Foliar iron application improves fruit quality in soilless cultivation of the short-day strawberry cultivar 'Joly‘

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Iron (Fe) is an essential micronutrient for strawberries and a component of many vital plant enzymes. It plays a critical role in plant metabolic processes such as DNA synthesis, respiration, and photosynthesis. Fertigation is a common practice in strawberry cultivation, where minerals are supplied through a solution that is distributed in the root zone of the plants. At some critical stages of the plant, certain nutrients are needed in larger quantities to achieve higher yield and excellent fruit quality. Therefore, it is necessary to supply the nutrients through foliar application, as the roots are not able to take up sufficient amounts of nutrients. Experiments were conducted in spring 2021 near Zagreb (Croatia) with short-day strawberry (*Fragaria* × *ananassa* Duch.) cultivar 'Joly' grown on soilless media. Foliar iron - Fe-EDDHA solutions were applied in two different treatments: 1) Fe-EDDHA solutions 10 mL Fe-EDDHA 6% (Poly-Feed™) solution once at the beginning of flowering and 2) Fe-EDDHA solutions 10 mL Fe-EDDHA 6% (Poly-Feed™) solution once at the beginning of flowering and a second time at full bloom. Harvested fruits were analyzed for physicochemical properties (weight, dry matter, firmness, pH, total soluble solids, and total acidity) and mineral composition (N, P, K, Fe, Zn, Mn, Cu). Foliar treatment with Fe-EDDHA significantly reduced the acidity and improved the sweetness of the fruits compared to the fruits of the untreated plants (control). Treatment with Fe-EDDHA increased dry matter and had no positive effect on the increase of Fe content in fruits, only Zn, Mn and Cu showed some decrease.

INTRODUCTION

Strawberry (*Fragaria* × *ananassa* Duch.) is the most important berry fruit crop in the world, with an annual production of over 8.5 million t in 2018-2020 (FAO, 2022). Fruit quality is determined by antioxidant capacity, physicochemical and phytochemical properties, and mineral composition. The modern diet in developed countries is rich in highly processed food that are not not rich in minerals. Some studies indicate that Fe content in modern horticultural products is decreasing, as are some other minerals. Strawberries can be not only a good source of vitamin C, but also a source of minerals.
The aim of this study was to determine how the additional application of Fe affects some physicochemical fruit properties and mineral composition of fruits of the cultivar 'Joly', which was widely grown in Croatia in recent years.

MATERIALS AND METHODS

The experiment was conducted at the strawberry farm Jagodar-HB Ltd. near Zagreb, Croatia (Petrovina Turopoljska, latitude N45°41'14.67" and longitude E16°01'5.84") and grown in white plastic bags filled with coconut coir. The cultivar 'Joly' was planted as green container plants at a density of 10 plants m–2 in fall of 2020. Standard nutritional management was applied to all plants, pH value in the root zone was between 5.5 and 6.5 and EC of drainage solution was below 2 dS m–1 during growth and harvest. A total of 450 plants were used in this study, 50 plants in 3 replicates (total 150 plants per treatment) were treated with Fe-EDDHA; EDDHA 6% solution at 10 ml/plant in a random block design with untreated plants as control. Two different Fe-EDDHA 6% treatments were applied: A – at the beginning of flowering (March 26) and B - at the beginning of flowering and in the foull bloom (March 26 and April 12). The fruits were harvested in 2021 on May 17. The fruits were transported to the laboratories of the Faculty of Agriculture at the University of Zagreb, where they were analyzed for their physicochemical and mineral content (N, P, K, Fe, Zn, Mn and Cu). For each analysis, 10 fully ripened randomly selected fruits were used in each replicate.

1. Physical analysis of the strawberry fruits

Fruit weight was measured using Enlarge Adventurer® Precision labaratory balance (OHAUS corporation, USA) and expressed in grams (g).

Firmness measurements were made using a Force Gauge PCE-FM 200 penetrometer with a 6-mm probe. The firmness value for each fruit was the average of two measurements taken on opposite sides of the fruit in the equatorial fruit zone and was expressed in g cm-2.

