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EFFECT OF CHELATED IRON AND SILICON ON THE YIELD AND QUALITY OF TOMATO PLANTS GROWN UNDER SEMI-ARID CONDITIONS

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ABSTRACT

The influence of chelated iron (0, 250 and 500 mg·L^{-1} as Fe-EDDHA 6%) and silicon (0, 2, 4 mmol·L^{-1} as K_2SiO_3) on the yield and quality of tomato (*Solanum lycopersicum* L.), Strain B cultivar, were investigated under semi-arid conditions in Ras Sudr region, Egypt, in years 2013–2014. A significant influence of chelated iron and silicon applications on tomato growth, yield and quality were observed. The highest plant growth, leaf mineral contents (N, P and K), vitamin C and Ca contents in fruit, fruit firmness, early and total yield were observed in plants which treated with 500 mg·L^{-1} chelated iron and 2 and 4 mmol·L^{-1} silicon. Meanwhile, these treatments decreased the proline content of leaves and T.S.S content of fruit.

Key words: *Solanum lycopersicum*, Fe-EDDHA, potassium silicate, proline, fruit weight

INTRODUCTION

Salinity is considered the major stress factor for plants, as well one of the most serious environmental problems that diminish crop growth and production in arid and semi-arid regions [Lopez et al. 2002]. Excessive soil salinity, resulting from natural processes in the soil or from crop irrigation with saline water, which affect plant growth and yield through the effects of osmotic pressure, nutritional imbalances, oxidative damage and/or specific ion toxicities [Mohsen et al. 2013]. In view of these reports, it was suggested that salt tolerance could be motivated by the applications of chelated iron and silicon.

Iron is an essential micronutrient for all living organisms because it plays a major role in metabolic processes such as DNA synthesis, respiration, photosynthesis, chlorophyll development [Eskandari 2011]. Further, many of metabolic pathways and enzymes are activated by iron [Rout and Sahoo 2015]. On calcareous soils, high pH and $CaCO_3$ content can induce the iron deficiency [Celik and Katkat 2007]. In saline condition, the reduction of the availability of Fe in soil solution may due to the disorder in elements balance which are absorbed by the plant. So, in these conditions, proper fertilizing and plant nutrition is very important to amend Fe shortage in the soil. The foliar application of Fe can reduce the effects of salinity [Ramezani et al. 2012] and adjusts the soil pH [Incesu et al. 2015] on plants and even can compensate them. Fe application can ameliorate the negative effect of salt stress on the growth and production of tomato plant [Tantawy et al. 2013]. In this line, as mentioned in other research Fe spraying resulted in

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increasing plant growth, yield and quality of pepper [Roosta and Mohsenian 2012], tomato [Kazemi 2013, Houimli et al. 2015] and squash [Al Janabi 2016].

Silicon (Si) is the second most abundant elements in soil [Ma and Takahashi 2002]. Although Si has not been proven to be an essential element for plant growth and development, it has a beneficial role in enhancing the resistance to stress in plants and pushing tolerance [Uchimura et al. 2000]. Silicon protect plants from a biotic and biotic stresses [Liang et al. 2007, Ma and Yamaji 2008], silicon relieves the salt stress on plants [Liang et al. 2003, Al-aghabary et al. 2004], also drought stress [Gong et al. 2005]. Different studies indicate the positive effect of silicon application on growth, yield and quality of plants such as: cucumber, sweet pepper, tomato and pumpkin [Gorecki and Danielski-Busch 2009, Kamal 2013, Jarosz 2014, Mohaghegh et al. 2015, Lu et al. 2016, Sukkaew et al. 2016]. The aim of the present study was to test the effects of foliar spraying of chelated Fe and silicon on the growth, yield and fruit quality of tomato plant.

MATERIALS AND METHODS

This study was conducted at Ras Sudr Research Station, Desert Research Center, at the South Sinai Governorate, Egypt to evaluate the effect of chelated iron and silicon on growth, chemical composition, yield and quality of tomato, Strain B cultivar. Seeds were sown in the first week of February under greenhouse conditions in 2013 and 2014 seasons. The seedlings were transplanted on March 15 in both seasons at stage of five real uniform leaves. The seeds of Strain B cultivar were provided by Agriculture Research Center, Egypt. The soil of the location was highly calcareous and saline, soil texture was sandy loam, pH 7.7, EC 8.65 $mS \cdot cm^{-1}$, $CaCO_3$ 56.99%. Physical and chemical properties of the soil were determined according to Burt [2004]. Plants were irrigated with saline water (4500 ppm), at 3-days intervals.

The experiment was laid out under split plot design with three replications, randomizing the chelated iron in main plots and keeping the silicon levels in sub plots. Plot area was 10.0 m^2 (5 rows 4 m in length and 50 cm apart) every experimental plot included 40 plants, the plots were separated by borders of 1.5 m in width. The experimental treatments included two study factors: the first factor was foliar chelated iron (Fe-EDDHA 6%) at three levels, namely, 0, 250 and 500 $mg \cdot L^{-1}$ and the second one foliar silicon (K_2SiO_3) at the rates of 0, 2, and 4 $mmol \cdot L^{-1}$. All foliar applications were carried out early in the morning, starting from 30 days after transplanting. A total of three sprays were given at an interval of 15 days. All agricultural practices of cultivation were performed as recommended by the Ministry of Agriculture, Egypt.

