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Effects of Gypsum Application at Different Levels of Nutrient Solution Electrical Conductivity on Yield, Quality and Antioxidant Activity of Soilless Strawberry Grown in Cocopeat

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RESEARCH ARTICLE

Abstract
Research on strawberry (*Fragaria* x *ananassa* Duch.) was carried out in greenhouse in 2022-2023, arranging a 4 x 2 factorial experiment, consisting of four levels of electrical conductivity of the nutrient solutions (1.2, 1.7, 2.2, and 2.7 dS m^{-1}) and application of gypsum (without application – control and application). The plants were grown in coconut fibre substrate from late October to early June. The 2.2 dS m^{-1} ECsol resulted in the highest yield, whereas the highest values of dry matter and soluble solids were recorded under 2.7 dS m^{-1} ECsol. Gypsum application resulted in the increase of dry matter, soluble solids, firmness and colour components. The 2.2 and 2.7 dS m^{-1} ECsol led to the highest levels of hydrophilic and lipophilic antioxidant activities as well as polyphenols and vitamin C. From the research carried out on strawberry grown in coconut fibre, it arose that the 2.2 dS m^{-1} EC of the nutrient solution showed the best effect on yield, but it did not generally differ from 2.7 dS m^{-1} regarding the quality of the 'fruits'. Gypsum treatment represents an effective strategy to improve some important qualitative characteristics of strawberry 'fruits', under the perspective of sustainable management of crop systems.

Keywords: *Fragaria* x *ananassa* Duch; soilless; firmness; dry matter; soluble solids; colour; polyphenols; vitamin C.

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INTRODUCTION

Most plants have the ability to adapt to sub-optimal environmental conditions, reacting to physiological stresses, such as limited water availability caused by high transpiration or electrical conductivity (EC) of the soil, adequately modulating cellular water potential and growth mechanisms (Tulipani et al., 2011). Salt stress leads to low water potential, i.e. high-water retention of the substrate, with a consequent decrease in plant water pressure limiting root absorption. The latter unbalances photosynthesis rate, lipid metabolism, synthesis of DNA, RNA and proteins, and cell mitosis (Ghorbanli et al., 2013; Niu et al., 2013; Ghonaim et al., 2021; Melo-Sabogal and Contreras-Medina, 2024), which finally cause the reduction of plant growth, fruit weight, relative fruit water content and crop yield (Sibomana et al., 2013; Niu et al., 2013). However, the mentioned stresses can promote the production of bioactive compounds, such as lycopene, beta-carotene, ascorbic acid, and polyphenols (Ghorbanli et al., 2013; Jacobo-Velázquez and Cisneros-Zevallos; Melo-Sabogal and Contreras-Medina, 2024).

Generally, the activation of this physiological phenomenology causes a yield reduction, but often a concurrent improvement of fruit quality, with accumulation of secondary metabolites or antioxidant molecules, beneficial for human health, variable depending on the persistence of exogenous stress (Dumas et al., 2003). High soil and/or water salinity occurring in some Mediterranean areas significantly hinder crop management, forcing the farmers to search for appropriate solutions, among which soilless system may be a valuable choice.

Within vegetable species, strawberry is poorly tolerant to salinity, both caused by NaCl and mixed balanced salts supplied with fertilization, which improves 'fruit' quality up to certain EC thresholds. Even the foliar or soil application of exogenous substances such as gypsum (hydrated calcium sulphate) can influence some qualitative characteristics, such as firmness and soluble solids content in strawberry 'fruits', which represent important parameters in the pre- and post-harvest phases as well as for consumption. In this respect, Dunn and Able (2006) carried out research on strawberry, reporting the positive effects of calcium application to sandy soil through calcium sulphate, on fruit properties among which soluble solids and texture, whereas in Naradisorn et al. (2006) research only firmness of strawberry fruits was significantly improved by calcium sulphate supply through nutrient solutions.

The present research was conducted with the aim of evaluating the yield and quality of strawberry fruits grown under the foliar application of gypsum, beginning in the fruiting phase, and different levels of electrical conductivity of nutrient solutions.