2. Chemical analysis of strawberry fruit juice

Strawberry fruits were crushed and homogenized using a laboratory homogenizer. The suspensions were centrifuged (9000 rpm, 20 min), and the supernatant was filtered through Whatman No.4 filter paper and used for further analysis. If necessary, the juice was diluted. The total soluble solids (TSS) content was measured with the juice and determinated by refractometer ATAGO PAL-1 (Atago Co., Ltd., Tokyo, Japan). *Total acidity (TA)* was determined by titrating the juice with 0.1 N NaOH and expressed as percent (%) of citric acid (Mitcham et al., 1996).The pH value of the samples was determined using a Testo 205 manual pH meter (Testo AG, Lenzkirch, Germany).

3. Analysis of the mineral composition of the strawberry fruit

Fruit samples were dried at 105°C to constant weight in an Inkolab (ST 360N) drying oven. The dried samples were ground using Tefal GT1108. To obtain sufficient dry samples for mineral content analysis, three composite samples were prepared by combining the material from 10 fruits from each treatment and the control. Total N content was determined by the modified Kjeldahl method (HRN ISO 11261:2004). After the digestion of plant material in a microwave oven (Milestone Ethos Up, Milestone Srl, Italy) using the mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$). K was determined with a flame photometer (PFP-7, Jenway, UK) and P with a spectrophotometer (Evolution 60 S, Thermo Fisher Scientific, Finland). Fe, Zn, Mn, and Cu were determined using an atomic absorption spectrometer (AAS Solar, Thermo Fisher Scientific, Finland).

4. Statistical analysis

Descriptive statistics were used to characterize the sample. The independent variable was foliar treatment with Fe-EDDHA (one- or two- fold exposure) and the dependent variables were: T– Firmness (kg/cm2); M - Weight (g); TSS - Total soluble solids (ºBrix); TA - Titratable acidity (%); DM - dry matter content (%); N - Nitrogen in DM (%); P2O5 - Phosphorus pentoxide in DM (%); P - Phosphorus in DM (%); K2O - Potassium oxide in DM (%); K – Potassium in DM (%); Fe - Iron in DM (mg/kg); Zn - Zinc in DM (mg/kg); Mn - Manganese in DM (mg/kg); Cu - Copper in DM (mg/kg). Discrete variables were tested by ANOVA. The level of significance for all tests was α≤0.05, and results were analyzed using SPSS software (v.22).

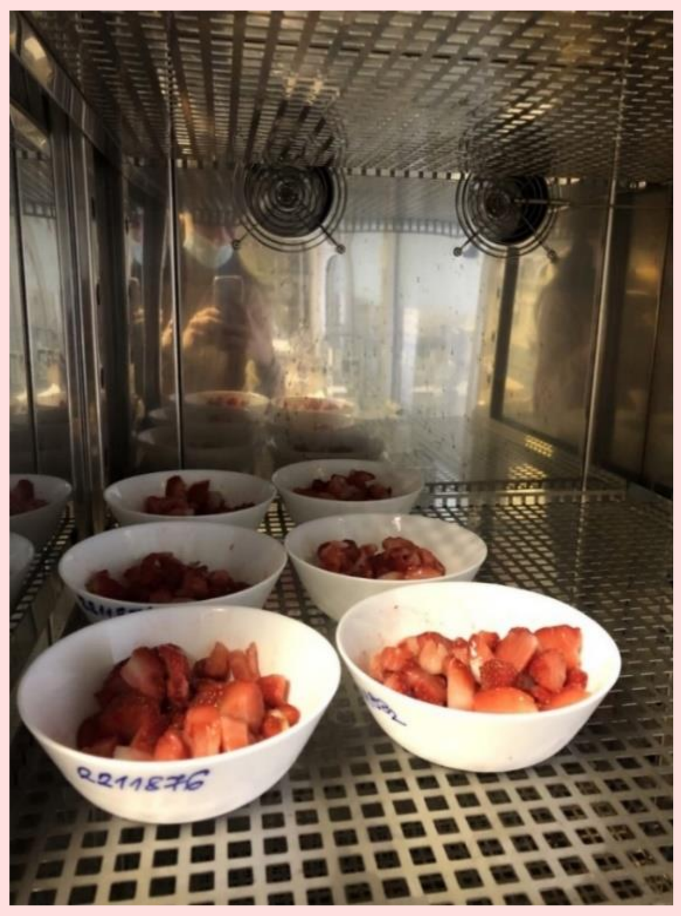

Figure 1 (top) Fe foliar treatment.

