Erwerbs-Obstbau (2023) 65:729–743
https://doi.org/10.1007/s10341-022-00685-8

ORIGINAL ARTICLE / ORIGINALBEITRAG

Hawthorn Rootstock (*Crataegus* spp.) Affects Scion Nutrition and Nutrient Composition of Fruit of Some Selected Quince (*Cydonia oblonga* Mill.) Genotypes

Mitra Mirabdulbaghi[1] · Hassan Akbari[2] · Hamid Abdollahi[1] · Reza Zarghami[3]

Received: 20 February 2022 / Accepted: 26 April 2022 / Published online: 31 May 2022

Abstract

Rootstocks are an essential component in modern fruit production due to their ability to adapt scion cultivars to diverse environmental conditions and cultural practices. According to the present study, the effect of rootstock as well as the effect of cultivar and the rootstock/cultivar combination on mineral concentrations in flowers and leaves were significant. However, the effect of rootstock for nutrient composition of fruits (at harvest time and after 3 months of cold storage at 0 °C), with the exception of K-fruit (at harvest time and after 3 months of cold storage at 0 °C), was not significant. There were positive correlations between the cultivar/hawthorn combination on the one hand, and flower-Fe, leaf-Zn, and leaf-B on the other, while negative correlations were found between fruit-B with flower-B and between fruit Zn with flower Zn. There was a steady yet genotype-dependent decrease in fruit-N and fruit-K content over storage time in all genotypes or cultivar/rootstock combinations tested. The trend in terms of changes for all other mineral nutrition in fruits, at harvest time and 3 months after cold storage, differed between genotypes. This study suggests that the higher mineral nutrient uptake in the studied cultivars or genotypes favored by hawthorn (*Crataegus* spp.) rootstocks makes them suitable for heavy and calcareous soils.

Keywords Rootstock/cultivar combination · Local cultivars · Promising genotypes · Soil lime · Tissue analyses

Introduction

Rootstocks are chosen according to their effect on the graft, together with precocity, production, infection resistance, their compatibility with the graft cultivar (Zarrouk et al. 2006), versatility to a broad spectrum of soil varieties and climes (Giorgi et al. 2005), as well as fruit status, including size, color, and resolvable solid contentment (Koepke and Dhingra 2013).

Tissue inorganic examination is a beneficial instrument for the evaluation of the nutritive value of crops (Wang et al. 2015), and the use of resistant rootstocks would prohibit nutritive defects that create excessive economic loss for agriculturalists (Jiménez et al. 2007, 2008). Furthermore, rootstocks may raise internal and external fruit quality, harvest, and postharvest values (Öztürk and Öztürk 2014; Milošević et al. 2015; Özturk et al. 2017).

Hawthorn (*Crataegus* spp.) is one of the largest genera in the predominantly woody Rosacea (Evans and Campbell 2002; Phipps et al. 2003; Campbell et al. 2007). Research on natural plant compounds has demonstrated their phar-

✉ Mitra Mirabdulbaghi
m.mirabdulbaghi@areeo.ac.ir

Hassan Akbari
ak.hassan@yahoo.com

Hamid Abdollahi
habdollahi@yahoo.it

Reza Zarghami
rezazarghami2001@yahoo.com

[1] Horticultural Science Research Institute, Ag. Research Education Extension Org, Temperate Fruits Research Center, Mardabad, Karaj, Iran

[2] Horticultural Science Research Institute, Ag. Research Education Extension Org., Agriculture and Natural Research Center of Isfahan, Agricultural Research, Education and Extension Organization (AREEO), Isfahan, Iran

[3] Department of Tissue and Cell Culture, Agricultural Biotechnology Research Institute of Iran (ABRII), Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran

maceutical properties (Edwards et al. 2012; Nazhand et al. 2020). The species is one of the most important edible and popular medicinal plants, with approximately 280 species found in Europe, North Africa, West Asia, and North America (Edwards et al. 2012; Nazhand et al. 2020). However, the importance of *Crataegus* in terms of environment and agrosystem has also been reported (Rahmani et al. 2015; Brown et al. 2016). Some *Crataegus* species are resistant to lime-induced Fe chlorosis and can be cultivated in alkaline calcareous soils (Betancourt-Olvera et al. 2018; Valipour et al. 2018).

It is known that some species of *Crataegus*, selected as a rootstock for quince, reduce the severity of lime-induced Fe chlorosis under farming in basic calcareous soils (Betancourt-Olvera et al. 2018; Valipour et al. 2018). Calcareous soils contain high levels of calcium carbonate ($CaCO_3$), which influences soil characteristics linked to plant growing mostly via the accessibility of plant nutrients (Elgabaly 1973). Such soils contribute to drastic growth decrease, reduced yield, nutrient shortage, and leaf chlorosis (Huang et al. 2012). They are common in the arid areas of the earth (FAO 2016) occupying >30% of the earth's surface, and their $CaCO_3$ content varies from just detectable up to 95% (Marschner 1995).

Iran is located in the arid and semi-arid zone of the world and, like some other countries in the Near East (like Pakistan, Indus Basin, Iraq, Jordan, Lebanon, and Egypt), as well as Mediterranean countries, (such as Portugal, Spain, Italy, and Greece), a sizeable part of the cultivated lands consist of calcareous soils (Faostat 1977). Quince trees (*Cydoniaoblonga* Mill.) are extremely susceptible to lime-induced iron chlorosis. When growing on calcareous soils, they exhibit prototypical expressions of yellowing in juvenile leaves that are generally more severe in summer (Alcántara et al. 2012). In addition, hawthorn (*Crataegus* spp.) is well known to be one of the most Fe insufficiency-resistant pome fruits, showing no or only slight manifestations of Fe insufficiency when grown in soils with high quantities of bicarbonate. Consequently, hawthorn rootstocks have been recommended for quince production under calcareous soil conditions as they are capable of alleviating the severity of Fe chlorosis (Valipour et al. 2018), providing good fruit quality, easing maintenance and harvesting, and decreasing the size of the tree compared to those grown from seedlings. Although using hawthorn as a rootstock for quince lessens the severity of lime-induced Fe chlorosis under farming in basic calcareous soils, one should note, however, that no articles have been published as yet comparing the nutritional status of hawthorn in comparison to quince.

The most universal diagnostic apparatus for orchards is leaf examination, which is generally performed approximately 120 days after full bloom (Bergmann 1992). However, the efficiency of this approach is limited as any nutrition input would be very unlikely to result in yield growth at this time of the growing season. For an accurate estimation of the nutrient status of fruit crops especially in high lime soils, several researchers have suggested flower analysis for the diagnosis of nutritional status in different fruit species (Sanz and Montañés 1995; Sanz et al. 1998; Vemmos 1999; Bouranis et al. 1999; Toselli et al. 2000; Abadía et al. 2000; Igartua et al. 2000; Bouranis et al. 2001; Pestana et al. 2001).

Against the above background, the primary objective of the present study was to assess the influence of rootstocks on the mineral nutrient uptake of flowers (at full bloom), leaves (90 days after full bloom), and fruits (at harvest time and 3 months following cold storage at 0 °C) of local cultivars, i.e., 'Vidoja,' 'Isfahan,' and 'Behta,' as well as promising quince genotypes NB2 and KVD2, grafted on quince seedling (*Cydoniaoblonga)* and hawthorn (*Crataegus* spp.) rootstock and grown in a calcareous soil in the city of Najafabad in Isfahan province, Iran, over 3 years (2018, 2019, and 2020). The second objective was to study the feasibility of using the mineral analysis of flowers as a prognostic tool for nutritional deficiencies.

