New Zealand Journal of Crop and Horticultural Science

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tnzc20

Leaf physiological variation and nutrient contents of pepper (*Capsicum annuum* L.) inbred lines as affected by different rootstock genotypes

Firdes Ulas, Halit Yetisir & Abdullah Ulas

To cite this article: Firdes Ulas, Halit Yetisir & Abdullah Ulas (13 Feb 2025): Leaf physiological variation and nutrient contents of pepper (*Capsicum annuum* L.) inbred lines as affected by different rootstock genotypes, New Zealand Journal of Crop and Horticultural Science, DOI: 10.1080/01140671.2025.2457995

To link to this article: https://doi.org/10.1080/01140671.2025.2457995

Published online: 13 Feb 2025.

Submit your article to this journal

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=tnzc20

NEW ZEALAND JOURNAL OF CROP AND HORTICULTURAL SCIENCE
https://doi.org/10.1080/01140671.2025.2457995

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

Check for updates

Leaf physiological variation and nutrient contents of pepper (*Capsicum annuum* L.) inbred lines as affected by different rootstock genotypes

Firdes Ulas[a], Halit Yetisir[a] and Abdullah Ulas[b]

[a]Department of Horticulture, Faculty of Agriculture, Erciyes University, Kayseri, Türkiye; [b]Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Erciyes University, Kayseri, Türkiye

ABSTRACT

We aimed to investigate the rootstock effects on plant growth performance and root nutrient contents and uptake of pepper inbred line (IL) based on the physiological and morphological response mechanisms. Four IL were grafted with two rootstocks, and ungrafted scions were used as control plants. As a result, among grafted and control plants substantial ($p < 0.001$) variances were found in morphological, physiological parameters and K, Ca, Mg, Mn and Zn composition. Significantly a higher leaf area, rootstock and scion diameter, shoot fresh and dry biomasses was found in IL 'ERÜ 1227' grafted with 'Scarface', significantly higher Ca and Mn composition were found in '21H-1-2' grafted with 'Scarface'; however, significantly higher root fresh-dry biomasses and Zn composition was recorded in 'ERÜ 1227' grafted onto '46 KB F1' rootstock. 'Scarface' rootstock performed better than the '46 KB F1' rootstock; thus, it is advised as the best rootstock genotype with wide scion compatibility. As conclusion, vigorous rootstocks which could be illustrated beside an effective nutrient uptake, perform key functions in the enhancement of plant growth performance and root nutrient contents.

ARTICLE HISTORY
Received 10 July 2024
Accepted 16 January 2025

KEYWORDS
Vegetable grafting; pepper; rootstock; inbred; leaf area; leaf chlorophyll index

Introduction

Pepper (*Capsicum annuum* L.) belongs to the family Solanaceae; it is commonly cultivated and nowadays it is economically one of the most important vegetables. Pepper fruits are considered as dried, processed, table vegetables and as spices (Geleta 1998) since they improve the acceptance of characterless principal nutrient foods. The nutritionary assessment of sweet and hot pepper merits specific consideration since it is a valuable source of vitamin A, vitamin C and vitamin E and an excellent source of vitamin B2, potassium, phosphorus and calcium like tomato and eggplant. In addition to their use as food or condiments, peppers are also used as medicine and have ornamental values (Grubben 1977). Grafting is the joining together of two or more surviving plant fragments (rootstock and scion) that grow as a single plant. Grafting horticultural vegetable production was initiated in Korea and Japan by the end of 1920, with *Citrullus lanatus* L. plants grafted on to squash rootstocks. Also, it became a widespread agricultural

CONTACT Firdes Ulas fulas@erciyes.edu.tr
© 2025 The Royal Society of New Zealand

practice in Japan, Korea, the Mediterranean basin, and various European countries (Pogonyi et al. 2005). Vegetable grafting is an innovative procedure for the appropriate production of fruit-bearing vegetables like tomato, bean, eggplant, cucumber, and melon (Pogonyi et al. 2005). Rootstocks with vigorous root characteristic systems can improve pest and disease resistance, plant growth, yield and quality, absorption of nutrients and mineral content in the aerial part of the plant, salt, drought, cold, high and low temperature, heavy metal, high and low N tolerance, as reported for different vegetables like watermelon, melon, tobacco, tomato, potato, pepper and pepino (Dasgan et al. 2015; Kumar et al. 2015; Sarabi et al. 2017; Ulas 2019, 2021a, 2021b; Ulas et al. 2019a, 2019b, 2019c; 2020a, 2020b; 2021a, 2021b; Al Rubaye et al. 2021). However, pepper grafting is not common owing to the deficiency of commercial rootstocks that accomplish acceptability, in spite of the fact that the use of acceptable rootstocks can be a substitute approach to decrease yield reduction caused by environmental stress (Singh et al. 2017). So far, slight attention has been paid to the effect of grafting on pepper plants regarding vegetative growth, fruiting characteristics and yield in insufficient researches and with an inadequate number of rootstocks (Penela et al. 2014, 2015, 2016; Soltan et al. 2017; Al Rubaye et al. 2021). The use of grafting in pepper plants is not yet extensively employed in Türkiye particularly using improved inbred lines of pepper such as ERÜ 1227, ERÜ 462, 21 H-1-2 and 33 H-3-1. Inbreeding influences because of selfing cause depression in growth and development in pepper (*Capsicum annuum* L.) inbred line (IL). Therefore, the aim of this study was to investigate the rootstock effects on plant growth performance and root nutrient contents and uptake of pepper IL based on the physiological and morphological response mechanisms.

Materials and methods

Experimental set-up

The experiment was conducted at the Faculty of Agriculture, University of Erciyes, Kayseri, in Türkiye (38° 43′ 56″ N, 35° 29′ 7″ E). Four *Capsicum annuum* L. IL (21 H-1-2, 33 H-3-1, ERÜ 1227 and ERÜ 462) were grafted with two *Capsicum annuum* L. rootstock genotypes (46 KB F1 and Scarface F1). Scion ERÜ 1227 and ERÜ 462 are long green pepper types, 21 H-1-2 and 33 H-3-1 are bell pepper types. The rootstock 46 KB F1 is bristle pepper genotypes. 21 H-1-2, 33 H-3-1 and 46 KB F1 were obtained from the Ministry of Agriculture and Forestry, Black Sea Agricultural Research Institute, Türkiye. The rootstock variety of Scarface F1 (Enza Zaden) is a commercial hybrid rootstock pepper. The seeds were sown in multi-pots in peat mixture (pH: 6.0–6.5) and perlite (2v:1v). After seedlings achieved five or six true leaves stage, grafting was carried out with the method of 'tube grafting' (Ulas 2019). Ungrafted scion varieties were determined as control plants. Grafted and ungrafted plants were transferred to the field 0.5-m arrangement among plants and 1.0-m arrangement among rows were managed through transferring in a randomised completely block design including three repetitions. Four plants were chosen at random and identified from every single treatment of trial units and measurements were done on these plants for yield and other morphological traits. Measurements were done on equal plants during the growing period. At harvesting, plants were taken to Plant Physiology Laboratory at Erciyes University.

