Research Article

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MEDITERRANEAN AGRICULTURAL SCIENCES
(2022) 35(1): 1-6
DOI: 10.29136/mediterranean.1020532

Effects of iron fertilization on plant growth, yield components and quality traits of industrial tomatoes

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ARTICLE INFO

Received: November 8, 2021
Received in revised form: December 13, 2021
Accepted: December 14, 2021

***Keywords*:**

FeEDDHA
Marketable yield
Paste yield
Titratable acidity

ABSTRACT

This study was conducted in order to investigate the effects of different iron applications on the yield and fruit quality traits of industrial tomatoes. Experiments were conducted in a randomized block design with three replications under field conditions. The H-5803 and Delfo hybrid industrial tomato cultivars were used as the plant material and experimental treatments included 0 (control), 1.0, 2.0, 3.0, 4.0 kg ha^{-1} FeEDDHA (6% Fe) applications. The greatest increases in plant growth parameters (fruit length and width), marketable and paste yields were achieved with 2.0 and 3.0 kg ha^{-1} FeEDDHA. Iron treatments had significant effects on fruit weight, width, and lengths, and the greatest values were obtained from 2.0 and 3.0 kg ha^{-1}. Increasing iron treatments also increased fruit quality traits (dry matter, soluble solids, total acidity). A significant relationship, however, was not observed between iron treatments and fruit pH values. In terms of plant nutrition, fertilizer cost, and yield increases, 2.0 kg ha^{-1} FeEDDHA treatment could be recommended as a useful fertilization strategy in tomato cultivation.

1. Introduction

Tomato (*Lycopersicon esculentum* Mill.) is the most commonly cultivated vegetable worldwide under field and greenhouse conditions (Kallo 1986). Tomato is consumed in different forms including bulk-paste, puree, ketchup, tomato juice, fresh and dry tomato. Several researchers have investigated the effects of different plant nutrients on tomato yield and quality and indicated that some of these nutrients play a key role in tomato cultivation (Dorais et al. 2001). Among these nutrients, micronutrients, especially iron, were reported as the key element. Iron plays a significant role in tomato nutrition, development, fruit yield, and quality of tomato. Iron acts as a cofactor for about 140 enzymes catalyzing biochemical reactions. Besides, iron plays an important role in chlorophyll synthesis, chloroplast development, transpiration function, electron transfer, and various other metabolic processes (Mengel et al. 1994; Chohura et al. 2009).

Previous studies have demonstrated that world and Turkish soils have various nutritional problems related to micronutrients and soils were mostly identified as being poor in micronutrients. Such deficiencies have various negative impacts on plants, as well as on humans and animals through the food chain. Iron deficiency is encountered in 27% of Turkish soils (Eyüpoğlu et al. 1998). Iron (Fe) deficiency in alkaline and/or calcareous soils result in a common nutritional disorder in plants grown in these soils because of the low solubility of Fe (Lindsay 1991). High pH, high bicarbonate ion concentrations in soils and irrigation waters, and high Ca^{+2}, Mg^{+2}, PO_4^{-3}, Cu^{+2}, Mn^{+2}, and Zn^{+2} concentrations of the soils significantly reduce the availability of iron in soils (Havlin et al. 1999; Kaçar and Katkat 2018).

Iron-containing fertilizers are used to improve the bioavailability of iron in soils. These fertilizers improve plant root development, positively influence plant iron uptakes and thus increase plant yield and quality (Chen and Aviad 1990; Padem and Öcal 1998). FeEDDHA efficiency is high in soils with different pH levels and iron-deficient plants (Kaçar and Katkat 2018). Sanchez-Sanchez et al. (2002, 2005) applied FeEDDHA compounds in soil and reported increased leaf iron concentrations and improved fruit quality parameters in tomato and citrus species. In another study, FeEDDHA was reported as the most efficient fertilizer in the prevention of chlorosis (Karaman 2003). Iron compounds are commonly applied through irrigation lines and such practices (fertigation) yield highly positive outcomes. Especially FeEDDHA could successfully be applied through drip lines (Kaçar and Katkat 2018).