MATERIALS AND METHODS

Research was carried out at the Department of Agricultural Sciences of University of Naples Federico II (40°49' N, 14°20' E, at an elevation of 63 m a.s.l.) in 2022-23 on soilless grown strawberry (*Fragaria* x *ananassa* Duch.), cultivar 'Marimbella', in greenhouse. The study was based on a randomized experimental design with eight treatments and three replications. A 4 x 2 factorial arrangement was used, consisting of four levels of electrical conductivity (Ecsol) of the nutrient solutions (1.2, 1.7, 2.2, and 2.7 dS m^{-1}) and application of gypsum (without application – control and application), assigning the nutrient solutions to the main plots and gypsum application to the sub-plots.

'Fresh' plants were transplanted in cocopeat (produced by S.I.S. S.p.A., Scicli, Ragusa, Italy) contained in white plastic bags supported at 100 cm from the floor, on 29 October 2022, with a density of 5.3 plants per m^2, in greenhouse consisting of three tunnels, 5 m wide, 30 m long, 2.0 and 3.5 m high at wall and roof, respectively.

The four nutrient solutions were delivered via fertigation, by drippers with a flow rate of 2 L h^{-1}, according to the ratios of 1.0:0.4:1.4:1.1:0.4:0.4 between the macroelements N, P, K, Ca, Mg and S, while the microelements Fe, Cu, Mn, Zn, B and Mo had the concentrations of 35.0, 1.8, 24.0, 11.0, 82 .0 and 1.0 µmol L^{-1}, respectively. The gypsum-based product (Fertigess by Oinos, Vita, Trapani, Italy) was foliarly applied at weekly basis, 18 times from January 30th (fruiting phase beginning) to May 29th (prior to the last week of crop cycle) at the concentration of 3 g L^{-1} (recommended by the product manufacturer).

The harvesting of fully ripe 'fruits' began on March 3rd and ended on June 6th 2023. At each harvest, the following quantitative and qualitative parameters of the 'fruits' were measured: total weight (kg m^{-2}) and number; average weight (g); soluble solids content (°Brix at 20°C, using a Bellingham and Stanley digital refractometer model RFM 81); dry weight (%, in an oven at 70° C until constant weight); firmness (kg cm^{-1}, by a Fruit Tester Effegi digital penetrometer, Milan, Italy); colorimetric parameters (L, a and b, referred to Cielab method, by Minolta colorimeter, CR-400, Tokyo, Japan); lipophilic and hydrophilic antioxidant activity (mmol trolox eq. 100 g^{-1} d.w. and mmol ascorbic acid eq. 100 g^{-1} d.w., respectively), polyphenols (mg gallic acid eq · 100 g^{-1} f.w.) and vitamin C (mg 100 g^{-1} f.w.) (Kampfenkel et al., 1995; Fogliano et al., 1999 Re et al., 1999; Singleton et al., 1999).

The data obtained were statistically processed using analysis of variance and the mean separation was performed using Duncan's test at $p \leq 0.05$, by SPSS software (v. 28.0).

RESULTS AND DISCUSSIONS

The electrical conductivity (ECsol) of 2.2 dS m^{-1} resulted in the highest yield (4.58 kg m^{-2}), as reported in Table 1, higher by 83.2% than the lowest salinity and by 22% on average compared to the 1.7 and 2.7 dS m^{-1} ECsol. The production performance elicited by the 2.2 dS m^{-1} ECsol was influenced both by the highest number of fruits per plant (54 fruits $plant^{-1}$) and their mean weight, though the latter did not statistically differ from that corresponding to the 1.7 dS m^{-1} ECsol (16.2 g on average). The application of gypsum at weekly basis during the fruiting phase did not have any significant effects on yield.

The nutrient solution electrical conductivity over the specific tolerance threshold, as well as other abiotic stresses, influences numerous physiological, biochemical and morphological functions of plants, such as development and metabolism, water and nutrient absorption, photosynthetic performance, antioxidant content, and yield (Manaf, 2016; Hu et al., 2012; Sofy et al., 2020). In this regard, it is known that the first response of a plant to osmotic pressure is to limit leaf development, especially in the presence of more intense stress levels (Parida et al., 2005), with the consequent production drop which occurred at the highest salinity in the present research.