Harvesting and morphological characterisation

Plant height (cm) was determined with a hand-ruler. The stem diameter of scion was measured above the grafting area though the stem diameter of the rootstock was measured below the grafting area of the grafted plant. Leaf, stem and roots were weighed on a digital scale for fresh weight determination. To determine the dry weight of the shoot and root, plants were stored in the oven for 72 h at 70 °C.

Physiological characterisation

The total leaf area (LA) was assessed using a destructive leaf area metre device of LI-COR (LI-3100C, Inc., Lincoln, NE, USA). Measurements were done in cm^2. For every treatment, leaf chlorophyll metre (SPAD) was read using Minolta SPAD-502. Throughout the experiment, two series of SPAD measurements were done at the leaf centre on fully developed young leaves of plants for every treatment.

Root mineral analysis

0.5 g of the dried plant tissues (root) was taken for the determination of K, Ca, Na concentrations. It was by dry ashing at 400 ∘C for 4.5 h, running ash in 5 ml of HCl (concentration of 20%) was included in ashed trials and then filtered. Filtered solutions were diluted with distilled water to a volume of 50 ml. Out of which 10 ml was taken for Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) analysis. The ICP-AES results were converted into percentages (%) and parts per million (ppm).

Nutrient uptake

The uptake of nutrient was determined by multiplying the concentration of nutrients of every plant fragment (shoot and root) by dry weight.

Statistical analysis

Analysis of variance (ANOVA) was made via SAS programme (SAS 9.0, SAS Institute Inc., Cary, NC, USA). If ANOVA controlled the effects of treatments were significant ($^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$, and ns means not significant for F-Test), then treatment means were separated by Duncan's Multiple Range Test ($p < 0.05$). Pearson correlation coefficients were done with the PROC CORR procedure of SAS.

Result and discussion

Shoot and root biomass production

According to the results, significant variations ($p < 0.001$) were observed among the graft combinations in the shoot- root fresh biomass and dry biomass (Table 1). The significantly greatest shoot fresh-dry matters were noted in 'ERÜ 1227' grafted onto 'Scarface' rootstocks. This demonstrated that grafting on selected rootstock has a positive influence on shoot growth since it increased the shoot fresh matter of the scion cultivar (inbred

Table 1. Influences of grafting on shoot-root fresh (FM), – dry matter (DM) of pepper plants.

Graft Combination	Shoot FM (g/plant)	Root FM (g/plant)	Shoot DM (g/plant)	Root DM (g/plant)
ERÜ 1227	353.61^{cd}	63.23^{ab}	45.59^{b}	19.08^{c}
ERÜ 1227/Scarface	475.17^{a}	58.11^{bc}	54.45^{a}	25.53^{b}
ERÜ 1227/46 KB F1	392.00^{b}	67.02^{a}	48.12^{b}	28.73^{a}
ERÜ 462	256.00^{h}	29.57^{e}	35.88^{c}	10.35^{e}
ERÜ 462/Scarface	261.33^{gh}	31.37^{e}	27.19^{d}	12.14^{de}
ERÜ 462/46 KB F1	328.93^{de}	29.72^{e}	37.76^{c}	13.40^{de}
21H-1-2	309.94^{ef}	57.18^{bc}	53.40^{a}	22.23^{c}
21H-1-2/Scarface	376.29^{bc}	61.28^{ab}	37.58^{c}	20.07^{c}
21H-1-2/46 KB F1	353.58^{cd}	56.34^{bc}	30.73^{d}	20.59^{c}
33 H-3-1	348.17^{cd}	52.51^{cd}	30.59^{d}	20.50^{c}
33 H-3-1/Scarface	265.89^{gh}	59.89^{abc}	28.28^{d}	19.38^{c}
33 H-3-1/46 KB F1	285.26^{fg}	48.23^{d}	21.95^{e}	13.86^{d}
Minimum	256.00	29.57	21.95	10.35
Maximum	475.17	67.02	54.45	28.73
Grafted + ungrafted mean	333.85	51.20	37.63	18.82
Ungrafted mean	305.65	47.46	39.18	16.76
Grafted mean	342.63	53.32	37.73	19.34
F-Test	***	***	***	***

Notes: Values denoted by different letters are significantly different between genotypes within columns at $p < 0.05$ (T-Test). ns, non-significant. ***$p < 0.001$ (F-Test).

line) of 'ERÜ 1227' by almost 34.38% compared to its ungrafted control plants. Furthermore, the inbred line 'ERÜ 462' (256.0 g/plant) increased its shoot fresh weight by 28.49% when it was grafted with the rootstock genotype of '46 KB F1'. In scion cultivar '21 H-1-2' shoot fresh weight increased in different ratios when it was grafted with the rootstock 'Scarface' (21%) and '46 KB F1' (14%). Similar to our results, grafting with vigorous rootstock affected aboveground growth at various levels in pepper (Colla et al. 2008), cucumber (Kumar et al. 2019) and watermelon plants (Kombo and Sari 2019) depending on rootstock characteristics. Our results were in line of those of Mohamed et al. (2014), Ulas (2019, 2021a, 2021b), Ulas et al. (2019a, 2019b, 2019c; 2020a, 2020b; 2021a, 2021b) and Al Rubaye et al. (2021) who determined that grafting create supplementary foliage and vigorous plants. On the other hand, conflicting results in our study were also found when inbred line 33 H-3-1 was grafted onto Scarface rootstock and consequently shoot fresh weight reduced by 23% and when it was grafted onto 46 KB F1 rootstock, it reduced by 18%. The reason for that decrease might be due to a graft incompatibility between a particular rootstock and scion combination that could be regarding the repair of the conducting vascular tissues (xylem and phloem) and encouragement or impairment of the graft development as a result of alterations of water and nutrient flows (Mudge and Janick 2009). Furthermore, the chemical and physical properties of scion can be influenced by rootstock because of an adjustment of transportation of metabolites via xylem or alteration of physiological methods (Gisbert et al. 2011). Consequently, the assortment of suitable rootstocks for the precise scions is a very important process which leads to an increase in grafting compatibility and, therefore, decreases the negative impact of grafting on both shoot and growth of vegetable plants.