Although iron is a very abundant nutrient in soils, chlorosis is very common in plants as a result of its deficiency. Finding high iron in soil analysis does not mean that the plant will not suffer from iron deficiency. Furthermore, high total iron concentrations in plant leaves do not guarantee that plants have adequate iron. Factors that cause iron deficiency in plants are those that prevent the absorption of iron from the soil through roots, its transport and metabolism within the plant. Differences between cultural processes and plant species are also among the factors that cause iron chlorosis. Fe-EDDHA is the recommended form of Fe to correct iron deficiency in calcareous soils (Lindsay 1984; Loué 1986; Benntt et al. 1988; Aktaş 1994; Shalau 2010; Kaçar and Katkat 2018). In the present study the effects of supplementary iron fertilization (FeEDDHA form) in the soil, on plant growth parameters of two commonly grown industrial tomato cultivars were investigated under field conditions and changes in fruit characteristics, fruit, and tomato paste yields with different iron treatments were assessed.

2. Material and Method

2.1. Experimental site and plant material

The experiments were conducted in the experimental fields of Mustafakemalpaşa Vocational School of Bursa Uludağ University (40°, 02ꞌ N, 28°, 23ꞌ E; altitude of 22 m) in the May-August growing season of the years 2020 and 2021. Commonly cultivated industrial-type hybrid tomato cultivars of ‘H-5803’ and ‘Delfo’ *(Lycopersicon esculentum* Mill.) were used as the plant materials for the experiments. Tomato seedlings were supplied from a commercial seedling company (Marmara Seedling Product. Agri. Industry Trade Co. Bursa, Turkey).

2.2. Soil and climate parameters of the experimental site

Experimental soils were clay-loam (sand: 23.6%; silt: 43.6%; clay: 32.8%) in texture with an average soil depth of 90 cm, nonsaline (0.49 dS m^{-1}) with slightly alkaline reaction (pH= 7.9) and high lime content (11.9%). Soils were rich in available potassium (283.0 mg kg^{-1}), low in phosphorus (11.8 mg kg^{-1}), poor in organic matter (1.8%), moderate in total nitrogen (0.17%). Available iron content was 7.70 mg kg^{-1}, volumetric water content was 38.3% at field capacity (0.03 MPa) and 23.2% at permanent wilting point (1.5 MPa); bulk density was identified as 1.41 g cm^{-3}.

In this region, the summers are generally hot and dry with precipitation in the winters. Climate data throughout the tomato growing season (May-August) of the years 2020 and 2021 and long-term (1928–2018) averages are provided in Table 1.

2.3. Experimental design and growth conditions

The experiments were conducted in a randomized block design with three replications. Each replicate (plot) was composed of one plant row and each row had 60 tomato plants. About 1.5 m spacing was provided between the plots and two plant rows were provided to prevent interactions with the surrounding environment. Treatments were randomly assigned to the plots. Before iron fertilization, nitrogen (ammonium sulphate), phosphorus (diammonium phosphate), and potassium (potassium sulphate) (150 kg ha^{-1} N, 80 kg ha^{-1} P_2O_5 and 50 kg ha^{-1} K_2O) were applied as basic fertilizers. All phosphorus and potassium fertilizers and half of the nitrogenous fertilizer were applied before planting at soil tillage and the rest of the nitrogen was applied at the small-fruit stage (Şalk et al. 2008). Tomato seedlings were manually planted on 14th of May in the first year (2020) and 20th of May in the second year (2021) at 30 x150 cm (*within-row spacing and between-row spacing)* spacing. Herbicide treatments were not applied and manual weed control was practiced with a hand hoe. Standard cultural practices were conducted throughout the growing season. Plants were irrigated from groundwater resources and applied through drip lines.

2.4. Iron fertilizer treatment

Five different iron doses [1.0 kg ha^{-1} (Fe_1), 2.0 kg ha^{-1} (Fe_2), 3.0 kg ha^{-1} (Fe_3) and 4.0 kg ha^{-1} (Fe_4)] were applied to the tomato plants. No iron fertilizer was applied to the control plots (Fe_0). The FeEDDHA with high availability at high pH conditions was used as iron fertilizer. FeEDDHA was supplied from a commercial dealer (Hunter Fe, Tarsa Agriculture, Industry and Trade Co, Antalya, Turkey). It contains 6% metallic iron (in iron chelate EDDHA form). It is in granular form and soluble in water. The iron fertilizer was dissolved in water, and then homogeneously applied to the soil manually. The first treatment was applied at the beginning of flowering, the second treatment was applied at the full-bloom stage and the last treatment was applied at the veraison stage of the fruits (Demir 2017).

2.5. Harvest, measurement and weighing, fruits analysis

Full-red fruits were harvested 5 times between 26 July and 25 August of the first year (2020) and 6 times between 4 August and 1 September of the second year (2021).