Materials and Methods

Growing Conditions and Plant Materials The experimental orchard was located in the city of Najafabad in Isfahan province, Iran (32°50′43″N; 51°36′00″E; altitude 1570 m), with a temperate of 5.9–38.0 °C, a relatively dry climate (34% relative humidity), and average annual rainfall of 120 mm (Fig. 1), mostly in cold seasons (The Statistical Center of Iran [SCI] 2011). The data for three parameters relating to average temperature (0 °C), crop year rainfall (mm) and relative humidity (%) for the 3-year study period (2018–2020) were obtained from synoptic meteorological stations in Iran (Figs. 2, 3 and 4). The soil in the experimental area consisted of silt (56%), loam (14%), and high lime (28%), with slight saline (2.08%), a pH of 7.67, soil available phosphorus (P) (18.50 ppm), soil available potassium (K) (186.23 ppm), and low organic matter (0.23%), which were obtained based on the results of soil samples taken from a depth of 30 cm. Hawthorn (*Crataegus* spp.) and quince seedling (*C. oblonga*) were used as rootstocks, which were budded with local cultivars 'Vidoja,' 'Isfahan,' and 'Behta,' as well as promising quince genotypes 'NB2' and 'KVD2' in 2012, and then grown in the nursery of the Cold and Temperate Fruits Research Center. In winter 2013, the plant material was moved to the experimental orchard.

Culture Treatments A computerized drip irrigation system was applied once a week for 2 h each time from May to October using a class-A pan according to the regional

Fig. 1 Najafabad region of Isfahan Province, Iran

recommendations. Each treatment (genotypes or cultivar/rootstock combinations) received the same amount of water in each growing season. All trees were also fertilized with essential minerals using the same fertigation method. Weed, disease, and pest control were carried out using the protocols commonly used for commercial production.

Tissue Sampling and Chemical Analysis In the present work, flowers, leaves, and fruits were sampled from 360 (three replications *12 trees per replicate*10 rootstock/cultivar combinations) planted trees in the experimental orchard in Najafabad city, Isfahan province, Iran. Plant samples were analyzed in laboratories of the Temperate and Cold Fruit Research Center and the Agricultural Biotechnology Research Institute.

Flower Sampling and Chemical Analysis In April of each of the studied years (2018, 2019, and 2020), at full bloom stage (more than 75% of flowers open), about 30 flowers were randomly collected from the distal part of the branches (in all orientations) of each tree. Before analysis, samples were washed thoroughly under running tap water, followed by dilute acid (0.2 N HCl) and distilled water to remove surface residues. The flowers were then kept at 65 ± 5 °C until they

Najafabad/Isfahan	
Long-term average (mm)	99.5
The average of a full year(mm)	143
Rain fall changing to previous year (%)	15
Changes to average	-28
Start of statistical course	2003
More>	

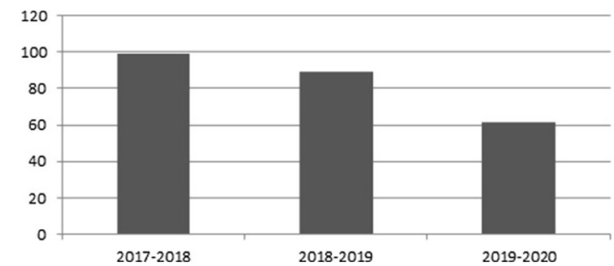

Fig. 2 Crop year rainfall in the Najafabad region of Isfahan Province, Iran, for the 3-year period 2018–2020

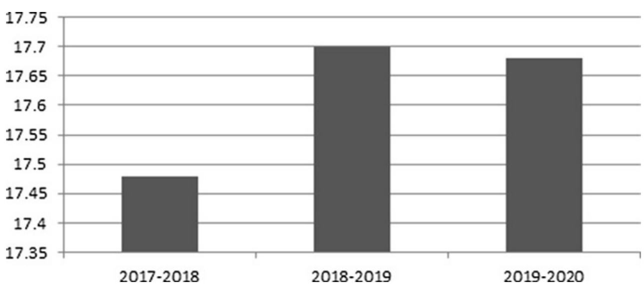

Fig. 3 Mean comparison of average temperature in the Najafabad region of Isfahan Province, Iran, for the 3-year period 2018–2020

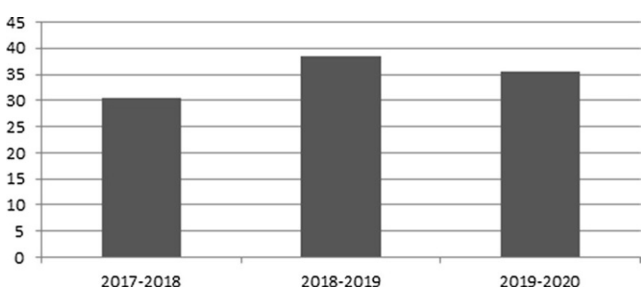

Fig. 4 Mean comparison of relative humidity in the Najafabad region of Isfahan Province, Iran, for the 3-year period 2018–2020

were fully dried and ground for nutrient analysis. Nutrient content was determined according to standard procedures described in {Association of Official Analytical Chemists (AOAC) 2016}.

Leaf Sampling and Chemical Analysis Leaf mineral analyses were carried out in July of each of the studied years (2018, 2019 and 2020). Five leaves were sampled from the middle part of 1-year-old and non-bearing shoots (measuring 30–50 cm in length) of disease-free and healthy-looking rootstock/cultivar combinations at 90 days after full bloom. Leaves were washed thoroughly with distilled water and oven dried at 70 °C with air circulation until attaining constant weight. The samples were then finely ground in a Wiley-type mill with a 20-mesh sieve prior to chemical analysis.

Fruit Sampling and Chemical Analysis Generally, harvest begins when fruits change their base color from deep green to lighter green (Kader 1996). Quince fruits were sampled at commercial harvest maturity in the Najafabad region of Isfahan Province, Iran. Due to drought stress and fruit drop, fruit samples were only taken in 2019. The harvested fruits were immediately transferred to the postharvest lab and graded to ensure that fruits were of uniform size and free of blemishes. The graded fruits were then divided into five major groups, each containing 30 fruits packed in boxes, and three replicates of 10 fruits per tree were assessed for mineral concentration at harvest and about 3 months following storage at 0 °C with 80–90% relative humidity. The wedges of fresh fruit were oven dried at 70 °C, ground to a powder, and approximately 0.3 g of each sample were digested in HNO_3/$HCLO_4$ and then submitted to chemical analysis.

Measurement of Mineral Nutrition Nutrient content was determined according to standard procedures described in {Association of Official Analytical Chemists (AOAC) 2016}. The nitrogen content was estimated using the Kjeldahl method (Jones 2001). Calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), and boron (B) were determined using atomic absorption spectrophotometry (Jones 2001). Phosphorous (P) was analyzed using the molybdovanadate method (Chapman and. Pratt 1978). Potassium (K) was also analyzed by flame photometry as described by Jones (2001).