In terms of root growth, the significantly highest root fresh and dry biomass was produced in 'ERÜ 1227' grafted onto '46 KB F1' rootstock combination. Grafting increased the root dry matter of 'ERÜ 1227' by almost 50.55% with '46 KB F1' rootstocks compared to its ungrafted control. It also increased the root dry matter of 'ERÜ 1227' by almost

33.78% with the rootstock of 'Scarface'. Another positive result on root dry weight was observed when genotype 'ERÜ 462' (10.35 g/plant) increased its root dry weight by grafting with the rootstock '46 KB F1' by almost 29.36% and with the rootstock 'Scarface' by almost 17.19%. Our results revealed that the weak root system of scion varieties can be improved by grafting using an appropriate rootstock. Similar to our results, Yetisir and Sari (2019) observed significantly greater shoot-root dry matter in grafted plants than ungrafted ones. The lowest root growth was shown by control plants of 'ERÜ 462' (Table 1). Conflicting results in our study were also observed when the scion (33 H-3-1) was grafted onto the rootstock '46 KB F1' registered root dry weight reduction by almost 32%. The decrease in root dry weight in the scion of 33 H-3-1 was lower in graft combination, involving rootstock 'Scarface' by 5.46%. Moreover, another scion cultivar (21 H-1-2) when grafted onto the rootstock 'Scarface' registered root dry weight reduction by 9.7% and with the rootstock '46 KB F1' by 7.38%. This might be due to graft incompatibility that is caused by a low or inappropriate callus formation between rootstock and scion (Johkan et al. 2009). A small or wrong callus development could result in defoliation, decreased scion growth and a low survival of grafted plants (Martínez-Ballesta et al. 2010).

Leaf chlorophyll index (SPAD), plant height, total leaf area, rootstock and scion stem diameter

Highly significant ($p < 0.001$) differences were found in leaf chlorophyll index (SPAD), plant height, total leaf area, rootstock and scion diameter among graft combinations (Figure 1 and Table 2). 'ERÜ 1227' grafted onto 'Scarface' rootstock recorded significantly highest leaf area followed by 'ERÜ 1227' grafted onto '46 KB F1' rootstock and ungrafted plants of 'ERÜ 1227'. This shows that grafting has a positive effect on leaf area formation since it increased the leaf area of the inbred line of 'ERÜ 1227' from 3283.78 cm^2/plant to 3780.17 cm^2/plant which was an increase by almost 15% with grafting on 'Scarface'. Furthermore, the inbred line 'ERÜ 462' (1875.67 g/plant) increased its leaf area formation by 25% when it was grafted with the rootstock genotype of 'Scarface' by almost 25%. Scion cultivar '21 H-1-2' increased its leaf area in different rates when it was grafted with the rootstock genotype of '46 KB F1' (49%) and 'Scarface' (19%). Conversely, the significantly lowest leaf area was recorded when '33 H-3-1' grafted onto '46 KB F1' rootstock (Figure 1). Up to now in many crop species such as cucumber Kumar et al. 2019, watermelon (Ulas et al. 2019a), melon (Ulas et al. 2019b, 2020a), tomato (Ulas et al. 2019b), eggplant (Ulas 2021a), pepper (Soltan Mahmoud et al. 2017, Ulas 2019, Ulas et al. 2020b, Al Rubaye et al. 2021), pepino (Ulas 2021b) and potato (Ulas et al. 2021b) it was stated that grafted plants produced more leaf area and specific leaf area than ungrafted plants. On the other hand, Khah (2011) stated that there were no significant variations examined in leaf area among grafted, ungrafted and self-grafted eggplants. In our study, significant differences were found in leaf areas among graft combinations. Regarding SPAD, the significantly highest SPAD value was observed when scion cultivars 'ERÜ 462' and '21 H-1-2' grafted onto '46 KB F1' rootstock and ungrafted plants of '33 H-3-1' (Figure 1). Al Rubaye (2017) observed that a SPAD value was significantly higher under both saline and non-saline conditions depending on the rootstock genotypes than ungrafted plants. Similar results were obtained by Adam (2018) on tomato genotypes, by Ulas (2019) on pepper genotypes and by Yücel (2020) on eggplant genotypes.

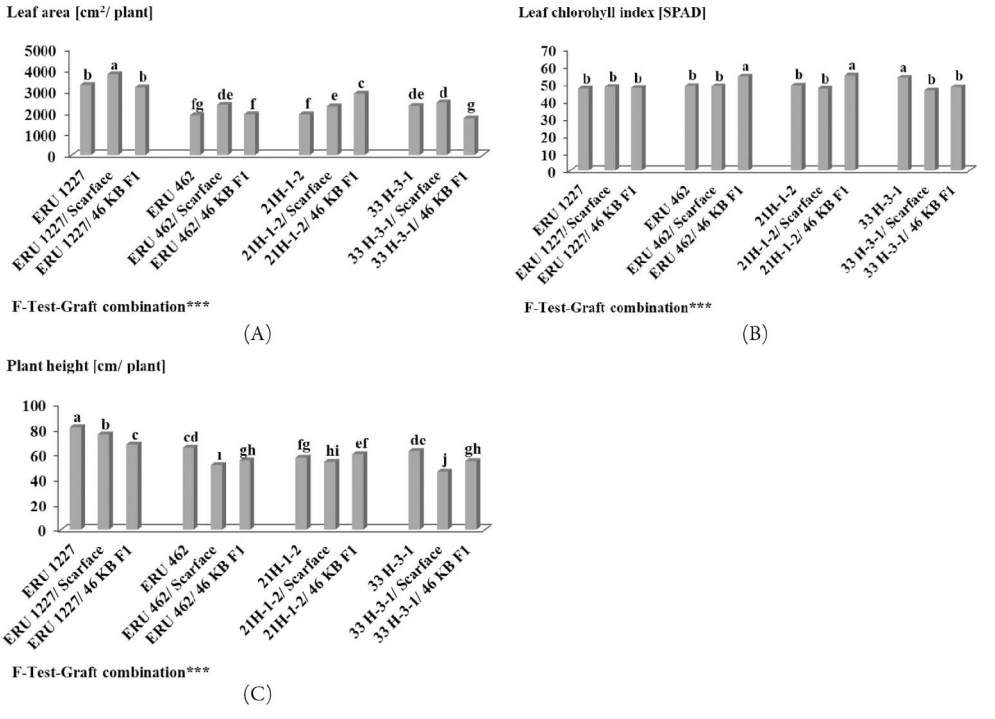


Figure 1. Influences of grafting on leaf area, leaf chlorophyll index (SPAD) and plant height of pepper plants. Values denoted by dissimilar letters are significantly different among genotypes within columns at $p < 0.05$ (T-Test). ns, non-significant. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$ (F-Test).