After each harvest, fruit diameter and length, single fruit weight, marketable yield, tomato paste yield, fruit dry matter, soluble solids contents, and fruit total acidity were determined. Following the last harvest, the average of all the parameters was calculated.

Before the harvest, plant height (*PH, cm*) and plant diameter (*PD, cm*) were measured in all treatment groups with the use of a tape measure.

Fruit weight *(FW, g)* was calculated by dividing the weight of all harvested fruits by the total number of fruits.

Fruit diameter *(FD, cm)* was measured from the middle cross-section of 30 fruits, and the average of them was taken. Fruit length *(FL, cm)* was measured with the use of a digital caliper.

For marketable yield *(MY, t* ha^{-1}*);* fruits were harvested at the full-red stage and classified as marketable or non-marketable fruits (fruits with mechanical, physiologic, and/or phytosanitary damages) (Campos et al. 2006). Following each harvest, marketable fruits were weighed and expressed in t ha^{-1} by considering 30 x150 cm spacing (Kuşçu et al. 2016).

For tomato paste yield *(PY, t* ha^{-1}*);* harvested tomatoes were washed and peeled. They were chopped, heated up to 85-90^{0}C (hot-processing method) and passed through a pulper. The resultant pulp was evaporated in open cookers until they reached soluble solids content of 28% (28^{0}Brix) (Cemeroğlu et al. 2003).

Following each harvest, three randomly selected fruits were washed with distilled water; seeds were removed, and ground. Dry matter (*DM, %*) was determined by oven drying at 70°C for 2 days. The soluble solids content *(SSC,* ^{0}*Brix)* of the fruit juice was measured with the use of a refractometer (Abbe-type refractometer, model 60/DR) (Tigchelaar 1986). Total acidity *(TA, %, in citric acid)* was determined by titration of the fruit juice with 0.1 N NaOH (Anonymous 1968).

2.6. Statistical analyses

Experimental results were subjected to analysis of variance (ANOVA) with the use of statistical software (IBM® SPSS® Statistics for Windows, Version 20.0, Copyright, 2011, IBM

Corp, Armonk, NY). Significant means (based on the F test) were compared with the use of Duncan's multiple range tests.

3. Results and Discussion

Different iron (FeEDDA) doses were applied to two different industrial tomato cultivars (H-5803 and Delfo) grown under field conditions and the relationships between the treatments and plant growth parameters PH and PD were investigated. As can be inferred from Table 2, significant differences were observed in PH and PDs among the treatments. The greatest PH in 'H-5803' and 'Delfo' cultivars were observed in Fe_2 and Fe_3 treatments respectively. Plant diameters significantly increased with the applications doses. In terms of plant diameters, Fe_2 was identified as the most efficient treatment. Similar to the present findings, Mohamadi et al. (2021) indicated that tomato PHs could significantly be increased with iron applications and combined iron and phosphorus treatments could even further increase PHs. Roosta and Mohsenian (2015) reported the greatest vegetative growth of eggplant was in iron-treated plants.

Iron treatments had significant effects on MYs of tomato plants and such effects varied with the iron doses (Table 2). Complying with the present findings, significant yield increases were reported in soybean (Schenkeveld et al. 2008), spinach (Zengin et al. 2010; Yılmaz et al. 2012), and tomato (Asri and Sönmez 2010) with iron treatments. Besides, Schenkeveld et al. (2008) investigated the effects of different iron compounds and indicated FeEDDHA as the most effective source of iron. In comparison to the control treatment, the greatest increase in MY was achieved with Fe_2 (21.62%) treatment in the 'H-5803' cultivar and with Fe_2 (32.22%) and Fe_3 (24.09%) treatments in 'Delfo' cultivar. The other treatments had limited effects on yield. For instance, in both cultivars, in comparison to the control, Fe_1 treatment did not have significant effects on yield. On the other hand, the degree of response of tomato cultivars to high-dose applications varied. For example, Fe_4 high dose treatment increased yield by 0.16% in 'H-5803' cultivar and decreased by 10.63% in 'Delfo' cultivar.