Measurements of the plants were performed at 70 days after transplanting. Five plants were taken randomly from each experimental plot to measure plant height, leaf area, leaf chlorophyll content [Inada 1985], fresh and dry weight per plant. Determination of N by using Kjeldahl's method [Ostrowska et al. 1991], P spectrophotometrically by using the phosphomolibdate yellow method [Kitson and Mellon 1944], K was determined by flame photometry [Chapman and Pratt 1982] and Fe was determined by atomic absorption spectrophotometer as described by Evenhuis and Dewaard [1980]. Proline was extracted and measured colorimetrically following the procedure described by Bates et al. [1973].

Tomato fruits were harvested at red stage maturity. Ten harvests from a period of 50 days were taken up in the first and the second seasons. The early yield consisted of tomatoes obtained during the first three harvests. All harvested fruits from all pickings during the entire season were weighed to determine the total yield. Five ripe fruits were selected randomly from each experimental plot to measure some characteristics of fruit quality, i.e., fruit weight, fruit size which was measured by putting five tomato fruits in the given volume of water then measures the displacement, fruit firmness was measured by Penetrometer [Cemeroglu 1992], total soluble solids (TSS) determined using a refractometer [Wang et al. 1996], vitamin C content according to AOAC [1990] and calcium content using the flame Photometric method [Chapman and Pratt 1982].

All data were subjected to ANOVA [Gomez and Gomez 1984] by using COSTAT software package and the means were compared by Duncan's multiple range test at $p \leq 0.05$ [Snedecor and Cochran 1980].

RESULTS AND DISCUSSION

Vegetative growth and chlorophyll content

Chelated iron supplementation had a significant effect on the plant height, leaf area, leaf chlorophyll content, fresh and plant dry weight (tab. 1). Linear increase was observed in all values with increasing the level of foliar chelated iron in two seasons. These results are in line with Roosta and Mohsenian [2012], Tantawy et al. [2013] and Houimli et al. [2015]. The favorable effect of chelated iron application on growth and leaf chlorophyll content may be due to the role of iron as a cofactor for enzymes that involved in a wide variety of oxidation-reduction reactions, i.e., photosynthesis, respiration, hormone synthesis, DNA synthesis, etc., [Rout and Sahoo 2015]. This function makes iron an essential nutrient to plant development and reproduction, thereby, enhance the plant growth and chlorophyll content.

Regarding, growth parameters and leaf chlorophyll responded positively to application of silicon (tab. 1). The values of plant height, leaf area, leaf chlorophyll, fresh and plant dry weight were significantly increased with silicon foliar applications as compared with control treatment in both seasons. The highest values were recorded with 2 mmol potassium silicate L^{-1} except leaf area during the first season where it recorded with 4 mmol potassium silicate L^{-1}. The differences between the 2 and 4 mmol potassium silicate L^{-1} were non-significant in both seasons. The results agree with the findings of Lu et al. [2016] and Sukkaew et al. [2016]. Increase the growth and chlorophyll of tomato under this application may be due to the act of silicon in alleviating the salt stress in plants by decreasing the permeability of plasma membranes and maintenance the form, structure of cells by increasing the antioxidative enzymes superoxide dismutase and catalase, also increase the tolerance of plant leaves to salinity by enhancing the chlorophyll content and photochemical efficiency [Al aghabary et al. 2004]. Silicon plays a key role in retaining the water capacity in plant cells under stress [Crusciol et al. 2009] also corrects the levels of endogenous growth hormones, i.e., auxins, gibberellins and cytokinins under stress conditions [Hanafy et al. 2008].

The interaction between iron and silicon on growth and leaf chlorophyll content were significant differences among the treatments in both seasons except plant height in the first season, leaf chlorophyll and plant fresh weight in the second season. The highest values were obtained from 500 mg chelated iron L^{-1} combined with 2 or 4 mmol silicon L^{-1}.

Nutrient elements and proline content

The mineral nutrients concentrations and proline content in tomato leaves as a function of the foliar chelated iron application are displayed in table 2, foliar spray of chelated iron (Fe-EDDHA 6%) increased the concentrations of N, P, K and Fe, but decreased the content of proline in tomato leaves. This result was significant during two growing seasons. In accordance with the present result, other researchers also reported that plant nutrients responded positively to iron foliar application. Tantawy et al. [2013] revealed that foliar application of Fe-EDDHA 6% increased N, P and K concentrations in tomato plants. Also Asri and Sonmez [2012] found that treatment of tomato by iron resulted in an increase of leaf N, K and Fe contents, this increase of nutrient element concentrations may be due to the iron role in increasing the efficiency of photosynthesis and the demand to increase the essential elements which cause enhancing in both absorption and transport of elements in plants [Roosta and Mohsenian 2012]. Other researchers have reported that iron foliar applications caused a decrease in the proline concentration in plant leaves under different stress conditions [Heidari and Sarani 2012, Pourgholam et al. 2013], this effect on plant proline content probably due to the positive impact of iron application in mitigation of the negative effects of salt stress [Ramezani et al. 2012, Tantawy et al. 2013] which led to significantly decreased proline content in the leaves [Abd El Razik et al. 2016].

