Application of microparticles with iron and zinc in strawberry production

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Strawberries (*Fragaria* × *ananassa* Duchesne) are sensitive to micronutrient deficiencies, and sensitivity varies among cultivars. Iron (Fe) and zinc (Zn) are essential micronutrients and, as components of many vital plant enzymes, play a critical role in many metabolic processes such as DNA synthesis, auxin, chlorophyll and some carbohydrate formation, respiration and photosynthesis. An innovative approach to providing essential micronutrients and ensuring their constant supply to plants throughout the fruit ripening period is encapsulation technology. Microparticles (microspheres and microcapsules) were produced using sustainable encapsulation methods (ionic gelation and polyelectrolyte complexation) and materials (biopolymers). Treatments with Fe/Zn-alginate microspheres and Fe/Zn-alginate/chitosan microcapsules were performed on the short-day strawberry cultivar 'Clery'. Plants were grown in plastic tunnels in double rows on raised beds covered with black plastic mulch and irrigated with drip irrigation near Zagreb (Croatia) in 2019. Fruits were analyzed for physicochemical properties (color and firmness, total soluble solids, and total acidity). Total fruit yield and firmness were not significantly affected by any of the treatments. All treatments affected total acidity and fruit color. All treatments significantly improved fruit sweetness compared to untreated plants. Micronutrient encapsulation is a simple, sustainable and environmentally friendly method that can ensure a constant supply of micronutrients and produce strawberries of higher sensory quality.

INTRODUCTION

Strawberry (*Fragaria* × *ananassa* Duch.) is the most important berry fruit crop in Croatia with the production of about 3,000 t annually in 2015-2020 (FAO, 2022). Strawberries in Croatia are grown mainly on the open field or in plastic tunnels using short-day cultivars frigo plants with planting in the summer and harvested in the following spring.

Fruit quality is generally, evaluated on the basis of physicochemical properties (firmness, color, total soluble solids content, titratable acidity, etc.) phytochemical content (flavonoids, anthocyanins, etc.), and antioxidant capacity.

Encapsulation of chemical agents has been shown to be effective in ensuring the uptake of readily available nutrients by the plant. Previous research has proposed the application of microparticles loaded with chemical agents to plants to stimulate the production of biologically active compounds and enhance plant nutrient quality.

The aim of this study was to determine how the additional application of microparticles affects the yield and some fruit properties of cv. ‘Clery’, one of the widely grown cultivars of the last decade in Croatia.

MATERIALS AND METHODS

The experiment was conducted in the strawberry plantation of Fragaria Ltd. in a plastic tunnel near Zagreb (Botinec, latitude 45°45’10’’N and longitude 15°55’16’’ E) in Croatia, where the cultivar 'Clery' was planted in the soil at a density of 4 plants/m^2 (40000 plants/ha) as cold-stored plants (frigo) in summer 2018. Plants were planted and grown in a tunnel in double rows on raised beds covered with black plastic mulch, using drip irrigation. All plants were treated with standard field management practices. The trial was set in 2019 and a total of 160 plants were used, 10 plants treated in 4 replicates (a total of 40 plants per treatment) in a random block design with untreated plants as the control. Three different treatments were applied on April 11, 2019: Fe/Zn-alginate microspheres (T1), Fe/Zn-alginate/chitosan microcapsules (T2), and iron leaf application (Fe-EDDHA; EDDHA 6%) (T3).

Fruits were harvested early in the morning from April 27 to May 24, 2019 (9 harvests) at 3- to 4-da intervals and weighed separately in the field for each replication. After the 4th harvest on May 6 in the strawberry fields and after weighing the fruit mass, the fruits were transported to the laboratories of Faculty of Agriculture at the University of Zagreb for physicochemical analysis. For each analysis, 10 fully ripened randomly selected fruits were used in each replicate.

Physical analysis of strawberry fruits

1. Fruit color.

Measurements were made using a ColorTec PCM colorimeter (ColorTec Associates Clinton, New Jersey, USA) and expressed as CIE Lab (CIELab) values: L* for the lightness from black (0) to white (100), a* from green (−) to red (+), b* from blue (−) to yellow (+), C* for chroma (distance from the L* axis) and h* for hue angle (expressed in degrees). The value for each fruit was the average of two measurements taken on opposite sides of the fruit.

2. Firmness.

Measurements were made using a penetrometer Force Gauge PCE-FM 200 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.

Chemical analysis of strawberry fruit juice

1. Preparation of fruit juice for analysis.

Strawberry fruit was 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. The juice was diluted if necessary.

2. Total soluble solids (TSS).

The juice was used for the determination of TSS (°Brix) using a refractometer ATAGO PAL-1 (Atago Co., Ltd., Tokyo, Japan).