Figure 2 (right) Drying fruits for mineral composition analysis.

Table 1. Physical properties of 'Joly' full ripened strawberry fruits

	n	Firmness (kg/cm^2)	Weight (g)	TSS (ºBrix)	pH	TA (%)	TSS/TA (ºBrix/%)	DM (%)
Foliar treatment		$p=0.42^{‡}$	$p=0.44^{‡}$	$p=0.57^{‡}$	$p\leq0.01^{†}$	$p\leq0.01^{†}$	$p\leq0.01^{†}$	$p\leq0.01^{†}$
A	3	0.29 ± 0.01^{a}	28.25 ± 1.91^{a}	7.93 ± 0.21^{a}	$3.43\pm0.15^{a,b}$	0.70 ± 0.02^{b}	11.41 ± 0.27^{a}	7.42 ± 0.04^{b}
B	3	0.31 ± 0.03^{a}	30.51 ± 5.89^{a}	7.64 ± 0.40^{a}	3.53 ± 0.04^{a}	0.69 ± 0.01^{b}	11.05 ± 0.66^{a}	7.63 ± 0.05^{a}
Control	3	0.32 ± 0.03^{a}	34.23 ± 7.29^{a}	7.59 ± 0.54^{a}	3.26 ± 0.04^{b}	0.83 ± 0.03^{a}	9.13 ± 0.67^{b}	7.15 ± 0.10^{c}
MEAN	9	0.31±0.03	31.00±5.45	7.72±0.39	3.40±0.14	0.74±0.07	10.53±1.17	7.40±0.22

Results are expressed as mean±standard deviation. Values represented with different letters are statistically different at p≤0.05;

Table 2. NPK content of 'Joly' full ripened strawberry fruits

	n	N (%)	P_2O_5 (%)	P (%)	K_2O (%)	K (%)
Foliar treatment		$p=0.36^{‡}$	$p=0.15^{‡}$	$p=0.14^{‡}$	$p=0.02^{†}$	$p=0.02^{†}$
A	3	1.63 ± 0.02^{a}	0.70 ± 0.03^{a}	0.31 ± 0.01^{a}	3.13 ± 0.04^{a}	2.59 ± 0.03^{a}
B	3	1.55 ± 0.06^{a}	0.70 ± 0.02^{a}	0.31 ± 0.01^{a}	2.93 ± 0.10^{b}	2.43 ± 0.08^{b}
Control	3	1.61 ± 0.09^{a}	0.74 ± 0.02^{a}	0.32 ± 0.01^{a}	2.99 ± 0.02^{b}	2.48 ± 0.01^{b}
MEAN	9	1.59±0.06	0.71±0.02	0.31±0.01	3.01±0.10	2.50±0.08

Results are expressed as mean±standard deviation. Values represented with different letters are statistically different at p≤0.05;

Table 3. Mineral content of 'Joly' full ripened strawberry fruits

	n	Fe (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Cu (mg/kg)
Foliar treatment		$p\leq0.01^{†}$	$p\leq0.01^{†}$	$p\leq0.01^{†}$	$p\leq0.01^{†}$
A	3	30.81 ± 0.75^{b}	15.19 ± 0.32^{b}	30.36 ± 1.24^{b}	2.85 ± 0.05^{b}
B	3	33.12 ± 0.46^{a}	14.87 ± 0.22^{b}	29.49 ± 0.78^{b}	2.67 ± 0.13^{b}
Control	3	32.55 ± 0.65^{a}	16.79 ± 0.22^{a}	33.56 ± 0.15^{a}	3.25 ± 0.16^{a}
MEAN	9	32.16±1.18	15.62±0.92	31.13±2.00	2.92±0.28

Results are expressed as mean±standard deviation. Values represented with different letters are statistically different at p≤0.05;

CONCLUSIONS

Application of Fe-EDDHA significantly reduced the total acidity and improved fruit sweetness compared to fruit from the untreated plants (control). The pH value was significantly higher when Fe-FEDHA was applied twice comprared to the control. Significant differences where found in the dry weight of the measured fruits, which was the lowest in the control and the highest in treatment B. We can conclude that treatment with Fe-EDDHA significantly increased dry matter. Fe-EDDHA had no positive effect on the increase of Fe content in the fruits, only Zn, Mn and Cu showed some decrease.