Iron deficiency has significant effects on agricultural practices of various regions and significantly limits the yield potential of field crops and vegetables (Hansen et al. 2006). According to Kobayashi et al. (2005), iron reduces crop yields in low-solubility calcareous and high-pH soils. Civelek (2006) conducted a study with soybean and reported significant increases in soybean yields with FeEDDHA treatments as compared to the control. In the present study, tomato plants were fertilized with iron fertilizers at different doses in the form of FeEDDHA, and the results are provided in Table 2. Variance analysis results revealed that iron treatments at different doses significantly increased PY. The greatest increase in PY in both cultivars was achieved with Fe_2 and Fe_3 treatments. In comparison to the control, Fe_2 and Fe_3 treatments increased PY respectively by 28.46 and 24.38% in the H-5803 cultivar and by 35.09 and 28.62% in 'Delfo' cultivar. The effects of low (Fe_1) and high (Fe_4) dose treatments on PY varied with the cultivars. Low dose treatment slightly increased the PY of both tomato cultivars (H-5803 and Delfo) (1.28 and 5.69%). On the other hand, Fe_4 treatment increased the PY of the 'H-5803' cultivar by 18.35% but reduced the PY of 'Delfo' cultivar by 5.69%.

The effects of different iron doses on tomato fruit characteristics (fruit length, width and weight) were found to be significant (Table 3). Increasing iron doses positively influenced fruit characteristics and fruit dimensions increased with increasing iron doses. The longest fruits were obtained from Fe_3 (H-5803) and Fe_2 (Delfo) treatments and the widest fruits were obtained from Fe_2 (H-5803) and Fe_4 (Delfo) treatments. Single fruit weights were influenced the most from Fe_2 and Fe_3 doses.

Table 1. Average weather conditions during the experimental period in 2020 and 2021

	Mean temperature °C			Precipitation (mm)		
Months	2020	2021	1928-2018	2020	2021	1928-2018
May	17.7	19.3	17.7	51.1	20.2	49.8
June	22.0	21.4	22.1	34.4	69.6	33.8
July	24.5	26.0	24.5	22.3	24.7	21.3
August	24.3	26.4	24.3	18.6	0.2	16.4

Table 2. The effect of iron applications (FeEDDHA) on some growth parameters and yield components in tomatoes

Treatments	PH (cm)	PD (cm)	MY ($t\ ha^{-1}$)	PY ($t\ ha^{-1}$)
		H-5803		
Fe_0	112.83 c	116.50 b	61.41 c	11.76 c
Fe_1	114.43 bc	116.33 b	61.90 c (0.81%)^X	11.91 bc (1.28%)^X
Fe_2	124.87 a	129.00 a	74.86 a (21.62%)	15.10 a (28.46%)
Fe_3	120.62 ab	121.83 b	73.80 ab (19.36%)	14.62 a (24.38%)
Fe_4	117.52 bc	119.33 b	61.50 bc (0.16%)	13.91 ab (18.35%)
		DELFO		
Fe_0	106.77 c	109.94 b	79.14 b	17.07 bc
Fe_1	105.60 c	112.16 b	83.42 b (5.39%)^X	18.04 b (5.69%)^X
Fe_2	113.09 b	121.66 a	104.67 a (32.22%)	23.06 a (35.09%)
Fe_3	120.14 a	120.24 a	98.93 a (24.09%)	21.96 a (28.62%)
Fe_4	106.99 c	117.07 ab	71.01 c (-10.53%)	16.10 c (-5.69%)

Different letters in each column represent significant differences at $P<0.05$ according to Duncan's multiple distribution tests. As: Fe_0 control "no iron application", Fe_1 1.0 kg ha^{-1}, (Fe_2) 2.0 kg ha^{-1}, Fe_3 3.0 kg ha^{-1} and Fe_4 4.0 kg ha^{-1}, PH plant height, PD plant diameter, MY marketable yield, PY paste yield, ^{X}% change from the control (Fe_0-Fe_1)/Fe_0)x100).

Table 3. The effect of iron applications (FeEDDHA) on fruit characteristics and quality in tomato

Treatments	FH (cm)	FD (cm)	FW (g)	SSC (⁰Brix)	pH	DM (%)	TA (%)
			H-5803				
Fe_0	5.76 c	5.30 c	92.62 c	5.33 d	4.38	5.43 e	0.35 c
Fe_1	5.90 bc	5.85 ab	98.17 b	5.44 c	4.33	5.57 d	0.39 c
Fe_2	6.05 ac	6.02 a	107.73 a	5.82 b	4.31	5.92 c	0.49 b
Fe_3	6.22 a	5.90 a	105.20 a	5.85 b	4.37	6.06 b	0.48 b
Fe_4	6.19 ab	5.55 bc	88.31 d	5.99 a	4.30	6.21 a	0.57 a
			DELFO				
Fe_0	5.86 c	4.88 c	102.40 b	6.04 c	4.40	6.21 c	0.32 d
Fe_1	6.06 ac	5.07 bc	102.21 b	6.07 c	4.39	6.22 c	0.31 d
Fe_2	6.38 a	5.20 ab	109.97 a	6.17 b	4.40	6.39 b	0.38 c
Fe_3	6.32 ab	5.18 ab	106.85 a	6.22 b	4.38	6.47 b	0.44 b
Fe_4	5.97 bc	5.38 a	91.31 c	6.35 a	4.37	6.57 a	0.54 a