According to the average for the analyzed values, the potassium silicate significantly influenced the leaf content of N, P, K, Fe and proline. The foliar application of potassium silicate gave greater N, P, K, Fe

Table 1. Effect of chelated iron and silicon on tomato plant height, leaf area, leaf chlorophyll content, fresh and dry weight in 2013 and 2014 seasons

Tested features	Chelated iron (mg·L^{-1})	2013				2014			
		silicon (mmol·L^{-1})							
		0	2	4	mean	0	2	4	mean
Plant height (cm)	0	37.91	41.07	40.25	39.74	42.35	45.31	45.34	44.33
	250	40.96	45.29	45.51	43.92	44.04	48.42	47.63	46.69
	500	42.63	48.06	47.84	46.18	46.15	53.18	52.05	50.46
	mean	40.50	44.80	44.53		44.18	48.97	48.34	
	LSD $_{p \le 0.05}$ for	iron – 1.04, silicon – 1.03, interaction – n.s.				iron – 0.42, silicon – 0.92, interaction – 1.86			
Leaf area (cm^2)	0	46.36	56.74	58.74	53.95	50.24	58.72	57.96	55.64
	250	51.02	60.33	59.90	57.08	54.04	63.07	63.74	60.28
	500	53.84	64.61	64.79	61.08	57.61	69.58	70.04	65.75
	mean	50.41	60.56	61.14		53.97	63.79	63.91	
	LSD $_{p \le 0.05}$ for	iron – 0.54, silicon – 0.89, interaction – 1.55				iron – 0.51, silicon – 0.63, interaction – 1.08			
Leaf chlorophyll content (Spad)	0	52.91	60.56	60.08	57.85	50.89	54.82	55.93	53.88
	250	57.89	69.57	68.09	65.18	53.51	58.48	57.97	56.65
	500	62.85	76.49	77.09	72.14	56.83	63.78	62.89	61.17
	mean	57.88	68.87	68.42		53.74	59.03	58.93	
	LSD $_{p \le 0.05}$ for	iron – 0.84, silicon – 0.67, interaction – 1.16				iron – 1.10, silicon – 1.55, interaction – n.s.			
Fresh weight (g)	0	473.74	523.80	513.86	503.80	508.07	536.10	533.89	526.02
	250	500.51	555.18	557.80	537.83	530.31	622.43	608.40	587.05
	500	542.53	635.99	634.78	604.43	600.62	702.18	697.42	666.74
	mean	505.59	571.66	568.81		546.33	620.24	613.24	
	LSD $_{p \le 0.05}$ for	iron – 10.57, silicon – 7.91, interaction – 13.70				iron – 43.48, silicon – 24.75, interaction – n.s.			
Dry weight (g)	0	68.16	75.37	73.94	72.49	73.63	77.70	77.38	76.23
	250	71.50	79.31	79.69	76.83	75.98	89.17	87.16	84.10
	500	77.28	90.60	90.42	86.10	85.68	100.17	99.49	95.11
	mean	72.32	81.76	81.35		78.43	89.01	88.01	
	LSD $_{p \le 0.05}$ for	iron – 1.51, silicon – 1.13, interaction – 1.96				iron – 1.02, silicon – 1.44, interaction – 2.49			

Chelated iron = Fe-EDDHA 6%, silicon = potassium silicate (K_2SiO_3)

Table 2. Effect of chelated iron and silicon on tomato leaf contents of N, P, K, Fe and proline in 2013 and 2014 seasons

Tested ingredients	Chelated iron ($mg \cdot L^{-1}$)	2013				2014			
		silicon ($mmol \cdot L^{-1}$)							
		0	2	4	mean	0	2	4	mean
N (%)	0	2.03	2.26	2.28	2.19	2.27	2.48	2.42	2.39
	250	2.21	2.41	2.35	2.32	2.43	2.61	2.59	2.54
	500	2.34	2.55	2.48	2.46	2.53	3.16	3.21	2.97
	mean	2.19	2.41	2.37		2.41	2.75	2.74	
	LSD $_{p \le 0.05}$ for	iron – 0.05, silicon – 0.03, interaction – 0.05				iron – 0.07, silicon – 0.03, interaction – 0.06			
P (%)	0	0.32	0.41	0.40	0.38	0.38	0.45	0.46	0.43
	250	0.39	0.49	0.50	0.46	0.44	0.55	0.52	0.50
	500	0.46	0.60	0.58	0.55	0.50	0.61	0.63	0.58
	mean	0.39	0.50	0.50		0.44	0.53	0.54	
	LSD $_{p \le 0.05}$ for	iron – 0.02, silicon – 0.03, interaction – n.s.				iron – 0.02, silicon – 0.02, interaction – n.s.			
K (%)	0	2.14	2.32	2.28	2.25	2.31	2.47	2.50	2.43
	250	2.31	2.56	2.47	2.45	2.48	2.72	2.69	2.63
	500	2.47	2.76	2.78	2.67	2.61	2.93	3.01	2.85
	mean	2.31	2.55	2.51		2.47	2.71	2.73	
	LSD $_{p \le 0.05}$ for	iron – 0.07, silicon – 0.05, interaction – 0.08				iron – 0.02, silicon – 0.05, interaction – 0.09			
Fe (ppm)	0	102.09	112.42	107.95	107.49	98.43	104.48	105.12	102.68
	250	122.92	132.69	133.69	129.77	111.58	120.45	122.90	118.31
	500	130.17	141.59	140.54	137.44	126.50	134.62	135.26	132.13
	mean	118.40	128.90	127.39		112.17	119.85	121.09	
	LSD $_{p \le 0.05}$ for	iron – 5.52, silicon – 2.53, interaction – n.s.				iron – 0.96, silicon – 0.97, interaction – 1.68			
Proline ($mg \cdot g^{-1}$)	0	6.24	5.09	5.19	5.51	5.86	4.11	4.09	4.69
	250	5.31	3.58	3.68	4.19	4.04	2.83	2.73	3.20
	500	4.12	2.88	2.78	3.26	3.10	1.96	2.04	2.37
	mean	5.22	3.85	3.88		4.33	2.97	2.96	
	LSD $_{p \le 0.05}$ for	iron – 0.31, silicon – 0.12, interaction – 0.21				iron – 0.41, silicon – 0.16, interaction – 0.29			