Thresholds for Possible Deficiencies Cited in the Literature Critical thresholds were used as references in interpreting flower (Sanz and Montañés 1995), leaf (Bergmann 1992), and pome fruit nutrient concentrations (Bergmann 1992) of studied quince rootstock/cultivar combinations (Table 1).

Statistical Analyses The experiments were conducted in a factorial arrangement based on a randomized complete block design (RCBD) with three replications and 12 trees per replicate and 10 rootstock/cultivar combinations to evaluate the effect of different factors tested. Data analyses were performed using SAS and SPSS statistical software. The least significant differences (LSD) test was used to compare the differences between mean values at a 5% level. Pearson correlation coefficient was determined to

Table 1 Critical thresholds as references (Bergmann 1992; Sanz and Montañés 1995) in interpreting flower, leaf, and fruit nutrient concentrations of studied quince rootstock/cultivar combinations

Macronutrients (%)	Critical level		
	Flower	Leaf	Fruit
N	2.95	2.50	0.40
P	0.40	0.24	Min. 0.09
K	1.64	1.30	1.06
Mg	0.59	0.26	>0.030
Ca	0.22	1.75	<0.035
Micronutrients (mg/kg)			
B	–	36	15
Fe	292.8	>50	14% of dry weight
Zn	55.6	33	

N nitrogen, *P* phosphorus, *K* potassium, *Mg* magnesium, *Ca* calcium, *B* boron, *Fe* iron, *Zn* zinc

identify a possible relationship between mineral content ($p<0.05$). Discriminant analysis was used to obtain insight into the data structure, identifying possible grouping patterns and exploring the relationships in mineral nutrition content in flower, leaf, and fruit among rootstocks and genotypes or cultivar.

Results and Discussion

Combined Analysis of Variance for Leaf and Flower Nutrition Concentration The authors results indicated that rootstock, year, and genotypes or cultivar alone (except for P in leaves) or in combination exhibited significant effects on mineral content in both leaf and flower samples tested (Table 2).

The effect of rootstock and cultivar on nutrient content of quince genotypes can be explained by the divergent genetic backgrounds leading to different nutrient uptake capacity (Donnini et al. 2009; Küçükyumuk and Erdal 2009; Moradi et al. 2017; Nazli and Erdal 2019).

Rootstock and Genotypes or Cultivar Effects on Leaf Nutrient Content Of all mineral elements studied, only leaf-P content was not affected by rootstocks, cultivars, and their combinations. Mean values of all studied rootstock/scion combinations over 3 years (2018, 2019, and 2020) showed the highest leaf-K, -Mg, -Fe, and -B amounts in hawthorn rootstock compared to quince rootstock. However, the differences between the rootstock/scion combinations were statistically different. The 'KVD2' when grafted on hawthorn showed the highest value of leaf-K (1.14%), leaf-Fe (62.70 ppm), and leaf-B (14.35 ppm) in 2020. The highest value of leaf-Mg (3.21%) was also obtained in the 'Behta'/hawthorn combination in 2018 (Table 3). The highest leaf-Ca and leaf-Zn, on the other hand, were observed in quince seedling rootstocks and the

Table 2 Combined analysis of variance (ANOVA) for leaf and flower mineral content of hawthorn (*Crataegus* spp.) and quince seedling (*Cydonia oblonga*) rootstocks grafted on a number of selected quince (*Cydonia oblonga* Mill.) genotypes or cultivars in the 3 years studied (2018, 2019, and 2020)

Source	DF	Mean square															
		Leaf nutrition concentration								Flower nutrition Concentration							
		N	K	P	Ca	Mg	B	Zn	Fe	N	K	P	Ca	Mg	B	Zn	Fe
		%					ppm			%					ppm		
Rootstock	1	3.25**	0.05**	0.002^{ns}	0.98**	1.54**	32.23**	1292.87**	153.00**	1.03**	3.83**	0.33**	0.12**	0.22**	5.42**	17.63**	1820.10**
Year	2	26.91**	3.85**	0.001^{ns}	3.16**	4.03**	188.32**	2398.74**	3412.96**	7.15**	0.001**	0.26**	1.19**	0.12**	435.65**	510.39**	8195.25**
Rootstock*year	2	3.25**	0.02**	0.002^{ns}	0.15**	1.51**	3.96**	8.12**	868.67**	0.15**	0.01**	0.17**	0.05**	0.06**	77.32**1	214.68**	513.22**
Block (rootstoc*year)	12	26.91**	0.01**	0.012**	0.01**	0.02**	0.01**	0.01**	0.01**	0.01**	0.02**	0.01**	0.01**	0.02**	0.95**	0.95**	0.95**
Cultvr	4	0.99**	0.02**	0.0001^{ns}	0.14**	0.45**	6.31**	134.56**	147.89**	1.46**	0.02**	0.05**	0.21**	0.15**	21.46**5	8.05**	587.89**
Cultvr*rootstock	4	0.01**	0.02**	0.001^{ns}	0.83**	0.87**	6.79**	218.98**	339.89**	1.17**	0.02**	0.07**	0.19**	0.04**	35.98**	45.59**	143.22**
Cultvr*year	8	1.47**	0.02**	0.001^{ns}	0.56**	1.28**	22.44**	91.29**	70.67**	0.61**	0.13**	0.15**	0.22**	0.07**	11.71**	133.99**	1466.13**
Cultvr*rootstoc*year	8	0.77**	0.03**	0.001^{ns}	0.28**	1.05**	36.62**	201.41**	579.26**	0.43**	3.83**	0.15**	0.37**	0.03**	23.93**	173.94**	379.59**
CV (%)		0.97	5.14	8.56	2.37	3.31	0.44	0.08	0.13	1.11	3.96	7.53	5.75	7.65	9.20	3.18	2.08

N nitrogen, *K* potassium, *P* phosphorus, *Ca* calcium, *Mg* magnesium, *B* boron, *Zn* zinc, *Fe* iron, *ppm* parts per million

*,** Means are significantly different at 0.05 and 0.01 levels, respectively. ns: Not significant

Table 3 Effect of rootstock on leaf and flower mineral content on a number of selected quince (*Cydonia oblonga* Mill.) genotypes or cultivars in 3 studied years (2018, 2019, and 2020)