Different letters in each column represent significant differences at $P<0.05$ according to Duncan's multiple distribution tests. As: Fe_0 control "no iron application", Fe_1 1.0 kg ha^{-1}, (Fe_2) 2.0 kg ha^{-1}, Fe_3 3.0 kg ha^{-1} and Fe_4 4.0 kg ha^{-1}, FH fruit length, FD fruit diameter, FW fruit weight, SSC soluble solids content, DM dry matter, TA titratable acidity.

In previous studies, it was reported that iron treatments increased the number of fruits, fruit size, and weight in tomatoes (Houimli et al. 2015; Sakya and Sulandjari 2019) and tuber weights in potatoes (Hadi et al. 2015). Chaurasia et al. (2005) pointed out the significance of foliar fertilizer applications and indicated that foliar treatments significantly increased the number of fruits and fruit dimensions (diameter and length) in tomatoes.

The soluble solids content is an important parameter in tomato paste production (Gould 1992). High dry matter and soluble solids content are desired in the tomato paste industry. Since high soluble solids content reduces the energy required to evaporate the juice from the fruit and shortens the process duration, it increases productivity in tomato paste production (DePascale et al. 2001; Johnstone et al. 2005; Patane and Cosentino 2010; Turhan 2020). As can be inferred from Table 3, the soluble solids content of tomato fruits was significantly influenced by the iron fertilizer treatments. The lowest soluble solids content was obtained from the control plants. In the control treatment, soluble solids content was identified as 5.33% in the 'H-5803'cultivar and 6.04% in the 'Delfo' cultivar. Increasing iron doses significantly increased the fruit soluble solids content and the greatest values were obtained from Fe_4 treatments. In Fe_4 treatment, soluble solids content was identified as 5.35% in 'H-5803' cultivar and 6.35% in 'Delfo' cultivar. Effects of different iron doses on fruit pH values were found to be nonsignificant. In other words, iron treatments did not any have positive or negative effects on fruit pH values (Table 3). As it was insoluble solids, some researchers indicated that tomato fruit quality parameters could be improved with micronutrient mixtures in which iron is included (Rahi et al. 2020). It was reported that different iron doses (Fetrilon-13 chelate) positively influenced grape soluble solids and total dry matter contents, pH and titratable acidity as compared to the control (Çoban et al. 2002).

The fruit dry matter contents were also significantly influenced by the iron treatments. There were significant positive relationships between iron doses and dry matter contents. Present findings on dry matter content comply with the findings of Asri and Sönmez (2010) which reported increasing tomato fruit dry matter contents with increasing potassium and iron treatments. In the present study, increasing dry matter contents were observed with increasing iron doses and the greatest values were obtained from F_4 treatments. On the other hand, in both cultivars (H-5803 and Delfo), the lowest dry matter contents were obtained from the control plants (Table 3).

Total acidity is an important quality parameter for tomato fruits. Organic acids give a sour taste to fruits and influence sweetness perception, thus influencing taste (Azodanlou et al. 2003). Micronutrients play a significant role in the fruit quality of tomatoes (Habashy et al. 2008). It was reported that the combined treatment of micronutrients (Zn+B+Fe) with potassium humate increased fruit acidity (Rahi et al. 2020). Similar findings were also observed in tomato plants treated with different iron doses. As can be inferred from Table 3, the lowest total acidity values were obtained from the control and Fe_1 treatments. The acidity values increased with increasing iron doses and the highest values were obtained from Fe_4 treatments.

4. Conclusions

The present findings revealed that soil iron treatments in FeEDDHA form had highly positive effects on tomato growth and development, FD and FL, thus FW, fruit dry matter, soluble solids content, and fruit titratable acidity. These findings also revealed that the marketable fruit yield and PY of industrial tomatoes could be improved with iron treatments. In terms of efficacy and economy, 2.0 kg ha^{-1} Fe treatment was found to be marked . The present findings proved that the inclusion of iron into fertilizer combinations might offer various advantages in crop and vegetable cultivation.

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