Chelated iron = Fe – EDDHA 6%, silicon = potassium silicate (K_2SiO_3)

contents and less proline content in tomato leaves than the control plants in two experiment seasons

However, there was no significant difference between the silicate doses (2 and 4 mmol·L^{-1}) for the analyzed variables (tab. 2). The results of other researches have shown that the silicon causes an increase in the contents of N, P, K and Fe in plants [Olle 2014, Ibrahim et al. 2015, Olle and Schnug 2016]. These results can be a positive consequence to enhanced silicon for root structures and that led to improve the root growth [Vlamis and Williams 1967, Carvalho-Pupatto et al. 2003] leading to more absorption of nutrients from the soil, which increases the concentration of nutrients in leaf tissue [Putra et al. 2010], the effect of silicon on K uptake may be due to the activation of H-ATPase in the membranes [Liang 1999]. Many studies reported that the application of silicon lowered the accumulation of proline in leaves of plants [Kaya et al. 2006, Tuna et al. 2008, Abu-Muriefah 2015, Hajipour and Jabbarzadeh 2015, Bybordi 2016]. This result may be due to that silicon application reduces the stress effects and activates antioxidant systems in plants. Silicon can reduce the amount of hydrogen peroxide and malondialdehyde that provide the context for proline decrease [Hajipour and Jabbarzadeh 2015].

The effect of interaction between the chelated iron and silicon on mineral nutrients and proline content, foliar application at 500 mg Fe-EDDHA 6% L^{-1} with 2 or 4 mmol K_2SiO_3 L^{-1} gave the highest values of leaf N, P, K and Fe concentrations and the lowest value of proline content in both seasons. The differences among treatments were significant in both seasons, except Fe content in the first season and P in both seasons where it was insignificant.

Yield and its components

The analysis of the results obtained in the present study showed a significant increase in fruit weight, fruit size, early and total yield feddan^{-1} with increasing of chelated iron levels in both seasons (tab. 3). The maximum values were found at 500 mg·L^{-1} of Fe-EDDHA 6%. However, the plants showed the minimum response to the control treatment. Resembling results were obtained by Kazemi [2013] and Houimli et al. [2015]. This might be due to the fact, that iron has a positive effect on the synthesis and activity of chlorophylls, thereby it increases the photosynthesis. The ability to photosynthesize and produce more food increase the generative power, enabling plants to hold more fruits [Kazemi 2013], thereby increase the yield and its component. In the present study the effect of iron chelated on tomato yield and its components may be due to the effect of chelated iron in leaf content of nutrient element (tab. 2), which reflected on growth and chlorophyll content of plant (tab. 1) and finally led to an increase of the yield and its components of tomato (tab. 3).

As shown in Table 3, the fruit weight, fruit size, early and total yield in both seasons were markedly higher in presence of K_2SiO_3 compared to its absence, the highest values were obtained with foliar application at 2 or 4 mmol K_2SiO_3 L^{-1} with no significant differences between them, while the lowest values were recorded in the control treatment in both seasons. The above results are in conformity with the findings of Jarosz [2014] and Lu et al. [2016]. Silicon increases the absorption of N, P, K and Fe and thus increasing plant content of them (tab. 2), besides, increased leaf chlorophyll content (tab. 1), resulted in enhanced of plant growth (tab. 1), thus helps in increased yield and its components.

Application of iron in combination with silicon resulted in a remarkable effect on fruit weight, fruit size, early and total yield in both seasons. The application of 500 mg Fe-EDDHA 6% L^{-1} with 2 or 4 mmol K_2SiO_3 L^{-1} gave the highest values, while the lowest values were obtained from plants grown without any applications of iron and silicon in the two seasons.

Fruit quality of tomato

The fruit contents of vitamin C, total soluble solids (T.S.S), Ca and fruit firmness are presented in Table 4. Statistically significant differences between the various chelated iron treatments were noted for vitamin C, Ca and fruit firmness. The highest contents of vitamin C (19.40 and 18.18 mg·100 g^{-1} juice), Ca (11.65 and 9.74 mg·100 g^{-1} DW) and fruit firmness (36.03 and 44.31 g·mm^{-2}) were obtained

Table 3. Effect of chelated iron and silicon on tomato fruit weight, fruit size, early and total yield in 2013 and 2014 seasons

Studied features	Chelated iron ($\text{mg}\cdot\text{L}^{-1}$)	2013				2014			
		silicon ($\text{mmol}\cdot\text{L}^{-1}$)							
		0	2	4	mean	0	2	4	mean
Fruit weight (g)	0	88.33	97.02	97.48	94.28	93.87	103.26	101.56	99.56
	250	94.89	109.48	107.13	103.83	101.10	115.32	114.67	110.36
	500	104.46	116.51	115.92	112.30	109.83	123.42	123.72	118.99
	mean	95.90	107.67	106.84		101.60	114.00	113.32	
	LSD $_{p\leq0.05}$ for	iron – 1.30, silicon – 1.15, interaction – 1.99				iron – 5.85, silicon – 3.65, interaction – n.s			
Fruit size (cm^3)	0	47.86	58.00	56.85	54.50	55.06	65.24	65.20	61.83
	250	53.63	70.98	69.86	64.82	63.49	76.57	77.54	72.53
	500	63.11	81.20	79.91	74.74	71.15	93.10	93.83	86.03
	mean	54.87	70.33	68.87		63.23	78.30	78.86	
	LSD $_{p\leq0.05}$ for	iron – 3.72, silicon – 2.79, interaction – n.s				iron – 1.69, silicon – 3.99, interaction – n.s			
Early yield (ton/fed)	0	0.95	1.22	1.20	1.12	1.20	1.32	1.35	1.29
	250	1.21	1.34	1.31	1.29	1.31	1.44	1.49	1.42
	500	1.26	1.40	1.42	1.36	1.40	1.58	1.56	1.51
	mean	1.14	1.32	1.31		1.30	1.45	1.47	
	LSD $_{p\leq0.05}$ for	iron – 0.07, silicon – 0.04, interaction – 0.06				iron – 0.02, silicon – 0.03, interaction – n.s			
Total yield (ton/fed)	0	6.81	8.07	7.97	7.62	7.26	8.30	8.34	7.96
	250	7.67	8.78	8.82	8.42	8.03	9.07	9.11	8.74
	500	8.21	10.04	9.84	9.36	8.84	10.30	10.35	9.83
	mean	7.56	8.96	8.88		8.04	9.23	9.26	
	LSD $_{p\leq0.05}$ for	iron – 0.07, silicon – 0.16, interaction – 0.28				iron – 0.07, silicon – 0.10, interaction – 0.18			

