstocks, limited number of rootstocks was used in tomato production. Evolution of pathogens and environmental changes might reduce efficiency of the currently used rootstocks. Thus, development of new rootstocks tolerant to biotic and abiotic stresses is essential for sustainable tomato production. Wild tomato species is considered as a good rootstock candidate due to conferring resistance to multiple soil-borne pathogens and abiotic stresses (Rivard et al., 2010). Although high yielding tomato cultivars were developed in tomato breeding programs to maximise tomato production in the world, biotic and abiotic stresses have negative effect on tomato production. Rootstock potentials of some interspecific hybrids derived from *S. habrochaites* were studied (Rivard et al., 2010). As a result, the interspecific hybrids were found to be resistant to *Sclerotium rolfsii* and southern root-knot nematode. Also, in another study, two interspecific hybrids (Beaufort and Multifort) derived from *S. habrochaites* were evaluated for nutritional quality parameters such as lycopene, β-carotene, and lutein contents, total titratable acidity (TTA), and soluble solids content (SSC) (Djidonou et al., 2016). As all studies focused on *S. habrochaites*, interspecific hybrids derived from other wild tomato species have not yet been evaluated for their genetic rootstock potential (Mahmoud, 2020). In addition, these studies focused mostly on fruit quality, few studies were performed in *Solanaceae* to understand the effect of interspecific rootstock on mineral nutrient uptake (Fernández-García et al., 2004b; Kawaguchi et al., 2008), and these studies did not include wild tomato species. In a study performed by Leonardi and Giuffrida (2006), the effects of different rootstocks (PG3, Energy, and Beaufort as interspecific hybrids) on macronutrient uptake were evaluated. Nutrient uptake in plants is important, because mineral nutrients directly affect plant development and survival due to their important molecular roles in cell structure and physiology. The present study aimed to analyse effects of two interspecific hybrids that can be used as rootstocks in tomato grafting, derived from two wild tomato species (*S. habrochaites* and *S. penellii*).

2. MATERIALS AND METHODS

2.1. Plant material

A total of four interspecific hybrid rootstock candidates derived from cross between two wild tomato species (*S. habrochaites* (LA1777 and LA1778) and *S. penellii* (LA0716)) and four *S. lycopersicum* cultivars (AK0020, AK0030, AK0050, and AK0070) (Table 1) were used for the studies. *S. lycopersicum* cv. AK0004 F1 (candidate tomato hybrid) was used as a source of scion and Amaron (Titiz Agrogroup seeds), Armstrong (Syngenta seeds), and Arazi (Syngenta seeds) commercial rootstocks were used as control.

2.2. Grafting of tomato seedlings

Grafting was performed using tube grafting method (Lee et al., 2010) using rootstock one month from germination planted 3 days earlier, and scions had three leaves. Grafted seedlings were incubated in post grafting growth chamber under 95% humidity at 25 °C.

2.3. Fruit quality traits

A total of six fruit quality traits were evaluated in the present study. Average fruit weight was calculated as a mean of 10 fruit weight. pH of fruit was determined with pH meter. Titrimetric method was used to determine the percent titratable acidity (TA%).

In order to determine TSS, first the fruit was homogenised with ultra-turrax for 1 min then centrifuged at 5000 r.p.m. at 4 °C (Sigma, 2-16KL). TSS content was determined from the supernatant by using a digital refractometer (A. Krüss Optronic GmbH, DR6000 series, Germany) at 20 °C.

For determination of lycopene content, tomato pulps (0.5 g) were placed into 50 ml centrifuge tubes and supplemented with 5 ml acetone (0.05% BHT), 5 ml 95% ethanol, and 10 ml hexane. Samples were shaken in an orbital shaker at 180 r.p.m. for 15 min, and then 3 ml of distilled water was added, shaken for a further 5 min, and allowed the phases to separate. Samples were taken from the upper phase, and absorbance readings were performed at 503 nm wavelength of a UV-Vis spectrophotometer (Shimadzu, UV-1800, Japan). Resultant absorbance value was used in the following equation to get the lycopene content of the sample (Fish et al., 2002).

$$\text{Lycopene content}\left(\text{mg kg}^{-1}\right) = (A_{503} \times 31.2/W)/g$$

W = Sample quantity, A_{503}: Absorbance read at 503 nm.