Rootstocks	Studied	Leaves								Flowers							
		N	K	P	Ca	**Mg**	B	Zn	Fe	N	**K**	**P**	**Ca**	**Mg**	**B**	**Zn**	**Fe**
	Years	%					ppm			%					ppm		
–		**Vidoja**															
Quince (*Cydonia oblonga* Mill)	2018	4.94	0.62	0.38	2.32	1.48	9.5	77.66	40.57	1.91	1.36	0.17	0.77	0.34	2.08	16.86	9.49
	2019	1.27	0.36	0.38	1.52	0.76	1.9	38.42	14.16	1.46	0.31	0.38	0.84	0.09	2.57	17	20.71
	2020	1.32	1.04	0.38	1.44	0.72	6.94	41.2	20.9	1.4	0.71	0.4	0.38	0.23	9.12	12.1	51.49
Mean of 3 years		*2.51*	*0.67*	*0.38*	*1.76*	*0.99*	*6.11*	*52.43*	*25.21*	*1.59*	*0.79*	*0.32*	*0.66*	*0.22*	*4.59*	*15.32*	*27.23*
Hawthorn (*Crataegus* spp.)	2018	3.33	0.48	0.38	1.75	0.72	11.97	45.13	23.94	2.01	1.15	0.47	0.9	0.41	3.2	17.88	10.01
	2019	1.49	0.42	0.38	0.8	0.92	4.37	36.79	17.1	1.53	0.61	0.5	0.48	0.32	5.69	18.31	38.85
	2020	1.51	1.08	0.4	0.91	0.78	9.6	31.07	62.51	1.48	0.75	0.43	0.46	0.18	6.84	24.53	78.47
Mean of 3 years		*2.11*	*0.66*	*0.39*	*1.15*	*0.81*	*8.65*	*37.66*	*34.52*	*1.67*	*0.84*	*0.47*	*0.61*	*0.30*	*5.24*	*20.24*	*42.44*
–		**NB2**															
Quince (*Cydonia oblonga* Mill)	2018	4.44	0.67	0.38	2.05	0.74	8.93	58.37	31.54	2.05	1.32	0.21	0.63	0.33	3.65	20.96	9.13
	2019	1.29	0.3	0.38	2.17	0.28	2.19	49.05	15.44	1.62	0.56	0.41	0.3	0.59	4.18	19.62	28.69
	2020	1.3	0.88	0.39	0.91	1.33	8.46	39.24	38.95	1.59	0.68	0.38	0.91	0.23	10.83	10.79	17.1
Mean of 3 years		*2.34*	*0.62*	*0.38*	*1.71*	*0.78*	*6.53*	*48.89*	*28.64*	*1.75*	*0.85*	*0.33*	*0.61*	*0.38*	*6.22*	*17.12*	*18.31*
Hawthorn (*Crataegus* spp.)	2018	3.24	0.53	0.38	1.29	0.49	9.17	40.22	18.57	2.22	1.08	0.57	1.15	0.71	2.06	14.94	7.36
	2019	1.22	0.38	0.38	1.6	0.16	9.5	31.07	13.73	1.84	0.65	0.42	0.38	0.6	8.84	21.91	52.82
	2020	1.24	0.97	0.4	0.99	1.67	1.71	31.07	38.76	1.77	0.74	0.38	0.3	0.28	9.6	11.45	15.77
Mean of 3 years		*2.23*	*0.46*	*0.38*	*1.45*	*0.33*	*9.34*	*35.65*	*16.15*	*2.03*	*0.87*	*0.50*	*0.77*	*0.66*	*5.45*	*18.43*	*30.09*
–		**Behta**															
Quince (*Cydonia oblonga* Mill)	2018	2.8	0.48	0.38	1.44	0.51	8.74	46.11	19.14	2.78	1.03	0.72	1.32	0.27	5.2	15.35	5.8
	2019	1.2	0.34	0.48	1.33	0.65	2.33	32.54	15.15	1.93	0.8	0.41	0.68	0.55	4.37	31.07	40
	2020	1.16	1.03	0.38	1.82	0.31	8.55	44.47	25.37	2.04	0.82	0.38	0.3	0.28	20.62	8.83	16.44

Table 3 (Continued)

Rootstocks	Studied Years	Leaves N %	K	P	Ca	Mg	B ppm	Zn	Fe	Flowers N %	K	P	Ca	Mg	B ppm	Zn	Fe
Mean of 3 years		*1.72*	*0.62*	*0.41*	*1.53*	*0.49*	*6.54*	*41.04*	*19.89*	*2.25*	*0.88*	*0.50*	*0.77*	*0.37*	*10.06*	*18.42*	*20.75*
Hawthorn (*Crataegus* spp.)	2018	3.08	0.51	0.38	1.63	3.21	9.17	46.92	20.52	2.8	1.59	0.41	0.77	0.74	4.14	28.61	11.28
	2019	1.51	0.34	0.37	1.18	0.37	8.5	28.45	14.06	2.06	0.44	0.58	0.57	0.62	4.4	11.45	34.46
	2020	1.58	1.14	0.39	0.99	0.7	8.74	27.8	41.61	1.99	0.65	0.38	0.53	0.37	7.6	11.45	19.38
Mean of 3 years		*2.06*	*0.66*	*0.38*	*1.27*	*1.43*	*8.80*	*34.39*	*25.40*	*2.28*	*0.89*	*0.46*	*0.62*	*0.58*	*5.38*	*17.17*	*21.71*
–	**KVD2**																
Quince (*Cydonia oblonga* Mill)	2018	3.02	0.45	0.38	1.82	0.46	11	46.27	32.21	2.77	1.09	0.27	0.63	0.26	1.19	36.87	7.57
	2019	1.49	0.33	0.38	1.6	0.42	3.99	44.96	19.29	0.97	0.43	0.4	0.38	0.37	4.56	13.08	34.39
	2020	2	1	0.38	1.06	0.89	6.56	31.39	18.81	1.09	0.69	0.39	0.15	0.37	15.2	8.18	22.33
Mean of 3 years		*2.17*	*0.59*	*0.38*	*1.49*	*0.59*	*7.18*	*40.87*	*23.44*	*1.61*	*0.74*	*0.35*	*0.39*	*0.33*	*6.98*	*19.38*	*21.43*
Hawthorn (*Crataegus* spp.)	2018	2.71	0.54	0.38	1.18	1.25	9.5	51.83	26.74	2.58	1.25	0.17	0.37	0.24	4.73	22.25	4.78
	2019	1.35	0.24	0.37	1.82	0.18	1.38	34.01	14.82	1.26	0.56	1.41	1.2	0.28	3.85	14.72	81.31
	2020	1.44	1.14	0.39	0.68	0.75	14.4	34.34	62.7	1.34	0.72	0.38	0.23	0.32	7.13	15.37	18.53
Mean of 3 years		*1.83*	*0.64*	*0.38*	*1.23*	*0.73*	*8.43*	*40.06*	*34.75*	*1.73*	*0.84*	*0.65*	*0.60*	*0.28*	*5.24*	*17.45*	*34.87*
–	**Isfahan**																
Quince (*Cydonia oblonga* Mill)	2018	3.42	0.45	0.38	1.67	0.74	9.55	44.15	25.98	3.21	1.34	0.36	0.24	0.3	3.71	15.14	8.09
	2019	3.22	0.38	0.39	0.69	0.65	9.03	41.93	19.98	2.53	0.63	0.42	0.3	0.42	1.71	20.6	31.64
	2020	3	1	0.41	0.68	1.16	6.65	33.68	44.46	2.22	0.65	0.4	0.23	0.28	6.56	12.75	37.15
Mean of 3 years		*3.21*	*0.61*	*0.39*	*1.01*	*0.85*	*8.41*	*39.92*	*30.14*	*2.65*	*0.87*	*0.39*	*0.26*	*0.33*	*3.99*	*16.16*	*25.63*
Hawthorn (*Crataegus* spp.)	2018	2.44	0.83	0.38	1.86	1.78	11.2	53.96	33.96	2.14	1.18	0.44	1.05	0.39	3.04	28.61	11.08
	2019	1.26	0.3	0.38	1.67	0.14	5.8	32.7	14.63	1.41	0.6	0.55	0.42	0.41	6	11.45	35.1
	2020	1.38	1.14	0.38	1.06	1.86	7.32	30.41	17.39	1.22	0.72	0.42	0.38	0.46	11.1	19.62	55.77
Mean of 3 years		*1.69*	*0.76*	*0.38*	*1.53*	*1.26*	*8.11*	*39.02*	*21.99*	*1.59*	*0.83*	*0.47*	*0.62*	*0.42*	*6.71*	*19.89*	*33.98*