Chelated iron = Fe-EDDHA 6%, silicon = potassium silicate (K_2SiO_3), fed (feddan) = 0.42 hectare

Table 4. Effect of chelated iron and silicon on tomato fruit contents of V.C, T.S.S, Ca and fruit firmness in 2013 and 2014 seasons

Tested features	Chelated iron ($mg \cdot L^{-1}$)	2013				2014			
		silicon ($mmol \cdot L^{-1}$)							
		0	2	4	mean	0	2	4	mean
V.C ($mg \cdot 100\ g^{-1}$)	0	15.75	16.36	16.68	16.26	14.92	15.71	16.00	15.54
	250	16.56	18.07	17.94	17.52	15.91	17.07	16.91	16.63
	500	18.06	20.26	19.88	19.40	16.82	18.95	18.76	18.18
	mean	16.79	18.23	18.17		15.88	17.25	17.22	
	LSD $_{p \leq 0.05}$ for	iron – 0.26, silicon – 0.23, interaction – 0.40				iron – 0.27, silicon – 0.26, interaction – 0.45			
T.S.S (%)	0	8.01	7.34	7.36	7.57	7.29	6.27	6.48	6.68
	250	7.14	6.81	6.70	6.88	5.64	5.07	5.18	5.30
	500	6.27	5.13	5.27	5.56	5.23	4.73	4.91	4.96
	mean	7.14	6.43	6.44		6.05	5.36	5.52	
	LSD $_{p \leq 0.05}$ for	iron – 0.15, silicon – 0.26, interaction – n.s.				iron – 0.09, silicon – 0.09, interaction – 0.15			
Ca ($mg \cdot 100\ g^{-1}$ DW)	0	7.91	9.33	9.51	8.92	6.99	8.01	7.94	7.65
	250	9.04	11.44	11.94	10.81	7.86	8.97	8.86	8.56
	500	10.40	12.63	11.93	11.65	8.76	10.27	10.18	9.74
	mean	9.12	11.13	11.13		7.87	9.08	8.99	
	LSD $_{p \leq 0.05}$ for	iron – 0.60, silicon – 0.36, interaction – 0.62				iron – 0.51, silicon – 0.31, interaction – n.s.			
Fruit firmness ($g \cdot mm^{-2}$)	0	26.45	30.01	30.45	28.97	32.90	37.97	36.84	35.90
	250	28.76	34.76	34.96	32.83	36.36	41.02	40.20	39.19
	500	31.23	38.92	37.94	36.03	39.53	47.03	46.37	44.31
	mean	28.82	34.56	34.45		36.26	42.01	41.13	
	LSD $_{p \leq 0.05}$ for	iron – 0.60, silicon – 0.56, interaction – 0.98				iron – 0.68, silicon – 0.47, interaction – 0.82			

Chelated iron = Fe-EDDHA 6%, silicon = potassium silicate (K_2SiO_3)

from the 500 $mg \cdot L^{-1}$ Fe-EDDHA 6% treatment, but the lowest values of vitamin C (16.26 and 15.54 $mg \cdot 100\ g^{-1}$ juice), Ca (8.92 and 7.65 $mg \cdot \cdot 100\ g^{-1}$ DW) and fruit firmness (28.97 and 35.90 $g \cdot mm^{-2}$) were obtained from the control treatment, in the first and second seasons, respectively. This was in agreement with Kazemi [2013], Awar and Karami [2016] and Houimli et al. [2016]. The improvement in vitamin C content might be due to the role of iron as activator of many enzymes in the increase of activity of ascorbic acid oxidase enzyme [Batra et al. 2006]. The increased Ca content and fruit firmness of tomato fruits might be attributed to the role of iron in the increase of Ca uptake and transport in plants [Roosta and Mohsenian 2012], which leads to increase the Ca concentration in fruits and increase of fruit firmness, as calcium has a role in the strength of tomato tissue because it halts the destruction of pectate which are necessary for cell wall and plant tissue strength [Malakouti and Rezaie 2001]. The application of chelated iron significantly reduced the T.S.S contents of tomato fruits (tab. 4). Fe-EDDHA 6% at 500 $mg \cdot L^{-1}$ reduced T.S.S contents by 7.34 and 7.42% to 5.56 and 4.96%, compared to 7.57 and 6.68% in the control, in the first and second seasons respectively. Asri and Sonmez [2010] found that the application of Fe was not effective on total soluble solids (TSS) of tomato fruits.