Concerning plant height, it was ranged from 49 to 82 cm and significant variations observed among grafted and control plants. Accordingly, ungrafted 'ERÜ 1227' recorded the highest plant height followed by 'ERÜ 1227' grafted onto 'Scarface' rootstock and

Table 2. Influences of grafting on stem diameters of rootstock and scion of pepper plants.

Graft Combination	Root. stem diameter (mm/plant)	Scion stem diameter (mm/plant)
ERÜ 1227	20.91^{bc}	17.30^{bc}
ERÜ 1227/Scarface	23.44^{a}	19.61^{a}
ERÜ 1227/46 KB F1	21.44^{ab}	17.22^{bc}
ERÜ 462	18.84^{c}	17.51^{b}
ERÜ 462/Scarface	18.42^{c}	16.77^{bc}
ERÜ 462/46 KB F1	19.22^{bc}	15.76^{c}
21H-1-2	18.82^{c}	17.08^{bc}
21H-1-2/Scarface	21.71^{ab}	16.73^{bc}
21H-1-2/46 KB F1	18.91^{c}	16.46^{bc}
33 H-3-1	19.38^{bc}	17.30^{bc}
33 H-3-1/Scarface	18.63^{c}	15.77^{c}
33 H-3-1/46 KB F1	18.33^{c}	16.08^{bc}
Minimum	18.33	15.76
Maximum	23.44	19.61
Grafted + ungrafted mean	19.84	16.97
Ungrafted mean	19.28	17.16
Grafted mean	20.28	17.06
F-Test	***	***

Notes: Values denoted by dissimilar letters are significantly different among genotypes within columns at $p < 0.05$ (T-Test). ns, non-significant. ***$p < 0.001$ (F-Test).

'ERÜ 1227' grafted onto '46 KB F1' rootstocks. The lowest plant height was found in the '33 H-3-1' grafted onto the 'Scarface' rootstocks (Figure 1). In Kombo and Sari (2019), it was stated that grafted watermelon produced considerably higher main stem length than control on field. Similar results were obtained by Ioannou et al. (2002) and Ulas et al. (2019) in watermelon, Bletsos (2006) and Yücel (2020) in eggplant, Colla et al. (2008) and Ulas (2019) in pepper, Khah (2011) in aubergine, Adam (2018) in tomato. However, in the present work, we observed that 'ERÜ 1227' grafted onto 'Scarface' rootstock showed a lower growth (plant height) than ungrafted 'ERÜ 1227' plants. Certainly, the results obtained from this study for plant height were higher than those obtained by Gómez et al. (2017), who examined Chitosan-PVA hydrogen using copper nanoparticles enhancing watermelon growth via grafting. The reason might be due to excessive rootstock and scion vigour examined.

In terms of rootstock stem diameter, 'ERÜ 1227' grafted onto 'Scarface' rootstock recorded the highest rootstock stem diameter followed by 'ERÜ 1227' grafted onto '46 KB F1' rootstock and '21 H-1-2' grafted onto 'Scarface' rootstock. This indicated that grafting has a positive effect on rootstock stem diameter since it increased the rootstock stem diameter of an ungrafted plant of 'ERÜ 1227' by almost 12% with 'Scarface'. Furthermore, scion cultivar '21 H-1-2' (18.82 mm/plant) increased its rootstock stem diameter when it was grafted with 'Scarface' (21.71 mm/plant) by almost 15.36%. The smallest rootstock stem diameter was noted in 'ERÜ 462' grafted onto 'Scarface' rootstocks, '21 H-1-2' grafted onto '46 KB F1' rootstocks, '33 H-3-1' grafted onto 'Scarface' and '46 KB F1' rootstocks and ungrafted control plants of 'ERÜ 462' and '21 H-1-2'. On the other hand, conflicting results in our study were also found when '33 H-3-1' was grafted onto '46 KB F1' and consequently, rootstock stem diameter was reduced by 5.4% and it was grafted onto 'Scarface' and consequently rootstock stem diameter reduced by 3.8% (Table 2). Adverse effects on scion and rootstock diameter have also been reported on pepper IL genotypes (Ulas 2019). The purpose might be due to a graft incompatibility among rootstock and scion varieties that could be regarding the reparation of the conducting vascular tissues (xylem and phloem) and the encouragement or impairment of the graft union growth because of modifications of the flow of water and nutrients (Mudge and Janick 2009).

Regarding scion stem diameter, 'ERÜ 1227' grafted onto 'Scarface' rootstock recorded the highest diameter. Diameter can be enhanced by grafting at an ungrafted plant of 'ERÜ 1227' by 13.35% with 'Scarface'. The smallest scion stem diameter was noted in 'ERÜ 462' grafted onto '46 KB F1' and '33 H-3-1' grafted onto 'Scarface'. On the other hand, conflicting results in our study were also found when the ungrafted control plant 'ERÜ 462' was grafted onto '46 KB F1' rootstock and consequently scion stem diameter by almost 9%. Ungrafted genotype '33 H-3-1' increased its scion stem diameter in different ratios when it was grafted with the rootstock genotype of 'Scarface' (8.9%) and '46 KB F1' (7.11%) (Table 2). Generally, grafted plants have a bigger stem diameter than control (Ioannou et al. 2002). The result of this research supports results on eggplant (Bletsos 2006) and watermelon (Kombo and Sari 2019) plants.

Root mineral composition and partitioning

Root macro- and microelement concentration and distribution of pepper plants are displayed in Table 3. A highly significant ($p < 0.001$) variations were observed in root

Table 3. Influences of grafting on root P, K, Ca, Mg, Mn and Zn concentration of pepper plants.