Table 1. Effects of nutrient solution electrical conductivity (EC) and gypsum application on yield parameters of strawberry cultivar Marimbella.

Experimental treatment	Yield (kg m^{-2})	Yield per plant (kg)	Number of 'fruits' per plant	Mean 'fruit' weight (g)
ECsol (dS m^{-1})				
1.2	2.50 c	0.47 c	31.1 c	15.2 b
1.7	3.81 b	0.72 b	43.9 b	16.4 a
2.2	4.58 a	0.86 a	54.0 a	16.0 a
2.7	3.70 b	0.70 b	45.7 b	15.3 b
Gypsum application				
Untreated control	3.59	0.68	43.1	15.7
Gypsum treatments	3.70	0.70	44.2	15.8
	n.s.	n.s.	n.s.	n.s.
CV ECsol (dS m^{-1})	0.24	0.23	0.22	0.04
CV Gypsum application	0.02	0.02	0.02	0.01

Note: Values associated to different letters are significantly different according to Duncan's test at $p \leq 0.05$; 'n.s.' means no significant differences. CV: coefficient of variation.

In a study conducted by Ferreira et al. (2019), the ECsol increase from 0.7 to 2.5 dS m^{-1} resulted in significant reduction of fruit number per plant and marketable yield in different strawberry cultivars, ranging between 18.7% to 52.3% in three out of five varieties, also highlighting the importance of the genotype in resilience to salinity stress. Gypsum application neither elicited a greater formation of 'fruits' per plant nor influenced their average weight, so the yield per surface area unit did not benefit from this treatment compared to the control.

As regards the qualitative aspects (Table 2), the 2.7 dS m^{-1} electrical conductivity (ECsol) of nutrient solution led to the highest accumulation of dry matter (12.8%) and soluble solids (10.8 °Brix) in the 'fruits', as well as their firmness enhancement (0.62 kg cm^{-1}), the latter not significantly different from the ECsol of 2.2 dS m^{-1}.
With the gypsum application, there was a significant increase in the three mentioned parameters, compared to the untreated control, by 9.5%, 8.1% and 19.2%, respectively (Table 2).

Table 2. Effects of nutrient solution electrical conductivity (ECsol) and gypsum application on 'fruit' quality parameters of strawberry cultivar 'Marimbella'.

Experimental treatment	Dry weight (%)	Soluble solids (°Brix)	'Fruit' firmness (kg cm^{-1})	Colour		
				L	**a**	**b**
ECsol (dS m^{-1})						
1.2	11.5 c	9.8 c	0.50 c	29.6	30.9	28.7
1.7	12.0 b	10.2 b	0.56 b	29.8	32.5	27.1
2.2	12.2 b	10.3 b	0.60 a	29.9	32.0	27.4
2.7	12.8 a	10.8 a	0.62 a	30.8	31.7	28.2
				n.s.	n.s.	n.s.
Gypsum application						
Untreated control	11.6 b	9.9 b	0.52 b	28.6 b	30.4 b	28.8 a
Gypsum treatments	12.7 a	10.7 a	0.62 a	31.4 a	33.2 a	26.9 b
CV ECsol (dS m^{-1})	0.04	0.04	0.09	0.02	0.02	0.03
CV Gypsum application	0.06	0.05	0.12	0.07	0.06	0.05

Note: Values associated to different letters are significantly different, according to Duncan's test at $p \leq 0.05$; 'n.s.' means no significant differences. CV: coefficient of variation.

Similarly to the findings of other authors (Awang et al., 1993; Sato et al., 2006; Tallarita et al., 2021), the parameters associated with shelf-life, such as dry matter, soluble solids and firmness of strawberry 'fruits', rose with the increase of the nutrient solution ECsol.

Though the 2.7 dS m^{-1} ECsol caused yield decrease compared to 2.2 dS m^{-1}, it was more effective on fruit dry matter and soluble solids because the soilless fertigation constantly provides all the essential nutrients to plants which tend to absorb them independently on the actual need. Indeed, in terms of production the nutrient concentration becomes toxic over a certain threshold, beyond which fruit quality still improves for a further ECsol range.