3. Total acidity (TA).

TA was determined by titrating the juice with 0.1 N NaOH and expressed as percent (%) of citric acid (Mitcham et al., 1996).

Figure 1 (top) Application of microparticles with Fe and Zn.

Figure 2 (right) Harvesting of fruit for physical and chemical analysis.

Table 1 Effect of treatments on color properties of 'Clery' strawberry fruits

Treatment	1	Rc %	2	Rc %	3	Rc %	Control
L	38,06^{ab}	-0,9	38,30^{ab}	-0,3	37,55^{b}	-2,2	38,40^{a}
a	20,15^{b}	-6,9	19,92^{b}	-7,7	21,46^{a}	-0,6	21,59^{a}
b	25,66^{b}	0,2	27,85^{a}	8,7	26,51^{ab}	3,5	25,61^{b}
C	32,87^{b}	-2,9	34,56^{a}	2,1	34,39^{a}	1,6	33,85^{ab}
h	51,33^{b}	5,00	53,48^{a}	9,4	50,38^{b}	3,000	48,90^{b}

The different lower-case letters in the rows indicate statistically significant differences according to the posthoc Tukey HSD test ($p<0.05$). *Relative change (%) with respect to the control treatment; T1 – Fe/Zn-alginate microspheres; T2 – Fe/Zn-alginate/chitosan microcapsules; T3 – foliar iron application (Fe-EDDHA; EDDHA 6%).

Table 2 Effect of treatments on some physicochemical properties of 'Clery' strawberry fruits

Treatment	TSS	Rc %	TA	Rc %	Ratio TSS/TA	Rc %	Firmness	Rc %
1	7,76^{a}	-1,6	0,63^{b}	-12,2	12,3 ^{a}	+12,8	0,292^{a}	0,7
2	7,76^{a}	-1,6	0,63^{b}	-12,2	12,3 ^{a}	+12,8	0,289^{a}	-0,3
3	7,90^{a}	0,6	0,67^{ab}	-6,5	11,8 ^{ab}	+8,3	0,298^{a}	2,8
Control	7,85^{a}		0,72^{a}		10,9^{b}		0,290^{a}	

The different lower-case letters in the rows indicate statistically significant differences according to the posthoc Tukey HSD test ($p<0.05$). *Relative change (%) with respect to the control treatment; T1 – Fe/Zn-alginate microspheres; T2 – Fe/Zn-alginate/chitosan microcapsules; T3 – foliar iron application (Fe-EDDHA; EDDHA 6%).

Table 3 Effect of treatments on yield relative to the harvest time of 'Clery' strawberry fruits (g/plant)

Treatment	1	Rc %	2	Rc %	3	Rc%	Control
27th April	31,6^{a}	-16,8	33,2^{a}	-12,7	33,6^{a}	-11,6	38,0^{a}
30th April	33,5^{a}	-16,5	49,3^{a}	23,1	44,8^{a}	11,9	40,1^{a}
3rd May	57,1^{a}	-6,5	70,0^{a}	14,5	65,1^{a}	6,5	61,1^{a}
6th May	49,6^{a}	29,5	38,6^{ab}	0,8	41,3^{ab}	8,0	38,3^{b}
10th May	59,5^{a}	-16,0	68,1^{a}	-3,8	63,0^{a}	-11,1	70,8^{a}
14th May	125,8^{a}	-13,4	144,7^{a}	-0,4	140,9^{a}	-3,0	145,3^{a}
17th May	40,1^{a}	-16,9	41,4^{a}	-14,2	42,4^{a}	-12,1	48,3^{a}
20th May	84,9^{a}	1,2	80,8^{a}	-3,6	80,0^{a}	-4,7	83,9^{a}
24th May	69,9^{a}	6,2	64,9^{a}	-1,5	69,3^{a}	5,3	65,8^{a}
Total	554,0^{a}	-6,4	591,0 ^{a}	-0,1	580,4 ^{a}	-1,9	591,6 ^{a}

The different lower-case letters in the rows indicate statistically significant differences according to the posthoc Tukey HSD test ($p<0.05$). *Relative change (%) with respect to the control treatment; T1 – Fe/Zn-alginate microspheres; T2 – Fe/Zn-alginate/chitosan microcapsules; T3 – foliar iron application (Fe-EDDHA; EDDHA 6%).

CONCLUSIONS

The application of microparticles containing Fe and Zn significantly reduced acidity in fruit compared to fruit from untreated plants. All treatments with microparticles resulted in higher values of TSS/TA ratio and sweeter fruits compared to untreated plants. Total yield was not significantly affected by microparticle application compared to control. Encapsulation of chemical agents by ionic gelation ensures that these compounds remain in the form that is easier for plant uptake. This method proved to be successful considering the quality of the final product.

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