Graft Combination	P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm)	Zn (ppm)
ERÜ 1227	0.19^{ef}	1.78^{cd}	0.49^{g}	0.11^{e}	11.79^{ef}	24.07^{d}
ERÜ 1227/Scarface	0.23^{bc}	1.47^{g}	0.66^{c}	0.08^{f}	11.61^{ef}	10.71^{g}
ERÜ 1227/46 KB F1	0.17^{f}	1.68^{e}	0.63^{d}	0.14^{bc}	10.65^{f}	32.83^{a}
ERÜ 462	0.17^{f}	1.54^{f}	0.70^{b}	0.08^{f}	11.46^{ef}	24.98^{cd}
ERÜ 462/Scarface	0.23^{bc}	1.88^{b}	0.77^{a}	0.12^{de}	14.17^{bc}	11.76^{fg}
ERÜ 462/46 KB F1	0.20^{de}	1.76^{d}	0.76^{a}	0.16^{a}	12.54^{de}	26.46^{b}
21H-1-2	0.22^{cd}	1.58^{f}	0.51^{fg}	0.14^{bc}	15.36^{b}	31.21^{a}
21H-1-2/Scarface	0.25^{ab}	1.87^{b}	0.79^{a}	0.11^{e}	17.71^{a}	13.32^{ef}
21H-1-2/46 KB F1	0.20^{de}	1.79^{cd}	0.72^{b}	0.15^{ab}	14.85^{bc}	26.09^{bc}
33 H-3-1	0.27^{a}	1.66^{e}	0.54^{ef}	0.11^{e}	14.59^{bc}	24.50^{cd}
33 H-3-1/Scarface	0.22^{cd}	1.99^{a}	0.70^{b}	0.09^{f}	12.31^{e}	14.08^{e}
33 H-3-1/46 KB F1	0.26^{a}	1.83^{bc}	0.56^{e}	0.13^{cd}	13.74^{cd}	32.18^{a}
Minimum	0.17	1.47	0.49	0.08	10.65	10.71
Maximum	0.27	1.99	0.79	0.16	17.71	32.83
Grafted + ungrafted mean	0.22	1.74	0.65	0.12	13.40	22.68
Ungrafted mean	0.21	1.64	0.56	0.11	13.30	26.19
Grafted mean	0.22	1.78	0.69	0.12	13.44	20.92
F-Test	***	***	***	***	***	***

Notes: Values indicated by different letters are significantly different among genotypes within columns at $p < 0.05$ (T-Test). ns, non-significant. ***$p < 0.001$ (F-Test).

macro- and microelement concentrations between grafted pepper. Substantially, the highest P concentration was recorded by '33 H-3-1' grafted onto '46 KB F1' rootstock and ungrafted control plants of '33 H-3-1' and followed by '21 H-1-2' grafted onto 'Scarface' rootstock. Regarding K concentration, the significantly highest values were observed in inbred line '33 H-3-1' grafted onto 'Scarface' rootstock and followed by 'ERÜ 462' and '21 H-1-2' grafted onto 'Scarface' rootstock. Al Rubaye (2017) examined the effect of grafting on different pepper IL onto different rootstock genotypes under saline and non-saline conditions. He observed that K concentration in root tissue was significantly higher under both saline and non-saline conditions depending on the rootstock genotypes than ungrafted plants. In terms of Ca concentration, the significantly highest values were observed when both '21 H-1-2' and 'ERÜ 462' grafted onto 'Scarface' rootstock and 'ERÜ 462' grafted onto '46 KB F1' rootstock. It was followed by '33 H-3-1' grafted onto 'Scarface' rootstock and '21 H-1-2' grafted onto '46 KB F1' rootstock and ungrafted control plants of 'ERÜ 462'. Yamac (2017) stated no significant variations observed among grafted and control watermelon regarding root K concentration under both salinity and control conditions. Nevertheless, Ca concentration was significantly higher under both saline and non-saline conditions depending on the rootstock genotypes than ungrafted plants. Concerning Mg concentration, the significantly highest values was found by 'ERÜ 462' grafted onto '46 KB F1' and followed by '21 H-1-2' grafted onto '46 KB F1' rootstock. Relating to Mn concentration, the significantly highest values were found by '21 H-1-2' grafted onto 'Scarface' rootstock and followed by ungrafted control plants of '21 H-1-2'. In terms of Zn concentration, the significantly highest values were observed by both 'ERÜ 1227' and '33 H-3-1' grafted onto '46 KB F1' rootstock and at the ungrafted control plants of '21 H-1-2' and followed by 'ERÜ 462' grafted onto '46 KB F1' rootstock. The plant macronutrient uptake and/or utilisation efficiency might be increased by grafting that is essentially root characteristics of the rootstocks, which are additional robust than those of the extremely constructive planted genotypes (Savvas et al. 2010).

Nutrient uptakes

The amount of P, K, Ca, Mg, Mn and Zn taken by shoot and root is shown in Tables 4 and 5. Substantially considerable ($p < 0.001$) differences were found in P, K, Ca, Mg, Mn and Zn uptakes among grafted plants. The highest P uptake was observed at the ungrafted pepper plants of 21H-1-2 in shoot, whereas the least P uptake was achieved when the scion genotype of 21H-1-2 was grafted onto 46 KB F1 rootstock genotype. Looking at the root P uptake, the highest value was produced when ERÜ 1227 IL was grafted onto Scarface rootstock, though the least P uptake was produced at the ungrafted pepper plants of ERÜ 462. The research demonstrated that P level is correlated with the interaction between scion and rootstock between different grapevines (Gautier et al. 2020). The shoot and root K uptake differed consistent with the rootstock genotypes. Regarding shoot total K uptake, the minimum value observed at the 33 H-3-1/46 KB F1 graft combination, while the maximum value occurred ERÜ 1227/Scarface grafted plants. In terms of the total K uptake in the root, the least K uptake occurred in the ungrafted ERÜ 462 plants, while the highest K uptake occurred ERÜ 1227/46 KB F1-grafted plants. 33 H-3-1/46 KB F1 was the graft combination in which the lowest Ca was removed by the green parts of the shoot and ERÜ 462 in root. The highest Ca removal was realised from ERÜ 1227/Scarface by the shoot and ERÜ 1227/46 KB F1 by root (Table 4). ERÜ 1227/Scarface was the graft combination that the highest Mg and Mn in the shoot were eliminated. The highest Zn in shoot elimination was observed in 21H-1-2 plants. The highest uptake of Mg and Mn in shoot data was observed when the pepper scion of 33 H-3-1 was grafted onto rootstock genotype of 46 KB F1. The lowest Zn uptake in shoot values was recorded when the pepper scion of ERÜ 462 was grafted onto rootstock genotype of Scarface. The highest total Mg and Zn removals in root were obtained from ERÜ 1227/46 KB F1-grafted plants. This alteration in nutrient concentration among rootstocks might be

Table 4. Influences of grafting on P, K, Ca uptakes of pepper plants.