The results showed that foliar application of silicon had significant effects on vitamin C, Ca, T.S.S contents and fruit firmness in the two seasons (tab. 4). Vitamin C, Ca contents and fruit firmness were increased by foliar silicon application. These findings agree with Stamatakis et al. [2003]. The highest values of vitamin C, Ca contents and fruit firmness were recorded in plants which treated with 2 mmol potassium silicate L^{-1}. The increase in vitamin C, Ca and fruit firmness were about (92.1 and 92.06%), (81.94 and 86.67%) and (83.39 and 86.31%) in the first and second seasons, respectively compared to control treatment. The physiological mechanisms underlying the effects of silicon on the uptake and translocation of Ca by plants are not clear. Differences in the modulation of cell walls due to deposition of silicon [Inanaga and Okasaka 1995, Epstein 1999] it may enhance the indiffusible anion sites, which adsorb Ca, thus imposing an elevated Ca content in the plant tissues, therefore an enhancement of fruit firmness [Malakouti and Rezaie 2001]. Fruits from plants treated with either 2 or 4 mmol potassium silicate L^{-1} showed significantly lesser of T.S.S compared to untreated plants. The lowest T.S.S was observed in fruits from plants treated with 2 mmol potassium silicate L^{-1} in both seasons, similar response was observed also in tomato [Weerahewa and David 2015]. Petersen et al. [1998] attributed the enhancing in T.S.S in tomato fruit under salt stress to the concentration effect which originating from the reduction of water content in fruits, due to the adaptation of the plants with this condition. The silicon foliar application may act on alleviating the salt stress and enhance the relative water content in the cells [Bybordi 2013], which may lead to increase contents of T.S.S in tomato fruit.

Regarding the effect of interaction between iron and silicon levels, it was significant, except the T.S.S in the first season, and Ca concentration in the second season. The highest values of vitamin C, Ca, fruit firmness and the lowest values of T.S.S were obtained from foliar application of 500 mg Fe-EDDHA 6% L^{-1} combined with 2 mmol K_2SiO_3 L^{-1} in the two seasons.

CONCLUSIONS

The present study showed that foliar application of chelated iron (Fe-EDDHA 6%) and silicon ($K_2SiO_{3)}$ may alleviate the effect of salt stress in tomato through increasing the overall growth, chlorophyll content, nutrient elements (N, P, K and Fe), yield and its components (fruit weight and size) and fruit quality (Vitamin C, Ca and firmness). The combination of a chelated iron (500 mg Fe-EDDHA 6% L^{-1}) with silicon (2 mmol K_2SiO_3 L^{-1}) may be an even more effective means to achieve this goal. Nevertheless, further research is required to confirm these results in various tomato cultivars under varying growth conditions.

REFERENCES

Abd El Razik, T.M., Sabra, A.S., Astatkie, T., Hegazy, M.H., Grulova, D., Said-Al Ahl, H.A.H. (2016). Response of growth, essential oil content and its constituents of plectranthus amboinicus to iron and/or urea foliar application under saline irrigation. Int. J. Pharm. Pharm. Sci., 8(8), 223–231.

Abu-Muriefah, S.S. (2015). Effects of silicon on membrane characteristics, photosynthetic pigments, antioxidative ability, and mineral element contents of faba bean (*Vicia faba* L.) plants grown under Cd and Pb stress. Int. J. Adv. Res. Biol. Sci., 2(6), 1–17.

Al-aghabary, K., Zhu, Z.J., Shi, Q.H. (2005). Influence of silicon supply on chlorophyll content, chlorophyll fluorescence, and antioxidative enzyme activities in tomato plants under salt stress. J. Plant Nutr., 27(12), 2101–2115.

Al Janabi, H.Y.A. (2016). Effect of irrigation water salinity and iron fertilizers on soil salinity, growth and yield of *Cucurbita pepo* (L.). Adv. Life Sci. Technol. 45, 13–21.

AOAC (1990). Official Methods of Analysis of the Association of Official Agriculture Chemists. Published by Association of Official Agriculture Chemists, 13 Ed. Washington, D.C.

Asri, F.O., Sonmez, S. (2010). Reflection of different applications of potassium and iron fertilization on tomato yield and fruit quality in soilless medium. J. Food Agric. Environ., 8(3–4), 426–429.

Asri, F.O., Sonmez, S. (2012). Effects of different potassium and iron levels on seasonal changes of nutrient concentrations of tomato plant grown in soilless culture. Afr. J. Agric. Res., 7(1), 28–33.

Awar, R., Karami, E. (2016). Effect of macro and micro elements foliar spray on the qaulity and quantity of tomato (*Solanum lycopersicum*). IJAPR, 4(2), 22–28.

Bates, L.S., Waldren, R.P., Teare, I.D. (1973). Rapid determination of free proline for water stress studies. Plant Soil, 39, 205–207.

Batra, V.K., Makhanlal, K.O.P., Arora, S.K., Suthar, M.R. (2006). Effect of foliar application of micronutrients on the quality and self life of tomato. Haryana J. Hort. Sci., 35(1–2), 140–142.

Burt, R. (ed.) (2004). Soil survey laboratory methods manual. Soil survey investigations report No 42. Natural Resources Conservation Services, USDA.

Bybordi, A. (2014). Interactive effects of silicon and potassium nitrate in improving salt tolerance of wheat. J. Integr. Agric., 13(9), 1889–1899.

Bybordi, A. (2016). Influence of zeolite, selenium and silicon upon some agronomic and physiologic characteristics of canola grown under salinity. Commun. Soil Sci. Plant Anal., 47(7), 832–850.

Carvalho-Pupatto, J.G., Bull, L.T., Crusciol, C.A.C., Mauad, M., Silva, R.H. (2003). Effect of blast furnace scoria on root growth and rice yield. Pesq. Agropec. Bras., 38, 938–943.