Table 1. Maternal and paternal parents used to develop interspecific F1 hybrids

Pedigree ID	Maternal parent	Paternal parent
AKH002	AK0020 (*S. lycopersicum)*	*S. habrochaites* (LA1778)
AKH009	AK0030 (*S. lycopersicum)*	*S. habrochaites* (LA1777)
AKH0014	AK0050 (*S. lycopersicum)*	*S. penellii*
AKH0016	AK0070 (*S. lycopersicum)*	*S. penellii*

2.4. Mineral nutrient composition

Mineral nutrient contents of all plant materials were evaluated. For determination of mineral nutrient composition, tomato fruit was incubated at 65 °C, then dried fruit was grinded for further analysis. Total nitrogen content (N) was determined according to modified nitrogen Kjeldahl methods. Contents of phosphor (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), manganese (Mn), and copper (Cu) were measured after digestion with nitric-perchloric using ICP-OES (Kacar and Inal, 2008).

2.5. Statistical analysis

All statistical analyses were performed using PASW software and Excel software (Kinnear et al., 2010). One-way ANNOVA test based significance level of 0.05 was used to compare the means of the experimental groups. Coefficient of variation was calculated based on the formula in Excel; coefficient of variation (%): (standard deviation/mean) $\times$ 100.

3. RESULTS AND DISCUSSION

3.1. Fruit quality traits

Fruit quality traits were evaluated in the present study to determine effect of rootstocks with different genetic backgrounds. First, four biochemical fruit quality traits (soluble solids content (SSC), pH, percent titratable acidity (TA%), and lycopene content) were analysed. Although soluble solids contents (SSC) ranged from 4.34 to 4.75 with a CV value of 2.96%, there was no significant difference between groups (ANOVA test, $P < 0.05$). Also, one-way ANOVA test showed that there were no significant differences between groups for pH and percent titratable acidity (TA%). For lycopene content, all grafted plant materials had much higher lycopene contents than ungrafted control. Hybrid rootstocks derived from *S. habrochaites* (AKH009) had higher lycopene content than all control groups except for Amaron. Interestingly, while one of the hybrid rootstocks derived from *S. penellii* (AKH0014) had 33.09 mg kg^{-1} lycopene content, other (AKH0016) hybrids had lower lycopene contents (8.03 mg kg^{-1}). Amaron commercial hybrid had the highest lycopene content (Table 2). For evaluation of fruit shape, equatorial (ED) (mm) and polar diameter (PD) (mm) of the fruits were measured. As result, fruit shape value ranged from 0.73 to 0.81 with range variation value of 0.08. All interspecific rootstocks except AKH0016 (172 g) derived from *S. penellii* (LA0716) produced smaller fruit than ungrafted controls, and all rootstock controls except Arazi (157.33 g) produced bigger fruits than ungrafted rootstock (171 g) (Table 3) (Fig. 1). The present study evaluated the effect of interspecific rootstocks derived from two wild tomato species. The study demonstrated that grafting did not affect soluble solids content (SSC), pH, and percent titratable acidity (TA%). The results were consistent with the study performed by Djidonou et al. (2016). Turhan et al. (2011) reported that grafting decreased soluble solids content (SSC) in tomato. Also, the study showed that two interspecific hybrids derived from *S. habrochaites* had no effect (TTA) in contrast to studies of Flores et al. (2010) and Turhan et al. (2011). Although Djidonou et al. (2016) reported that lycopene content was not significantly affected, the present study found that grafting had positive effect on lycopene content similar to findings of Fernández-Garcia et al. (2004a) and Sánchez-Rodriguez et al. (2012). Interestingly, two F1 hybrids derived from the same wild

Table 2. Fruit quality traits (SSC, pH, TA, and lycopene)

Pedigree ID	Origin	SSC*	pH*	% TA*	Lycopene (mg kg^{-1})*
AKH009	Hybrid rootstock derived from *S. habrochaites*	4.6 ± 0.282	4.28	0.43 ± 0.014	26.75 ± 0.176
AKH002	Hybrid rootstock derived from *S. habrochaites*	4.75 ± 0.212	4.27 ± 0.007	0.44	34.9 ± 0.212
AKH0014	Hybrid rootstock derived from *S. penellii*	4.35 ± 0.212	4.24 ± 0.056	0.43 ± 0.028	33.09 ± 0.113
AKH0016	Hybrid rootstock derived from *S. penellii*	4.39 ± 0.148	4.34 ± 0.070	0.39 ± 0.035	8.03 ± 0.212
AKH004	Un-grafted control (Scion)	4.48 ± 0.304	4.29 ± 0.035	0.39 ± 0.021	36.71 ± 0.254
Arazi	Commercial rootstock control	4.40 ± 0.134	4.35 ± 0.063	0.38 ± 0.021	27.43 ± 0.063
Amaron	Commercial rootstock control	4.34 ± 0.077	4.35 ± 0.049	0.39 ± 0.007	38.62 ± 0.353
Armstrong	Commercial rootstock control	4.43 ± 0.233	4.3 ± 0.042	0.39 ± 0.021	27.81 ± 0.296