	P uptake (g/plant)		K uptake (g/plant)		Ca uptake (g/plant)	
Graft Combination	Shoot	Root	Shoot	Root	Shoot	Root
ERÜ 1227	17.78^{bc}	3.62^{e}	196.96^{bc}	33.95^{de}	74.77^{cd}	9.35^{fg}
ERÜ 1227/Scarface	22.32^{a}	5.87^{a}	255.92^{a}	37.53^{bc}	127.41^{a}	16.85^{b}
ERÜ 1227/46 KB F1	15.40^{d}	4.88^{bc}	184.29^{cd}	48.27^{a}	51.97^{gh}	18.10^{a}
ERÜ 462	13.28^{ef}	1.76^{f}	141.38^{fg}	15.94^{g}	57.41^{fg}	7.25^{g}
ERÜ 462/Scarface	13.32^{ef}	2.79^{ef}	120.46^{hi}	22.83^{fg}	66.62^{ef}	9.35^{fg}
ERÜ 462/46 KB F1	15.48^{d}	2.68^{ef}	173.69^{ef}	23.59^{fg}	75.52^{bc}	10.19^{ef}
21H-1-2	24.03^{a}	4.89^{bc}	203.45^{b}	35.13^{cd}	76.36^{bc}	11.34^{e}
21H-1-2/Scarface	18.79^{b}	5.02^{b}	175.49^{ef}	37.52^{bc}	89.44^{b}	15.85^{bc}
21H-1-2/46 KB F1	11.68^{g}	4.12^{de}	137.07^{fg}	36.85^{cd}	69.46^{de}	14.82^{cd}
33 H-3-1	16.83^{cd}	5.54^{ab}	130.63^{gh}	34.03^{de}	44.05^{hi}	11.07^{e}
33 H-3-1/Scarface	14.70^{e}	4.26^{cd}	129.50^{gh}	38.57^{b}	58.53^{fg}	13.57^{de}
33 H-3-1/46 KB F1	11.85^{fg}	3.60^{e}	97.68^{i}	25.36^{ef}	37.10^{i}	7.76^{g}
Minimum	11.68	1.76	97.68	15.94	37.10	7.25
Maximum	24.03	5.87	255.92	48.27	127.41	18.10
Grafted + ungrafted mean	16.51	4.05	164.29	32.41	70.94	12.20
Ungrafted mean	17.98	3.95	168.10	29.76	63.15	9.75
Grafted mean	15.44	4.15	159.26	33.82	72.00	13.31
F-Test	***	***	***	***	***	***

Notes: Values indicated by dissimilar letters are significantly different among genotypes within columns at $p < 0.05$ (T-Test). ns, non-significant. ***$p < 0.001$ (F-Test).

Table 5. Influences of grafting on Mg, Mn and Zn uptakes of pepper plants.

	Mg uptake (g/plant)		Mn uptake (g/plant)		Zn uptake (g/plant)	
Graft Combination	Shoot	Root	Shoot	Root	Shoot	Root
ERÜ 1227	9.57^{de}	2.10^{cd}	1459.85^{bc}	224.89^{de}	1952.24^{cd}	459.14^{de}
ERÜ 1227/Scarface	15.25^{a}	2.04^{de}	1659.64^{a}	296.44^{cd}	1004.06^{fg}	273.46^{fg}
ERÜ 1227/46 KB F1	9.62^{de}	4.02^{a}	1284.23^{cd}	306.01^{bc}	2694.05^{bc}	943.32^{a}
ERÜ 462	11.48^{cd}	0.83^{g}	946.60^{gh}	118.65^{g}	1928.73^{cd}	258.63^{gh}
ERÜ 462/Scarface	8.97^{ef}	1.46^{fg}	977.81^{fg}	172.05^{fg}	602.30^{h}	142.79^{h}
ERÜ 462/46 KB F1	9.82^{de}	2.14^{cd}	1144.46^{de}	168.06^{fg}	2742.01^{b}	354.61^{ef}
21H-1-2	14.42^{b}	3.11^{b}	1544.33^{b}	341.50^{b}	4226.08^{a}	693.90^{b}
21H-1-2/Scarface	12.40^{bc}	2.21^{bc}	1255.12^{de}	355.38^{a}	986.43^{fg}	267.29^{fg}
21H-1-2/46 KB F1	9.53^{de}	3.09^{b}	901.10^{hi}	305.69^{bc}	1400.21^{ef}	537.06^{bc}
33 H-3-1	7.95^{ef}	2.26^{bc}	998.82^{ef}	299.10^{cd}	1545.19^{de}	502.25^{cd}
33 H-3-1/Scarface	8.48^{ef}	1.74^{ef}	868.61^{ij}	238.61^{de}	737.98^{gh}	272.92^{fg}
33 H-3-1/46 KB F1	6.15^{g}	1.80^{ef}	711.18^{k}	190.44^{ef}	1606.08^{de}	446.01^{de}
Minimum	6.15	0.83	711.18	118.65	602.30	142.79
Maximum	15.25	4.02	1659.64	355.38	4226.08	943.32
Grafted + ungrafted mean	10.36	2.26	1151.61	249.35	1875.27	445.53
Ungrafted mean	10.86	2.07	1237.40	246.04	2413.06	478.48
Grafted mean	10.03	2.31	1100.27	254.08	1471.64	404.68
F-Test	***	***	***	***	***	***

Notes: Values denoted by different letters are significantly different between genotypes within columns at $p < 0.05$ (T-Test). ns, non-significant. ***$p < 0.001$ (F-Test).

recognised to varied nutrient absorption capacities between rootstocks from soil, as plants on strong rootstocks uptake nutrients supplementary vigorously compared to dwarfing and semi-dwarfing rootstocks (Kucukyumuk and Erdal 2011). The highest total Mn removals in root was observed from 21H-1-2/Scarface-grafted plants. The lowest total Mg and Mn removals in root were obtained from ERÜ 462 plants. The lowest total Zn removals in the root were obtained when pepper scion genotype of ERÜ 462 was grafted onto Scarface rootstock genotype (Table 5). Trace elements, such as Mg and Zn, are likewise essential for the growth and development of plants (Liu et al. 2003; Aihemaiti et al. 2019) and Mg is the greatest profuse divalent cations in plants (Tang and Luan 2017). Our results demonstrated four rootstocks explained various capabilities to adsorb Mg and Zn at grafted plants. Once an estimation is completed in terms of some nutrients detached by grafted pepper plants, it has been understood that P, K, Ca, Mg, Mn and Zn vary between 24.03-5.87, 255.92-48.27, 127.41-18.10, 15.25-4.02, 1659.64-355.38 and 4226.08-943.32 g per plant in the shoot and root, respectively.