Consistently with our results, Dunn and Able (2006) recorded the significant effect of gypsum application to strawberry, which led to the highest soluble solids in fruits at 300 ppm Ca concentration, compared to 900 and 1800 ppm, and the highest texture level and storage life at 10°C with 900 ppm Ca. In other research (Naradisorn et al., 2006) soluble solids were not significantly affected by calcium sulphate supply, whereas firmness was higher at 2000 ppm Ca concentration in the nutrient solution, compared to 400 ppm, at the second post-harvest storage day at 10°C. Tuna et al. (2007) reported that the addition of calcium sulphate to a high nutrient solution EC was significantly beneficial to growth and physiological variables, i.e. plant growth, fruit yield, and membrane permeability, of tomato plants affected by salt stress.

The nutrient solution electrical conductivity did not significantly influence the 'fruit' colorimetric parameters, while the gypsum treatment resulted in the increase of 'L' and 'a' and decrease of 'b'.

The 2.2 and 2.7 mS·cm^{-1} electrical conductivities of nutrient solution resulted in the highest values of the hydrophilic (AAI) and lipophilic (AAL) antioxidant activities, as well as the polyphenol and vitamin C contents of strawberry 'fruits' (Table 3), while the gypsum application did not differ from the untreated control.

Table 3. Effects of nutrient solution electrical conductivity (ECsol) and gypsum application on hydrophilic and lipophilic antioxidant activities, polyphenol and vitamin C contents of 'fruits' of strawberry cultivar 'Marimbella'.

Experimental treatment	AAI (mmol trolox eq. 100 g^{-1} d.w.)	AAL (mmol ascorbic acid eq. 100 g^{-1} d.w.)	Polyphenols (mg gallic acid eq. 100 g^{-1} f.w.)	Vitamin C (mg 100 g^{-1} f.w.)
ECsol (dS m^{-1})				
1.2	8.9 b	87.6 b	5.2 b	61.5 b
1.7	9.1 b	90.3 b	5.4 b	63.9 b
2.2	9.7 a	97.0 a	5.9 a	69.4 a
2.7	9.8 a	100.2 a	6.0 a	70.6 a
Gypsum application				
Untreated control	9.5	95.2	5.7	67.3
Gypsum treatments	9.3	92.4	5.6	65.5
	n.s.	n.s.	n.s.	n.s.
CV ECsol (dS m^{-1})	0.05	0.06	0.07	0.07
CV Gypsum application	0.02	0.02	0.01	0.02

Note: Values associated to different letters are significantly different, according to Duncan's test at p≤0.05; 'n.s.' means no significant differences. CV: coefficient of variation.

As can be seen from the present study, the most concentrated nutrient solutions led to the highest values of AAI and AAL, consistently with previous reports by other scholars (Cogo et al., 2011; Ripoll et al., 2014).

The application of gypsum did not determine changes in antioxidant activity, presumably because it did not cause significant stress to the plants, compared to the untreated control, and therefore did not arise further production of secondary metabolites. Unlike the results of this research, in previous investigations (Guo et al., 2018) calcium sulfate stimulated the antioxidant activity as well as the synthesis of polyphenols and ascorbic acid in broccoli sprouts. Birgin et al. (2021) also recorded an increase of total polyphenols in tomato fruits upon the application of calcium sulphate under semi-optimal water conditions.

Increasing EC level may cause stress in plants which, consequently, are elicited to synthesize antioxidant compounds contributing to their defense response, as they play a crucial role in safeguarding cells from oxidative degeneration (Vincente et al., 2014). Additionally, nutrient management can affect genetic regulation of antioxidant production, for instance polyphenols, prompting the upregulation of enzymes involved in their synthesis (Vincente et al., 2014).

CONCLUSIONS

From research conducted on soilless strawberry grown in cocopeat, it arose that the 2.2 mS·cm^{-1} EC of the nutrient solution had the best effect on yield, generally not differing from 2.7 mS·cm^{-1} Ecsol with regard to 'fruit' quality.

Gypsum application, at the concentration of 3 g L^{-1}, represents an effective strategy to improve some important quality characteristics of strawberry 'fruits', such as dry matter, soluble solids, firmness and some colour components, under the perspective of sustainable crop system management.

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Conflicts of Interest
The authors declare that they do not have any conflict of interest.

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