Celik, H., Katkat, A.V. (2007). Some parameters in relation to iron nutrition status of peach orchards. J. Biol. Environ. Sci., 13, 111–115.

Cemeroglu, B. (1992). Basic analysis methods in fruit and vegetables processing industry. Biltav Publication, Ankara, 381 p.

Chapman, H.D., Pratt, P.F. (1982). Methods of analysis for soil, plant and water. Chapman Publishers, Riverside, California.

Epstein, E. (1999). Silicon. Annu. Rev. Plant Physiol. Plant Mol. Biol., 50, 641–664.

Crusciol, C.A.C., Pulz, A.L., Lemos, L.B., Soratto, R.P., Lima, G.P.P. (2009). Effects of silicon and drought stress on tuber yield and leaf biochemical characteristics in potato. Crop Physiol. Metab., 49, 949–954.

Eskandari, H. (2011). The importance of iron (Fe) in plant products and mechanism of its uptake by plants. J. Appl. Environ. Biol. Sci., 1(10), 448–452.

Evenhuis, B., Dewaard, T.W. (1980). Principles and practices in plant analysis. FAO Soils Bull., 38, 152–165.

Gomez, K.N., Gomez, A.A. (1984). Statistical procedures for agricultural research, 2nd ed. John Wiley and Sons, New York, 68 p.

Gong, H., Zhu, X., Chen, K., Wang, S., Zhang, C. (2005). Silicon alleviates oxidative damage of wheat plants in pots under drought. Plant Sci., 169, 313–321.

Gorecki, R.S., Danielski-Busch, W. (2009). Effect of silicate fertilizers on yielding of greenhouse cucumber (*Cucumis sativus* L.) in container cultivation. J. Elementol., 14(1), 71–78.

Hajipour, H., Jabbarzadeh, Z. (2015). Effect of foliar application of silicon on physiological responses of chrysanthemum (*dendranthema×grandiflorum*) at two different growth stages. J. Ornam. Plants, 6(1), 39–47.

Hanafy, A.H., Harb, E.M., Higazy, M.A., Morgan, S.H. (2008). Effect of silicon and boron foliar applications on wheat plants grown under saline soil conditions. Int. J. Agric. Res., 3(1), 1–26.

Heidari, M., Sarani, S. (2012). Growth, biochemical components and ion content of Chamomile (*Matricaria chamomilla* L.) under salinity stress and iron deficiency. J. Saudi Soc. Agric. Sci., 11, 37–42.

Houimli, S.I.M., Jdidi, H., Boujelben, F., Denden, M. (2015). Improvement of tomato (*Lycopersicon esculentum* L.) productivity in calcareous soil by iron foliar application. Int. J. Adv. Res., 3(9), 1118–1123.

Houimli, S.I.M., Jdidi, H., Boujelben, F., Denden, M. (2016). Fruit yield and quality of iron-sprayed tomato (*Lycopersicon esculentum* Mill.) grown on high pH calcareous soil. IJISR, 20(2), 268–271.

Ibrahim, H.I.M., Sallam, A.M., Shaban, K.A. (2015). Impact of irrigation rates and potassium silicate fertilizer on seed production and quality of Fahl Egyptian clover and soil properties under saline conditions. Am.-Eurasian J. Agric. Environ. Sci., 15(7), 1245–1255.

Inada, K. (1985). Spectral ratio of reflectance for estimating chlorophyll content of leaf. Jpn. J. Crop Sci., 54, 261–265.

Inanaga, S., Okasaka, A. (1995). Calcium and silicon binding compounds in cell walls of rice shoots. Soil Sci. Plant Nutr., 41, 103–110.

Incesu, M., Yesiloglu, T., Cimen, B., Yilmaz, B. (2015). Influences of different iron levels on plant growth and photosynthesis of W. Murcott mandarin grafted on two rootstocks under high pH conditions. Turk. J. Agric. For., 39, 838–844.

Jarosz, Z. (2014). The effect of silicon application and type of medium on yielding and chemical composition of tomato. Acta Sci. Pol. Hortorum Cultus, 13(4), 171–183.

Kamal, A.M. (2013). Influence of irrigation levels, antitranspirants and potassium silicate on growth, fruit yield and quality of sweet pepper plants (*Capsicum annnuum* L.) grown under drip irrigation. J. Plant Prod. Mansoura Univ., 4(11), 1581–1597.

Kaya, C., Tuna, L., Higgs, D. (2006). Effect of silicon on plant growth and mineral nutrition of maize grown under water-stress conditions. J. Plant Nutr., 29, 1469–1480.

Kazemi, M. (2013). Effect of foliar application of iron and zinc on growth and productivity of cucumber. Bull. Env. Pharmacol. Life Sci., 2(11), 11–14.

Kazemi, M. (2013). Effect of Zn, Fe and their combination treatments on the growth and yield of tomato. Bull. Env. Pharmacol. Life Sci., 3(1), 109–114.

Kitson, R.E., Mellon, M.G. (1944). Colorimetric determination of phosphorus as vanadomolydophosphoric acid. Ind. Eng. Chem. Anal. Ed., 16, 379–383.

Liang, Y. (1999). Effects of silicon on enzyme activity and sodium, potassium and calcium concentration in barley under salt stress. Plant Soil, 209, 217–224.

Liang, Y.C., Chen, Q., Liu, Q., Zhang, W.H., Ding, R.X. (2003). Exogenous silicon (Si) increases antioxidant enzyme activity and reduces lipid peroxidation in roots of salt-stressed barley (*Hordeum vulgare* L.). J. Plant Physiol., 160, 1157–1164.