Conclusions

Different pepper inbred lines grafting with pepper rootstocks and control plants performed significantly ($p < 0.001$) differently in terms of shoot-root fresh/dry biomasses, leaf chlorophyll index (SPAD), plant height, total leaf area, rootstock and scion stem diameter and root P, K, Ca, Mg, Mn and Zn composition. 'Scarface F1' responded better than other rootstocks and was suggested as the best one regarding shoot fresh and dry biomasses, leaf area, rootstock and scion stem diameter, and K and Mn compositions in root tissue in diverse grafted plants than control plants. The convincing rootstock, which may be described by effective nutrient uptake, performs the main function in the enhancement of growth performance and root nutrient contents.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Author's contributions

Firdes Ulas carried out the research study as a main researcher, writer of the introduction, materials and methods, results and discussion. Halit Yetisir is a methodologist at the research study. Abdullah Ulas carried out the research study, analysed and interpreted the data, and drafted the manuscript. Authors read and approved the final manuscript.

References

Adam, M.B. 2018. Genotypic differences in nitrogen efficiency and rootstock potential of some local Tomato varieties of Ghana and Turkey. [Master Thesis]. Erciyes University, Graduate School of Natural and Applied Sciences, Kayseri, Turkey, 109p.

Aihemaiti A, Jiang J, Gao Y, Meng Y, Zou Q, Yang M, Xu Y, Han S, Yan W, Tuerhong T. 2019. The effect of vanadium on essential element uptake of Setaria viridis' seedlings. Journal of Environmental Management. 237:399–407. doi:10.1016/j.jenvman.2019.02.054.

Al Rubaye, O.A.M. (2017). Effect of rootstocks with vigorous root system on plant growth of pepper (*Capsicum annuum* L.) inbred lines under salt stress. [Master Thesis]. Erciyes University, Graduate School of Natural and Applied Sciences, Kayseri, Turkey, 138p (in Turkish).

Al Rubaye OAM, Yetisir H, Ulas F, Ulas A. 2021. Enhancing salt stress tolerance of different pepper (*Capsicum annuum* L.) inbred line genotypes by rootstock with vigorous root system. Gesunde Pflanzen. 73(3):375–389. doi:10.1007/s10343-021-00564-4.

Bletsos F. 2006. Grafting and calcium cyanamide as alternatives to methyl bromide for greenhouse eggplant production. Scientia Horticulturae. 107:325–331. doi:10.1016/j.scienta.2005.09.003.

Colla G, Rouphael Y, Cardarelli M, Temperini O, Rea E, Salerno A, Pierandrei F. 2008. Influence of grafting on yield and fruit quality of pepper (*Capsicum annuum* L.) grown under greenhouse conditions. Acta Horticulturae. 782:359–364. doi:10.17660/ActaHortic.2008.782.45.

Dasgan HY, Balacheva E, Yetişir H, Yarsi G, Altuntas O, Akhoundnejad Y, Coban A. 2015. The effectiveness of grafting to improve salt tolerance of sensitive melon when the tolerant melon is use as rootstock. Procedia Environmental Sciences. 29:268.

Gautier AT, Cochetel N, Merlin I, Hevin C, Lauvergeat V, Vivin P, Mollier A, Ollat N, Cookson SJ. 2020. Scion genotypes exert long distance control over rootstock transcriptome responses to low phosphate in grafted grapevine. BMC Plant Biology. 20:367. doi:10.1186/s12870-020-02578-y.

Geleta, L. (1998). Genetic variability and association study for yield, quality and other traits of yield of hot pepper (Capsicum species). [M.Sc. thesis (Hort.)]. Hramaya University.

Gisbert C, Prohens J, Raigo´n MD, Stommel JR, Nuez F. 2011. Eggplant relatives as sources of variation for developing new rootstocks: effects of grafting on eggplant yield and fruit apparent quality and composition. Scientia Horticulturae. 128:14–22. doi:10.1016/j.scienta.2010.12.007.

Gómez HG, Godina FR, Ortiz HO, Mendoza AB, Torres VR, De la Fuente MC. 2017. Use of chitosan-PVA hydrogels with copper nanoparticles to improve the growth of grafted watermelon. Molecules. 22:1031. doi:10.3390/molecules22071031.

Grubben GJH. 1977. Tropical vegetables and their genetic sources. Rome, 197pp: IBPGR.

Ioannou N, Ioannou M, Hadjiparaskevas K. 2002. Evaluation of watermelon rootstocks for off-season production in heated greenhouses. Acta Horticulturae. 579:501–506. doi:10.17660/ActaHortic.2002.579.87.

Johkan M, Mitukuri K, Yamasaki S, Mori G, Oda M. 2009. Causes of defolation and low survival rate of grafted sweet pepper plants. Scientia Horticulturae. 119:103–107. doi:10.1016/j.scienta.2008.07.015.