*Mean ± Standard deviation

Table 3. Fruit shape evaluation of plant material

Pedigree ID	Origin	Equatorial diameter (ED) (mm) Mean ± Standard deviation	Polar diameter (PD) (mm) Mean ± Standard deviation	FW (g)
AKH009	Hybrid rootstock derived from *S. habrochaites*	73.60 ± 3.394	58.23 ± 2.023	145.3
AKH002	Hybrid rootstock derived from *S. habrochaites*	67.3 ± 1.837	52.26 ± 0.669	153
AKH0014	Hybrid rootstock derived from *S. penellii*	69.93 ± 0.267	52.63 ± 0.267	168
AKH0016	Hybrid rootstock derived from *S. penellii*	71.36 ± 1.320	57.73 ± 0.299	172
AKH004	Un-grafted control (Scion)	74.26 ± 1.399	54 ± 1.414	171
Arazi	Commercial Rootstock control	73.23 ± 2.594	54 ± 1.296	157.3
Amaron	Commercial Rootstock control	71.6 ± 3.062	57.86 ± 2.057	188.6
Armstrong	Commercial Rootstock control	70.4 ± 1.359	54.33 ± 0.659	178.3

species (*S. penellii*) had different effect on lycopene content. This showed that even the maternal parent of the F1 hybrids might affect lycopene content. Effects of rootstocks on fruit size are controvertible, Fernández-Garcia et al. (2004a) reported that rootstocks had no effect on fruit size under salinity stress, Rivard et al. (2010) reported that grafting increased fruit size, and Djidonou et al. (2016) reported that grafting reduced fruit size. In the present study, although

Fig. 1. Fruit shape of interspecific hybrids (a, b, c, d), scion (e), and controls (f, g, h)

fruit shape was not affected by rootstock type, all rootstock controls except Arazi had bigger fruits similar to results of Rivard et al. (2010). All interspecific rootstocks except AKH0016 derived from *S. penellii* (LA0716) had smaller fruits similar to results of Djidonou et al. (2016). The reason behind bigger fruits of candidate rootstock derived from *S. penellii* (AKH0016) is needed to be further investigated. The reason of this difference might be due to different root structure of rootstocks, which effects water and mineral uptake (Martínez-Ballesta et al., 2010).

3.2. Mineral nutrient composition

Mineral composition of scions grafted to interspecific hybrids was evaluated to understand the effect of the rootstock newly developed in the present study. A total of eight mineral nutrients (nitrogen (N), phosphor (P) potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), manganese (Mn), and copper (Cu)) were measured in hybrids and controls. It was found that all plant materials including interspecific hybrid rootstock and control groups had similar potassium (K), phosphor (P), calcium (Ca), and magnesium (Mg) contents. For nitrogen content, rootstock control (Amaron) had the highest value. AKH002 derived from *S. habrochaites* (LA1778) had 1.83% nitrogen content, other rootstock (AKH009) derived from another accession of *S. habrochaites* (LA1777) had higher nitrogen content with 2.6%. For iron, rootstock AKH002 derived from *S. habrochaites* (LA1778) had the highest content (47 ppm). Also, control rootstock (Armstrong) had higher iron content than the rest of the plant material (26.8 ppm). For the zinc element, two rootstocks (AKH002 and AKH009) derived from *S. habrochaites* had higher amounts than the controls. Control and interspecific hybrid rootstocks derived from *S. penellii* (LA0716) had lover zinc contents than the un-grafted control. For manganese, all controls and rootstock except for Arazi (9.6 ppm) had lower contents than un-grafted control (9.2 ppm). Also, for copper (Cu) content, all controls and plant materials had lower contents than un-grafted control similarly to manganese content (Table 4). Effect of origin of rootstock on mineral nutrient content was investigated in the present study due to importance of mineral nutrients in plant survival and human health. Previous studies in plants demonstrated that mineral nutrient uptake was affected by types of rootstocks and scions affected by nutrient type and changing environment (Martínez-Ballesta et al., 2010; Djidonou et al., 2017). In this perspective, the study showed that rootstock had no effect on content of potassium (K), phosphor (P), calcium (Ca), and magnesium (Mg) in contrast to results of the study performed by Fernández-Garcia et al. (2004b), who reported that grafting increased phosphor (P), calcium (Ca), and magnesium (Mg) contents and results of Martínez-Rodriguez et al. (2008), who reported that grafting increased K content. From the perspective of nutrient content, an interspecific rootstock (AKH009) derived from *S. habrochaites* and rootstock control (Amaron) had good potentials. Iron content in tomato fruits of AKH002 increased, thus, from the nutrient point of view, it had good potential. AKH002 and AKH009 rootstocks derived from