Liang, Y.C., Sun, W.C., Zhu, Y.G., Christie, P. (2007). Mechanisms of silicon-mediated alleviation of abiotic stresses in higher plants: a review. Environ. Pollut., 147, 422–428.

Lopez, C.M.L., Takahashi, H., Yamazaki, S. (2002). Plant-water relations of kidney bean plants treated with NaCl and foliarly applied glycinebetaine. J. Agron. Crop Sci., 188, 73–80.

Lu, M.M.D., De Silva, D.M.R., Peralta, E.K., Fajardo, A.N., Peralta, M.M. (2016). Growth and yield of tomato applied with silicon supplements with varying material structures. Philip. e-Journal Appl. Res. Dev., 6, 10–18.

Ma, J.F., Takahashi, E. (2002). Soil, fertilizer and plant silicon research in Japan. Elsevier, Amsterdam, pp. 1–2.

Ma, J.F., Yamaji, N. (2008). Functions and transport of silicon in plants. Cell. Mol. Life Sci., 65, 3049–3057.

Malakouti M.J., Razaie H. (2001). The role of sulfur, calcium and magnesium on the quantity and improve the quality of agricultural products. Agriculture Education Press.

Mohaghegh, P., Khani, A.M., Tehrani, A.F. (2015). Effects of silicon on the growth, ion distribution and physiological mechanisms that alleviate oxidative stress induced by powdery mildew infection in pumpkin (*Cucurbita pepo*, var. *Styriac*). J. Crop Prot., 4(3), 419–429.

Mohsen, A.A., Ebrahim, M.K.H., Ghoraba, W.F.S. (2013). Effect of salinity stress on *Vicia faba* productivity with respect to ascorbic acid treatment. Iran. J. Plant Phys., 3, 725–736.

Olle, M. (2014). The effect of silicon on the organically grown cucumber transplants growth and quality. Proceedings of 16th World Fertilizer Congress of CIEC, Rio de Janeiro, pp. 90–92.

Olle, M., Schnug, E. (2016). The influence of foliar applied silicic acid on N, P, K, Ca and Mg concentrations in field peas. J. Kulturpflanz., 68(1), 7–10.

Ostrowska, A., Gawlinski, S., Szczubialka, Z. (1991). Methods of analysis and evaluation of soil and plants. IOŚ, Warszawa (in Polish).

Petersen, K.K., Willumsen, J., Kaack, K. (1998). Composition and taste of tomatoes as affected by increased salinity and different salinity sources. J. Hort. Sci., 73, 205–215.

Pourgholam, M., Nemati, N., Oveysi, M. (2013). Effect of zinc and iron under the influence of drought on prolin, protein and nitrogen leaf of rapeseed (*Brassica napus*). Ann. Biol. Res. 4(7), 200–203.

Putra, E.T.S., Zakaria, W., Abdullah, N.A.H., Saleh, G. (2010). Weak neck of Musa sp. cv. Rasthali: A review on its genetic, crop nutrition and post-harvest. J. Agron., 9(2), 45–51.

Ramezani, M.R., Seghatoleslami, M.J., Mousavi, G., Sayyari-Zahan, M.H. (2012). Effect of salinity and foliar application of iron and zinc on yield and water use efficiency of Ajowan (*Carum copticum*). Int. J. Agric. Crop Sci., 4(7), 421–426.

Roosta, H.R., Mohsenian, Y. (2012). Effects of foliar spray of different Fe sources on pepper (*Capsicum annum* L.) plants in aquaponic system. Sci. Hortic., 146, 182–191.

Rout, G.R., Sahoo, S. (2015). Role of iron in plant growth and metabolism. Rev. Agric. Sci., 3, 1–24.

Snedecor, G.A., Cochran, W.G. (1980). Statistical Methods, 7th ed. Iowa State Univ. Press, Ames, Iowa.

Stamatakis, A., Papadantonakis, N., Savvas, D., Kefalas, P. (2003). Effects of silicon and salinity on fruit yield and quality of tomato grown hydroponically. Acta Hortic., 609, 141–147.

Sukkaew, E., Amkha, S., Inboonchoy, T., Mala, T. (2016). Utilization of silicon fertilizer application on pepper seedling production. Modern Appl. Sci., 10(11), 264–272.

Tantawy, A.S., Salama, Y.A.M., Abdel Mawgoud, A.M.R., Zaki, M.F. (2013). Interaction of Fe and salinity on growth and production of tomato plants. World Appl. Sci. J., 27(5), 597–609.

Tuna, A.L., Kaya, C., Higgs, D., Murillo-Amador, B., Aydemir, S., Girgin, A.R. (2008). Silicon improves salinity tolerance in wheat plants. Environ. Exp. Bot., 62, 10–16.

Uchimura, Y, Ogata, T., Sato, H., Matsue, Y. (2000). Effects of silicate application on lodging, yield and palatability of rice grown by direct sowing culture. Jpn J. Crop Sci., 69, 487–492.

Vlamis, J., Williams, D.E. (1967). Manganese and silicon interaction in the gramineae. Plant Soil, 27, 131–140.

Wang, Y.M., Wyllie, S.G., Leach, D.N. (1996). Chemical changes during the development and ripening of the fruit of *Cucumis melo* (cv. Makdimon). J. Agric. Food Chem., 44, 210–216.

Weerahewa, D., David, D. (2015). Effect of silicon and potassium on tomato anthracnose and on the postharvest quality of tomato fruit (*Lycopersicon esculentum* Mill.). J. Natl. Sci. Found. Sri Lanka, 43(3), 273–280.