Khah EM. 2011. Effect of grafting on growth, performance and yield of aubergine (*Solanum melongena* L.) in greenhouse and open-field. International Journal of Plant Production. 5(4):359–366.
Kombo MD, Sari N. 2019. Rootstock effects on seed yield and quality in watermelon. Horticulture, Environment, and Biotechnology. 60:303–312. doi:10.1007/s13580-019-00131-x.
Kucukyumuk Z, Erdal I. 2011. Rootstock and cultivar effect on mineral nutrition, seasonal nutrient variation and correlations among leaf, flower and fruit nutrient concentrations in apple trees. Bulgarian Journal of Agricultural Science. 17(5):633–641.
Kumar P, Edelstein M, Cardarelli M, Ferri E, Colla G. 2015. Grafting affects growth, yield, nutrient uptake, and partitioning under cadmium stress in tomato. HortScience. 50(11):1654–1661. doi:10.21273/HORTSCI.50.11.1654.
Kumar P, Khapte PS, Saxena A, Kumar P. 2019. Evaluation of gynoecious cucumber (*Cucumis sativus*) hybrids for early-summer greenhouse production in western Indian arid plains. The Indian Journal of Agricultural Sciences. 89:545–550.
Liu JG, Liang JS, Li KQ, Zhang ZJ, Yu BY, Lu XL, Yang JC, Zhu QS. 2003. Correlations between cadmium and mineral nutrients in absorption and accumulation in various genotypes of rice under cadmium stress. Chemosphere. 52:1467–1473. doi:10.1016/S0045-6535(03)00484-3.
Martínez-Ballesta MC, Alcaraz-López C, Muries B, Mota-Cadenas C, Carvajal M. 2010. Physiological aspects of rootstock–scion interactions. Scientia Horticulturae. 127:112–118. doi:10.1016/j.scienta.2010.08.002.
Mohamed FH, AbdEl-Hamed KE, Elwan MWM, Hussien MNE. 2014. Evaluation of different grafting methods and rootstocks in watermelon grown in Egypt. Scientia Horticulturae. 168:145–150. doi:10.1016/j.scienta.2014.01.029.
Mudge K, Janick J. 2009. A history of grafting. Horticulture Review. 35:437–493. doi:10.1002/9780470593776.ch9.
Penella C, Landi M, Guidi L, Nebauer SG, Pellegrini E, Bautista AS, Remorini D, Nali C, Lopez-Galarza S, Calatayud A. 2016. Salt-tolerant rootstock increases yield of pepper under salinity through maintenance of photosynthetic performance and sinks strength. Journal of Plant Physiology 193:1–11. doi:10.1016/j.jplph.2016.02.007.
Penella C, Nebauer SG, Bautista AS, Lopez-Galarza S, Calatayud A. 2014. Rootstock alleviates PEG-induced water stress in grafted pepper seedlings, physiological responsesJournal of Plant Physiology 171:842–851. doi:10.1016/j.jplph.2014.01.013.
Penella C, Nebauer SG, Quinones A, Bautista AS, Lopez-Galarza S, Calatayud A. 2015. Some rootstocks improve pepper tolerance to mild salinity throughionic regulation. Plant Science 230:12–22. doi:10.1016/j.plantsci.2014.10.007.
Pogonyi Á, PéK Z, Helyes L, Lugasi A. 2005. Effect of grafting on the tomato's yield, quality and main fruit components in spring forcing. Acta Alimentaria. 34:453–462. doi:10.1556/AAlim.34.2005.4.12.
Sarabi B, Bolandnazar S, Ghaderi N, Ghashghaie J. 2017. Genotypic differences in physiological and biochemical responses to salinity stress in melon (Cucumis melo L.) plants: Prospects for selection of salt tolerant landraces. Plant Physiology and Biochemistry. 119:294–311.
Savvas D, Colla G, Rouphael Y, Schwarz D. 2010. Amelioration of heavy metal and nutrient stress in fruit vegetables by grafting. Scientia Horticulturae. 127:156–161. doi:10.1016/j.scienta.2010.09.011.
Singh H, Kumar P, Chaudhari S, Edelstein M. 2017. Tomato grafting: a global perspective. HortScience. 52:1328–1336. doi:10.21273/HORTSCI11996-17.
Soltan MM, ElAidy FA, Scheerens JC, Kleinhenz MD. 2017. Grafting, scion and rootstock effects on survival rate, vegetative growth and fruit yield of high tunnel-grown grafted pepper (*Capsicum annuum* L.) plants. Advances in Crop Science and Technology. 5:312.
Tang RJ, Luan S. 2017. Regulation of calcium and magnesium homeostasis in plants: from transporters to signaling network. Current Opinion in Plant Biology. 39:97–105. doi:10.1016/j.pbi.2017.06.009.
Ulas A, Aydın A, Ulas F, Yetisir H, Miano TF. 2020a. Cucurbita rootstocks improve salt tolerance of melon scions by inducing physiological, biochemical and nutritional responses. Horticulturae. 6:66. doi:10.3390/horticulturae6040066.

Ulas A, Doganci E, Ulas F, Yetisir H. 2019a. Root-growth characteristics contributing to genotypic variation in nitrogen efficiency of bottle gourd and rootstock potential for watermelon. Plants. 8:77. doi:10.3390/plants8030077.

Ulas, F. (2019). Effects of rootstocks with vigorous root system on plant growth, seed yield and quality of pepper (*Capsicum annuum* L.) inbred lines. [PhD Thesis (Unpublished)]. Erciyes University, Graduate School of Natural and Applied Sciences, Kayseri, Turkey, 228p, (in Turkish).

Ulas F. 2021a. Response of different rootstocks on vegetative growth, fruit and seed yield of eggplant (*Solanum melongena* L.). Genetika. 53(2):593–608. doi:10.2298/GENSR2102593U.

Ulas F. 2021b. Effects of grafting on growth, root morphology and leaf physiology of pepino (*Solanum muricatum* Ait.) as affected by salt stress under hydroponic conditions. International Journal of Agriculture Environment and Food Sciences. 5(2):203–212.

Ulas F, Aydin A, Ulas A, Yetisir H. 2021a. The efficacy of grafting on alkali stressed watermelon cultivars under hydroponic conditions. Gesunde Pflanzen. 73:345–357. doi:10.1007/s10343-021-00559-1.

Ulas F, Aydın A, Ulas A, Yetişir H. 2019b. Grafting for sustainable growth performance of melon (*Cucumis melo*) under salt stressed hydroponic condition. European Journal of Sustainable Development. 8(1):201–210.

Ulas F, Fricke A, Stützel H. 2019c. Leaf physiological and root morphological parameters of grafted tomato plants under drought stress conditions. Fresenius Environmental Bulletin. 28(4A):3423–3434.

Ulas F, Yetisir H, Ulas A. 2020b. Effects of grafting on fruit yield and leaf nutrient contents of pepper (*Capsicum annuum* L.) inbred lines. Genetika. 52(3):1041–1053. doi:10.2298/GENSR2003041U.

Ulas F, Yetisir H, Ulas A. 2021b. Root-growth characteristics contributing to nitrogen efficiency of reciprocally grafted potatoes (*Solanum tuberosum* L.) under hydroponic conditions. Gesunde Pflanzen. 73(4):417–425. doi:10.1007/s10343-021-00560-8.

Yamac, M. (2017). Rootstock potential of some selected bottle gourd (*Lagenaria Siceraria*) genotypes from Turkish germplasm for watermelon under saline conditions. [Master Thesis (Unpublished)]. Erciyes University, Graduate School of Natural and Applied Sciences, Kayseri, Turkey, 95p (in Turkish).

Yetisir H, Sari N. 2019. Effects of bottle gourd (*Lagenaria siceraria*) rootstocks on plant nutrient content of watermelon [*Citrullus lanatus* (Thunb.). Mats. & Nak.] leaf and nitrogen use efficiency. Derim. 36(1):24–32. doi:10.16882/derim.2019.443162.

Yücel, Y.C. (2020). Agronomical, physiological and morphological characterization of some selected eggplant (*Solanum melongena* L.) genotypes for nitrogen efficiency and rootstock potential. [Master Thesis (Unpublished)]. Erciyes University, Graduate School of Natural and Applied Sciences, Kayseri, Turkey, 186p, (in Turkish).