Table 4. Mineral nutrient content of plant material

Pedigree ID	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)
AKH002	1.83	0.23	2.14	0.12	0.07	47.00	34.40	6.20	5.40
AKH009	2.60	0.24	2.27	0.13	0.08	8.80	24.40	7.00	6.80
AKH0014	1.94	0.22	2.18	0.12	0.08	13.80	11.60	6.80	6.00
AKH0016	1.52	0.30	2.35	0.11	0.08	8.20	17.20	7.00	5.80
AKH004 (Scion)	1.88	0.29	2.37	0.14	0.09	15.60	24.20	9.20	14.00
Arazi	1.53	0.26	2.37	0.15	0.08	9.20	13.80	9.60	5.40
Amaron	3.90	0.27	2.26	0.09	0.07	7.80	17.40	6.20	5.80
Armstrong	1.70	0.28	2.46	0.11	0.09	26.80	14.80	8.20	6.40

S. habrochaites had positive effect on zinc content. Summarising, rootstocks derived from *S. habrochaites* had positive effect on fruit mineral nutrients for nitrogen, iron, and zinc. Thus, *S. habrochaites* might be more efficient in mineral uptake and transport to scions than *S. penellii*. Also, this study showed that grafting reduced the Cu content similarly to result of Kawaguchi et al. (2008), who reported that grafting reduced Cu, Mn, and Zn contents.

4. CONCLUSIONS

Development of new tomato rootstocks having high quality fruit is important for sustainable tomato production due to prevalent usage of rootstocks in tomato cultivation. Wild tomato species are promising for development of new rootstock. The present study evaluated two newly developed interspecific hybrids derived from two wild tomato species. While hybrid rootstocks derived from *S. penellii* had good rootstock potential for lycopene, hybrids derived from *S. habrochaites* had more genetic potential for mineral nutrient composition. This is the first study to evaluate effects of two wild tomato species on mineral nutrient composition.

REFERENCES

Ashita, E. (1927). Grafting of watermelons (in Japanese). *Korea (Chosun) Agricultural Newsletter*, 1: 9.

Bletsos, F.A. (2006). Grafting and calcium cyanamide as alternatives to methyl bromide for greenhouse eggplant production. *Scientia Horticulturae*, 107(4): 325–331.

Colla, G., Rouphael, Y., Cardarelli, M., Massa, D., Salerno, A., and Rea, E. (2006). Yield, fruit, quality and mineral composition of grafted melon plants grown under saline conditions. *Journal of Horticultural Science and Biotechnology*, 81(1): 146–152.

Djidonou, D., Simonne, A.H., Koch, K.E., Brecht, J.K., and Zhao, X. (2016). Nutritional quality of field-grown tomato fruit as affected by grafting with interspecific hybrid rootstocks. *HortScience*, 51(12): 1618–1624.

Djidonou, D., Zhao, X., Brecht, J.K., and Cordasco, K.M. (2017). Influence of interspecific hybrid rootstocks on tomato growth, nutrient accumulation, yield, and fruit composition under greenhouse conditions. *HortTechnology*, 27(6): 868–877.

Edelstein, M., Plaut, Z., and Ben-Hur, M. (2011). Sodium and chloride exclusion and retention by non-grafted and grafted melon and *Cucurbita* plants. *Journal of Experimental Botany*, 62(1): 177–184.

FAO (2018). Statistics of Food and Agriculture Organization of the United Nations, Available at: http://www.fao.org/statistics/en/.

Fernández-Garcia, N., Martinez, V., Cerda, A., and Carvajal, M. (2004a). Fruit quality of grafted tomato plants grown under saline conditions. *The Journal of Horticultural Science and Biotechnology*, 79: 995–1001.

Fernández-Garcia, N., Martinez, V., and Carvajal, M. (2004b). Effect of salinity on growth, mineral composition, and water relations of grafted tomato plants. *Journal of Plant Nutrition and Soil Science*, 167(5): 616–622.

Fish, W.W., Perkins-Veazie, P., and Collins, J.K. (2002). A quantitative assay for lycopene that utilizes reduced volumes of organic solvents. *Journal of Food Composition and Analysis*, 15: 309–317.

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., and Bolarín, M.C. (2010). The effectiveness of grafting to improve tomato fruit quality. *Scientia Horticulturae*, 125(3): 211–217.