N nitrogen, *K* potassium, *P* phosphorus, *Ca* calcium, *Mg* magnesium, *B* boron, *Zn* zinc, *Fe* iron, *ppm* parts per million

Table 4 Wilks' lambda test of equality of group means (studied rootstocks) for flower and leaf mineral nutrition. Data are the mean of 2018, 2019, and 2020

Concepts		Wilks' lambda	F	df1	df2	Sig
N	Leaf	0.702	3.404	1	8	0.102
K		0.747	2.709	1	8	0.138
P		0.860	1.307	1	8	0.286
Ca		0.798	2.021	1	8	0.193
Mg		0.775	2.326	1	8	0.166
B		0.619	4.922	1	8	0.057*
Zn		0.522	7.314	1	8	0.027*
Fe		0.927	0.627	1	8	0.451
N	Flower	0.967	0.275	1	8	0.614
K		0.952	0.403	1	8	0.543
P		0.583	5.715	1	8	0.044*
Ca		0.927	0.628	1	8	0.451
Mg		0.788	2.147	1	8	0.181
B		0.977	0.186	1	8	0.678
Zn		0.924	0.662	1	8	0.439
Fe		0.616	4.980	1	8	0.056*

N nitrogen, *K* potassium, *P* phosphorus, *Ca* calcium, *Mg* magnesium, *B* boron, *Zn* zinc, *Fe* iron
Source: discriminant analysis. *Significant at $P < 0.05$

Table 5 Correlations between mineral nutrient content of leaves and flowers for studied quince rootstock/cultivar combinations. Data are the mean of 2018, 2019, and 2020

	B-leaf		Zn-leaf		P-flower		Fe-flower
B-leaf	1						
Zn-leaf	0.799^{**1} 0.930^{**2} 0.996^{**3} 0.999^{**5}	920^{**8} 0.934^{**10}	1				
P-flower	–0.677^{*1}	–0.858^{**9}	–0.940^{**1} 0.971**2	0.921**^{7}	1		
Fe-flower	–0.938^{**2} –0.960^{**3} –0.765^{*5}	–0.938^{**8} –0.854^{**9} –0.728^{*10}	–0.980^{**3} –0.787^{*5}	–0.980**^{6} –0.748^{*8} –0.924^{**10}	0.709^{*1} 0.783^{*2}	0.831^{**8} 0.999^{**9}	1

B boron, *Zn* zinc, *P* phosphorus, *Fe* iron
$^{*, **}$ $p \leq 0.05$, $p \leq 0.001$, respectively (F-probabilities)
[1]Relative to 'Vidoja /quince; [2]relative to NB2'/quince; [3]relative to 'Behta'/quince; [4]relative to 'KVD2'/quince; [5]relative to 'Isfahan'/quince; [6]relative to 'Vidoja /hawthorn; [7]relative to NB2'/hawthorn; [8]relative to 'Behta'/hawthorn; [9]relative to 'KVD2'/hawthorn; [10]relative to 'Isfahan'/hawthorn

highest value of leaf-Ca (2.32%) and leaf- Zn (77.66 ppm) in the 'Vidoja' grafted in 2018. Furthermore, the highest leaf-N was observed in quince seedling (*Cydonia oblonga*) compared to hawthorn (*Crataegus* spp.) rootstock, meaning that the 'Vidoja'/quince seedling combination exhibited the highest value of leaf-N (4.94%) in 2018 (Table 3). Also, the interpretation of leaf analyses in 2020 showed that of all mineral elements studied, only leaf-P and leaf-Mg were generally in adequacy ranges. In contrast, insufficiency ranges were observed in leaf-K and leaf-B. Of all rootstock/cultivar combinations studied, only the 'KVD2' and 'Vidoja' when grafted on hawthorn showed sufficiency ranges of leaf-Fe content. Adequacy ranges of leaf-N and leaf-Ca content were observed only in 'Isfahan' and 'Behta' cultivars grafted in quince seedling (*Cydonia oblonga*), respectively. Of all cultivar/hawthorn combinations studied, only the 'KVD2' showed sufficiency ranges of leaf-Zn content (Tables 2 and 3). In the present study, variation in leaf nutrient content of hawthorn (*Crataegus* spp.) and quince seedling (*Cydonia oblonga*) rootstocks was observed, although these variations differed depending on the cultivar/rootstock. These results were in agreement with the results found by Valipour et al. (2018).

Rootstock and Genotype or Cultivar Effects on Flower Nutrient Concentration Mean values of all studied rootstock/

Table 6 Group statistics (rootstocks) for nutrient composition of fruits (at harvest time and after 3 months of cold storage at 0 °C)

Rootstocks	Nutrient composition of fruits		Mean	SD	Valid *n* (list-wise)	
					Unweighted	Weighted
Quince seedling (*Cydonia oblonga*) rootstocks	N	At harvest	0.41	0.05	5	5
		Cold storage	0.30	0.03	5	5
	P	At harvest	0.37	0.00	5	5
		Cold storage	0.37	0.00	5	5
	K	At harvest	0.55	0.12	5	5
		Cold storage	0.36	0.19	5	5
	Ca	At harvest	0.29	0.35	5	5
		Cold storage	0.30	0.34	5	5
	Mg	At harvest	0.35	0.12	5	5
		Cold storage	0.29	0.12	5	5
	Fe	At harvest	4.28	2.20	5	5
		Cold storage	2.24	2.38	5	5
	B	At harvest	5.61	2.41	5	5
		Cold storage	4.54	1.70	5	5
	Zn	At harvest	4.58	0.83	5	5
		Cold storage	5.76	1.68	5	5
Hawthorn (*Crataegus* spp.)	N	At harvest	0.38	0.09	5	5
		Cold storage	0.35	0.08	5	5
	P	At harvest	0.38	0.01	5	5
		Cold storage	0.38	0.01	5	5
	K	At harvest	0.71	0.10	5	5
		Cold storage	0.62	0.09	5	5
	Ca	At harvest	0.17	0.08	5	5
		Cold storage	0.12	0.04	5	5
	Mg	At harvest	0.28	0.11	5	5
		Cold storage	0.26	0.12	5	5
	Fe	At harvest	5.36	3.70	5	5
		Cold storage	2.63	1.37	5	5
	B	At harvest	6.16	3.58	5	5
		Cold storage	4.83	3.02	5	5
	Zn	At harvest	5.10	0.60	5	5
		Cold storage	6.61	1.67	5	5
Total	N	At harvest	0.40	0.07	10	10
		Cold storage	0.32	0.06	10	10
	P	At harvest	0.37	0.01	10	10
		Cold storage	0.37	0.01	10	10
	K	At harvest	0.63	0.14	10	10
		Cold storage	0.49	0.20	10	10
	Ca	At harvest	0.23	0.25	10	10
		Cold storage	0.21	0.25	10	10
	Mg	At harvest	0.31	0.12	10	10
		Cold storage	0.28	0.12	10	10
	Fe	At harvest	4.82	2.92	10	10
		Cold storage	2.44	1.84	10	10
	B	At harvest	5.88	2.89	10	10
		Cold storage	4.69	2.32	10	10
	Zn	At harvest	4.84	0.74	10	10
		Cold storage	6.18	1.64	10	10