Kacar, B., and Inal, A. (2008). Bitki analizleri. *Nobel Yayinlari*, 1241(63): 912 pages (Ankara, In Turkish).

Kawaguchi, M., Taji, A., Backhouse, D., and Oda, M. (2008). Anatomy and physiology of graft incompatibility in solanaceous plants. *The Journal of Horticultural Science and Biotechnology*, 83(5): 581–588.

Kinnear, P.R. and Gray, C.D. (2010). *PASW statistics 17 made simple*. Psychology Press, New York, p. 255.

King, S.R., Davis, A.R., Zhang, X., and Crosby, K. (2010). Genetics, breeding and selection of rootstocks for *Solanaceae* and *Cucurbitaceae*. *Scientia Horticulturae*, 127(2): 106–111.

Lee, J.M., Kubota, C., Tsao, S.J., Bie, Z., Echevarria, P.H., Morra, L., and Oda, M. (2010). Current status of vegetable grafting: diffusion, grafting techniques, automation. *Scientia Horticulturae*, 127(2): 93–105.

Leonardi, C. and Giuffrida, F. (2006). Variation of plant growth and macronutrient uptake in grafted tomatoes and eggplants on three different rootstocks. *European Journal of Horticultural Science*, 71(3): 97–101.

Lopez-Perez, J.A., Le Strange, M., Kaloshian, I., and Ploeg, A.T. (2006). Differential response of Mi gene-resistant tomato rootstocks to root-knot nematodes (*Meloidogyne incognita*). *Crop Protection*, 25(4): 382–388.

Mahmoud, A.M.A. (2020). Tomato rootstock breeding: evaluation of tomato interspecific hybrid rootstocks under greenhouse conditions. *The Horticulture Journal*, 89(5): 575–585.

Martínez-Ballesta, M. C., Alcaraz-López, C., Muries, B., Mota-Cadenas, C., and Carvajal, M. (2010). Physiological aspects of rootstock–scion interactions. *Scientia Horticulturae*, 127(2): 112–118.

Martínez-Rodriguez, M.M., Estañ, M.T., Moyano, E., Garcia-Abellan, J.O., Flores, F.B., Campos, J.F., Al-Azzawi, M.J., Flowers, T.J., and Bolarin, M.C. (2008). The effectiveness of grafting to improve salt tolerance in tomato when an 'excluder' genotype is used as scion. *Environmental and Experimental Botany*, 63(1–3): 392–401.

Oda, M., Nagata, M., Tsuji, K., and Sasaki, H. (1996). Effects of scarlet eggplant rootstock on growth, yield, and sugar content of grafted tomato fruits. *Journal of the Japanese Society for Horticultural Science*, 65(3): 531–536.

Otani, T. and Seike, N. (2007). Rootstock control of fruit dieldrin concentration in grafted cucumber (*Cucumis sativus*). *Journal of Pesticide Science*, 32(3): 235–242.

Rivard, C.L. (2006). *Grafting tomato to manage soilborne diseases and improve yield in organic production systems.* Master's thesis. North Carolina State University, Raleigh, NC. 102 pages.

Rivard, C.L., O'Connell, S., Peet, M.M., and Louws, F.J. (2010). Grafting tomato with interspecific rootstock to manage diseases caused by *Sclerotium rolfsii* and southern root-knot nematode. *Plant Disease*, 94(8): 1015–1021.

Sánchez-Rodríguez, E., Leyva, R., Constán-Aguilar, C., Romero, L., and Ruiz, J.M. (2012). Grafting under water stress in tomato cherry: improving the fruit yield and quality. *Annals of Applied Biology*, 161(3): 302–312.

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(2): 162–171.

Singh, H., Kumar, P., Chaudhari, S., and Edelstein, M. (2017). Tomato grafting: a global perspective. *HortScience*, 52(10): 1328–1336.

Turhan, A., Ozmen, N., Serbeci, M.S., and Seniz, V. (2011). Effects of grafting on different rootstocks on tomato fruit yield and quality. *Horticultural Science*, 38(4): 142–149.

Urlić, B., Runjić, M., Mandušić, M., Žanić, K., Vuletin Selak, G., Matešković, A., and Dumičić, G. (2020). Partial root-zone drying and deficit irrigation effect on growth, yield, water use and quality of greenhouse grown grafted tomato. *Agronomy*, 10(9): 1297.

Yetisir, H., Caliskan, M.E., Soylu, S., and Sakar, M. (2006). Some physiological and growth responses of watermelon [*Citrullus lanatus* (Thunb.) Matsum. and Nakai] grafted onto *Lagenaria siceraria* to flooding. *Environmental and Experimental Botany*, 58(1–3): 1–8.