N nitrogen, *K* potassium, *P* phosphorus, *Ca* calcium, *Mg* magnesium, *B* boron, *Zn* zinc, *Fe* iron, *ppm* parts per million
Source: discriminant analysis

Table 7 Wilks' lambda test of equality of group means (studied rootstocks) for nutrient composition of fruits (at harvest time and after 3 months of cold storage at 0 °C) in 2019

Nutrient composition of fruits		Wilks' lambda	F	df1	df2	Sig
N	At harvest	0.954	0.382	1	8	0.553
	Cold storage	0.828	1.665	1	8	0.233
P	At harvest	0.780	2.250	1	8	0.172
	Cold storage	0.909	0.800	1	8	0.397
K	At harvest	0.606	5.207	1	8	0.052*
	Cold storage	0.523	7.291	1	8	0.027*
Ca	At harvest	0.932	0.580	1	8	0.468
	Cold storage	0.852	1.385	1	8	0.273
Mg	At harvest	0.890	0.984	1	8	0.350
	Cold storage	0.973	0.218	1	8	0.653
Fe	At harvest	0.962	0.318	1	8	0.588
	Cold storage	0.988	0.097	1	8	0.764
B	At harvest	0.990	0.082	1	8	0.782
	Cold storage	0.996	0.034	1	8	0.859
Zn	At harvest	0.860	1.297	1	8	0.288
	Cold storage	0.926	0.643	1	8	0.446

N nitrogen, *K* potassium, *P* phosphorus, *Ca* calcium, *Mg* magnesium, *B* boron, *Zn* zinc, *Fe* iron, *ppm* parts per million
Source: Discriminant analysis, *Significant at $P < 0.05$

scion combinations over 3 years (2018, 2019, and 2020) showed the highest flower-K, -P, -Mg, -Fe, -Ca, and -Zn levels in hawthorn (*Crataegus* spp.) rootstock compared to quince (*Cydonia oblonga*) rootstock. However, the differences between the rootstock/scion combinations were statistically different (Table 3). The 'Behta' grafted on hawthorn showed the highest value of flower-K (1.59%) in 2018, while the highest flower-Mg (0.74%) was observed in 'Behta' when grafted on hawthorn (*Crataegus* spp.) rootstocks in 2018. The highest flower-P (1.42%) was observed in 'KVD2' when grafted on hawthorn (*Crataegus* spp.) rootstock in 2019. The highest flower-Fe (81.31 ppm) was observed in 'KVD2' when grafted on hawthorn (*Crataegus* spp.) rootstock in 2019. The highest value of flower-Ca (1.32%) was also obtained in the 'Behta'/quince combination in 2018. The highest flower-N was detected in quince seedling (*Cydonia oblonga* Mill) rootstock in all years studied (Table 3). The 'Isfahan' when grafted on quince seedling (*Cydonia oblonga*) rootstock showed the highest value of flower-N (3.22%) in 2018. Also in 2018, the highest flower-Zn (36.87 ppm) was achieved in 'KVD2' on quince seedling (*Cydonia oblonga*) rootstock. The 'Behta'/quince seedling (*Cydonia oblonga*) combination showed the highest value for flower-B (20.62 ppm) in 2020 (Table 2). In this study, variation in flower nutrient content of hawthorn (*Crataegus* spp.) and quince seedling (*Cydonia oblonga*) rootstocks was detected, although these variations differed depending on the cultivar/rootstock combination. Also, the interpretation of flower analyses in 2020 showed that of all mineral elements studied, only flower-P and flower-Ca were generally in adequacy ranges. Mean values of all studied rootstock/scion combinations over the studied years showed that when mineral element concentrations of flowers were compared with those obtained in leaves, the K contents appeared to be higher in flowers than in leaves on all cultivar/rootstock combinations studied. Flower-B content was higher than in leaves of quince seedling (*Cydonia oblonga*) rootstock grafted on 'Behta.' In addition, flower-P content was higher than in leaves of hawthorn (*Crataegus* spp.) rootstock grafted on all cultivars studied. Furthermore, the values of Fe and N appeared to be higher in flowers than in leaves of the 'Behta'/hawthorn (*Crataegus* spp.) combination. Similar results have been shown in pear (Sanz et al. 1994), cherry trees (Betrán et al. 1996; Moreno et al. 1996; Jiménez et al. 2004), and coffee (Martinez et al. 2003).

Wilks' Lambda Test Statistic for Flower, Leaf, and Fruit To determine whether the group means (studied rootstocks) do have a significant impact on the mineral nutrition content in flower, leaf, and fruit, the Wilks' lambda statistic is used.

Wilks' Lambda Test Statistic for Flower and Leaf The amounts of leaf-B, leaf-Zn, flower-Fe, and flower-P are explained by differences between group means (studied rootstocks) (Table 4). While at the same time, with the exception of 'KV2'/quince combination, positive correlations were also found between leaf-B and leaf-Zn in all genotypes or cultivars grafted on quince seedling rootstocks, 'Behta'/hawthorn (*Crataegus* spp.) and 'Isfahan'/hawthorn (*Crataegus* spp.) combinations showed a significant positive correlation between leaf-B and leaf-Zn (Table 5). In the present study, in

Table 8 Mean comparison of nutrient composition of fruits (at harvest time and after 3 months following cold storage at 0 °C) in different genotypes or cultivar/rootstock combinations grown under calcareous soil in the Najafabad region of Isfahan province, Iran, in 2019

Treatments		N		P		K		Ca		Mg		Fe		B		Zn	
		%										ppm					
		At Harvest	Cold Storage	At Harvest	Cold Storage	At Harvest	Cold Storage	At Harvest	Cold Storage	At Harvest	Cold Storage	At Harvest	Cold Storage	At Harvest	Cold Storage	At Harvest	Cold Storage
Quince	Vidoja	0.46ba	0.28dc	0.37a	0.37a	0.43e	0.40d	0.08dc	0.15b	0.19d	0.32cbd	5.32c	0.95ba	5.32g	2.47ed	5.56cb	6.54c
	NB2	0.41bc	0.26d	0.37a	0.37a	0.428f	0.41d	0.91a	0.90a	0.32c	0.23cd	5.61c	1.90dc	7.13d	4.09ef	4.91c	5.56f
	Behta	0.37dc	0.32c	0.37a	0.38a	0.62cd	0.20e	0.15c	0.15b	0.32c	0.14e	2.47d	6.27a	4.28h	3.80ef	3.27f	3.27h
	KVD2	0.37dc	0.33c	0.37a	0.38a	0.71b	0.62b	0.15c	0.15b	0.42b	0.46a	2.85d	2.00dc	2.57j	6.94b	4.58d	5.56f
	Isfahan	0.41bc	0.31dc	0.38a	0.38a	0.57d	0.14f	0.15c	0.15b	0.51a	0.32b	2.95d	0.105d	8.74b	5.42 cd	4.58d	7.85b
Hawthorn (*Crataegus* spp.)	Vidoja	0.46ba	0.30dc	0.39a	0.37a	0.67cb	0.51dc	0.31b	0.15b	0.19e	0.46a	10.17a	1.81dc	5.80f	5.80c	5.23b	7.85b
	NB2	0.34de	0.29dc	0.37a	0.37a	0.81a	0.72a	0.15c	0.08c	0.19e	0.14e	2.57d	4.66ba	1.22i	1.25f	4.25e	5.89e
	Behta	0.49a	0.40b	0.37a	0.39a	0.71b	0.66ba	0.15c	0.15b	0.37cb	0.28cb	2.76d	3.33bc	8.55c	6.08cb	4.91c	8.50a
	KVD2	0.34de	0.46a	0.38a	0.38a	0.81a	0.65b	0.15c	0.15b	0.23ed	0.23 cd	2.76d	1.24dc	9.41a	8.36a	5.23b	6.54d
	Isfahan	0.29e	0.29dc	0.385a	0.38a	0.57d	0.54c	0.08dc	0.08c	0.42b	0.19ed	8.55b	2.10dc	6.75e	3.52ef	5.89a	4.25g

For each trait, means followed by the same letter in each column are not significantly different at according to Least Significant Differences (LSD) test

all studied cultivar/rootstock combinations, no correlation was found between flower-Fe and leaf-Fe. However, significant positive correlations were found between flower-Fe and flower-P in 'Vidoja /quince, NB2'/quince, 'Behta'/hawthorn, and'KVD2'/hawthorn. Correlations between leaf-Fe and root-Fe and other parameters for hawthorn (*Crataegus persica* Pojark.) and quince seedling (*Cydonia oblonga* Mill.) rootstocks were observed by Valipour et al. (2018). They reported that in both rootstocks, a significant positive correlation was found between proton and phenolic compound secretion by the roots and $Fe(OH)_3$ solubilization. In hawthorn (*Crataegus persica* Pojark.) a significant positive correlation was found between proton release from roots and activity of Fe(III) chelate reductase (FCR), whereas no such correlation was found in quince. In response to bicarbonate-induced Fe deficiency, hawthorn roots released more protons to the surrounding media, whereas no such response was observed in quince. A higher release of protons under Fe-deficiency conditions results from the increased activity of an ATPase enzyme localized in the root plasma membrane (Tagliavini et al. 1995). In calcareous soils, the protons secreted can be buffered by the high content of calcium carbonate; therefore, root H^+ secretion into the rhizosphere is believed to have no major influence on Fe.

Wilks' Lambda Test Statistic for Fruits There were no significant group (rootstocks) differences for nutrient composition of fruits (at harvest time and after 3 months of cold storage at 0 °C), except for K-fruit (at harvest time and after 3 months of cold storage at 0 °C) (Tables 6 and 7). Mean comparison of the nutrient composition of fruits (at harvest time and after 3 months of cold storage at 0 °C) for studied genotypes or cultivar/rootstock combinations were carried out only in 2019. With the exception of fruit-P content at both harvest time and after cold storage, there were significant differences between all macro- and micro-mineral contents studied in quince genotypes grafted on both hawthorn and quince seedling rootstocks (Table 8). The highest value of fruit-K (0.81% at harvest time and 0.72% after 3 months of cold storage at 0 °C), on the other hand, was observed in the NB2/hawthorn combination. The highest value of fruit-B (9.41 ppm at harvest time and 8.36 ppm after 3 months of cold storage at 0 °C %) was also obtained in the 'KVD2'/hawthorn combination in 2019. In addition, the interpretation of fruit analyses showed that fruit-P, fruit-Mg, and fruit-Ca were generally in adequacy ranges. However, fruit-B in all studied genotypes or cultivar/rootstock combinations was generally in insufficiency ranges (Table 8). A wide range of variation in fruit mineral content among Iranian quince genotypes has already been reported by Moradi et al. (2017). Furthermore, the present results revealed a steady decrease in fruit-N and

Table 9 Correlation matrix for the mineral nutrient content of leaves[a], flowers[b], and fruits[c]. This assay was performed only in the year of commercial fruiting (2019)

		K	Ca	Fe	B	P	Mg	Zn	N	N	K	P	Ca	Mg	B	Zn	Fe	N	K	P	Ca	Mg	B	Zn	Fe
		Fruits								Leaves								Flowers							
K	Fruits	1	–0.427	–0.474	–0.216	0.195	–0.162	–0.248	–0.355	–0.098	–0.064	–0.086	–0.119	–0.339	0.334	–0.538	–0.044	–0.109	0.235	0.5	0.239	0.224	0.511	–0.12	0.761*
Ca		–0.427	1	0.142	0.141	–0.03	–0.041	–0.015	0.123	–0.111	–0.165	–0.107	0.429	–0.1	–0.283	0.635*	0.022	–0.019	0.071	–0.145	–0.337	0.351	–0.027	0.144	–0.181
Fe		–0.474	0.142	1	0.092	0.612	–0.294	0.675*	0.204	–0.208	0.264	–0.286	–0.087	0.367	–0.244	0.109	–0.086	–0.299	–0.19	–0.182	–0.105	–0.46	0.072	–0.247	–0.366
B		–0.216	0.141	0.092	1	0.12	0.323	0.42	0.221	0.392	–0.4	–0.165	–0.135	0.018	–0.128	0.03	0.074	0.248	–0.113	0.508	0.319	–0.143	–0.647*	–0.332	0.106
P		0.195	–0.03	0.612	0.12	1	–0.372	0.233	0.191	0.017	0.467	–0.087	–0.54	0.498	0.015	–0.212	0.109	–0.018	0.245	0.128	0.03	–0.211	0.215	–0.001	0.148
Mg		–0.162	–0.041	–0.294	0.323	–0.372	1	–0.107	–0.216	0.615	–0.182	0.101	–0.201	–0.151	0.341	0.262	0.583	0.325	0.103	–0.216	–0.475	0.294	–0.397	–0.168	–0.321
Zn		–0.248	–0.015	0.675*	0.42	0.233	–0.107	1	0.111	–0.075	–0.209	–0.766**	0.155	–0.119	–0.109	0.06	–0.149	–0.393	–0.604	0.271	0.149	–0.547	–0.098	–0.795**	–0.074
N		–0.355	0.123	0.204	0.221	0.191	–0.216	0.111	1	0.142	0.503	–0.125	–0.405	0.671*	–0.027	0.106	0.016	0.253	–0.527	–0.281	0.047	–0.216	–0.448	–0.052	–0.503
N	Leaves	–0.098	–0.111	–0.208	0.392	0.017	0.615	–0.075	0.142	1	0.285	–0.059	–0.641*	0.287	0.481	0.276	0.726*	0.639*	0.105	–0.119	–0.321	–0.035	–0.541	0.043	–0.175
K		–0.064	–0.165	0.264	–0.4	0.467	–0.182	–0.209	0.503	0.285	1	0.079	–0.736*	0.701*	0.456	–0.073	0.24	0.42	0.07	-.0656*	–0.446	–0.013	0.145	0.318	–0.47
P		–0.086	–0.107	–0.286	–0.165	–0.087	0.101	–0.766**	–0.125	–0.059	0.079	1	–0.166	0.311	–0.247	–0.168	0.003	0.29	0.648*	–0.2	0.102	0.242	–0.122	0.815**	–0.044
Ca		–0.119	0.429	–0.087	–0.135	–0.54	–0.201	0.155	–0.405	–0.641*	–0.736*	–0.166	1	–0.692*	–0.486	0.232	–0.472	–0.574	–0.184	0.24	0.188	0.088	0.222	–0.154	0.213
Mg		–0.339	–0.1	0.367	0.018	0.498	–0.151	–0.119	0.671*	0.287	0.701*	0.311	–0.692*	1	–0.171	0.16	0.382	0.208	–0.042	–0.373	0.001	–0.428	–0.433	0.347	–0.45
B		0.334	–0.283	–0.244	–0.128	0.015	0.341	–0.109	–0.027	0.481	0.456	–0.247	–0.486	–0.171	1	–0.343	0.121	0.618	0.137	–0.305	–0.561	0.484	0.326	–0.119	–0.108
Zn		–0.538	0.635*	0.109	0.03	–0.212	0.262	0.06	0.106	0.276	–0.073	–0.168	0.232	0.16	–0.343	1	0.604	–0.207	–0.223	–0.283	–0.37	–0.178	–0.422	0.012	–0.383
Fe		–0.044	0.022	–0.086	0.074	0.109	0.583	–0.149	0.016	0.726*	0.24	0.003	–0.472	0.382	0.121	0.604	1	0.091	0.06	–0.215	–0.414	–0.153	–0.423	0.008	–0.215
N	Flowers	–0.109	–0.019	–0.299	0.248	–0.018	0.325	–0.393	0.253	0.639*	0.42	0.29	–0.574	0.208	0.618	–0.207	0.091	1	0.398	–0.286	–0.305	0.457	–0.209	0.432	–0.21
K		0.235	0.071	–0.19	–0.113	0.245	0.103	–0.604	–0.527	0.105	0.07	0.648*	–0.184	–0.042	0.137	–0.223	0.06	0.398	1	0.008	–0.167	0.504	0.312	0.700*	0.321
P		0.5	–0.145	–0.182	0.508	0.128	–0.216	0.271	–0.281	–0.119	–0.656*	–0.2	0.24	–0.373	–0.305	–0.283	–0.215	–0.286	0.008	1	0.772**	–0.243	–0.081	–0.301	0.866**
Ca		0.239	–0.337	–0.105	0.319	0.03	–0.475	0.149	0.047	–0.321	–0.446	0.102	0.188	0.001	–0.561	–0.37	–0.414	–0.305	–0.167	0.772**	1	–0.507	–0.253	–0.052	0.598
Mg		0.224	0.351	–0.46	–0.143	–0.211	0.294	–0.547	–0.216	–0.035	–0.013	0.242	0.088	–0.428	0.484	–0.178	–0.153	0.457	0.504	–0.243	–0.507	1	0.429	0.268	0.007
B		0.511	–0.027	0.072	–.647*	0.215	–0.397	–0.098	–0.448	–0.541	0.145	–0.122	0.222	–0.433	0.326	–0.422	–0.423	–0.209	0.312	–0.081	–0.253	0.429	1	0.024	0.288
Zn(f)		–0.12	0.144	–0.247	–0.332	–0.001	–0.168	–.795**	–0.052	0.043	0.318	0.815**	–0.154	0.347	–0.119	0.012	0.008	0.432	0.700*	–0.301	–0.052	0.268	0.024	1	–0.012
Fe(f)		0.761*	–0.181	–0.366	0.106	0.148	–0.321	–0.074	–0.503	–0.175	–0.47	–0.044	0.213	–0.45	–0.108	–0.383	–0.215	–0.21	0.321	0.866**	0.598	0.007	0.288	–0.012	1

N nitrogen, *K* potassium, *P* phosphorus, *Ca* calcium, *Mg* magnesium, *B* boron, *Zn* zinc, *Fe* iron

[a]Leaves sampled at 90 DAFB

[b]Flowers sampled at full bloom stage

[c] Fruits sampled at 180 DAFB

*, ** Correlation is significant at 0.05 and 0.01 levels (two-tailed), respectively

fruit-K content over storage time in a genotype- and cultivar/rootstock combination-dependent manner. The trend in changes for the remaining minerals at both harvest time and after 3 months following cold storage was also different among genotypes investigated.

Correlations Between Flower, Leaf, and Fruit Nutrient Content This assay was performed only in the year of commercial fruiting (2019). There were positive correlations between fruit-Ca with leaf-Zn (0.635), fruit-K with flower-Fe (0.761), and fruit-N with leaf-Mg (0.671). Furthermore, negative correlations between fruit-B with flower-B (–0.647) and fruit-Zn with flower-Zn (–0.795) were detected (Table 9). The relationship between mineral concentrations in different plant tissues of quince trees and fruit quality has been well documented (Moradi et al. 2017; Rasheed et al. 2018). The nutrients with the most notable influence on fruit quality are N, Ca, and K, although several studies have attributed much greater importance to the ratio of nutrients than the concentration of individual mineral elements on fruit quality (Casero et al. 2004). Commercial aspects such as quality of the quince fruits as well as resistance to leaf chlorosis due to iron deficiency are a part of the quince fruit breeding program in Iran (Valipour et al. 2018), Germany, Portugal, Czech Republic, and Spain (Schirmer 2000; Rop et al. 2011). Mineral elements, especially calcium and its complexes with galacturonic acid, are also important in the field of the production of fruit spreads since they participate in the formation of gels (Saarimaa et al. 2007). Therefore, the present results are of paramount importance in order to establish the most suitable agricultural practices and give some accurate choice of suitable genotype/rootstock in typical alkaline soils. Moreover, the results presented herein can assist breeders to release promising cultivars in their quince production pipeline.

Conclusion

Discriminant analysis was effective in summarizing the complex relationships of the data, distinguishing between studied rootstocks and genotypes or cultivar on the basis of mineral nutrition content in flower, leaf, and fruit. In summary, the effect of rootstock on mineral uptake as well as the effect of cultivar and the rootstock/cultivar combination on mineral concentrations in flowers and leaves were significant. However, the group statistics and tests of equality of group means revealed that there were no significant group (rootstocks) differences for nutrient composition of fruits (at harvest time and after 3 months of cold storage at 0 °C), except for K-fruit (at harvest time and after 3 months of cold storage at 0 °C). Generally, higher mineral nutrient uptake by hawthorn (*Crataegus* spp.) rootstock makes it more suitable for heavy and calcareous soils. The use of flower analysis would permit the early detection and correction of each deficiency of these elements. A wide range of variation in fruit mineral content among studied quince genotypes grafted on hawthorn and quince seedling rootstocks has also been detected. The 'KVD2'/hawthorn combination in this study demonstrated higher mineral nutrient uptake in heavy and calcareous soils.

Acknowledgements These results were obtained with the support of project 0-72-33-065-970850 funded by the Ministry of Agriculture and Horticultural Science Research Institute (HSRI), Temperate and Cold Fruit Research Center, Karaj, Iran.

Conflict of interest M. Mirabdulbaghi, H. Akbari, H. Abdollahi and R. Zarghami declare that they have no competing interests.

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