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Effects of cultural cycle and nutrient solution electrical conductivity on plant growth, yield and fruit quality of ‘Friariello’ pepper grown in hydroponics

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Abstract

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‘Friariello’ pepper (*Capsicum annuum* L.) was grown with nutrient film technique (NFT) in order to evaluate the effects of four nutritive solutions, at electrical conductivities (EC) of 3.5, 3.8, 4.1, 4.4 mS/cm, in two cultural cycles (winter-summer versus spring-autumn) on growth, yield and fruit quality. In the winter-summer cycle, fruit yield was significantly higher than in the spring-autumn one. The 3.8 mS/m EC resulted in the highest yield in the winter-summer crops, whereas the 4.1 mS/m EC was the most effective under the spring-autumn cycle. Water consumption was 34% higher in winter-summer than in spring-autumn season. The 3.8 mS/m EC caused the highest water consumption, whereas a 25% reduction was recorded under 4.4 mS/cm. The macronutrients absorption was the highest with 3.8–4.1 mS/cm EC and the lowest with 3.5 mS/cm. Fruits harvested in late summer and berries obtained under 4.4 mS/cm EC mostly showed the best quality. The fruit ascorbic acid and α-carotene content was higher in late summer than in late spring and all fruit antioxidants attained the highest values with 4.4 mS/cm EC.

Keywords: *Capsicum annuum* L.; fruit production; sugars; antioxidants; mineral composition

‘Friariello’ pepper (*Capsicum annuum* L.) is a niche product, but it is very requested by the fresh market. Compared to the more commonly grown bell pepper, this crop is characterized by higher production costs, owing to the hand harvest of much smaller fruits, which however have a high market value. Pepper fruits serve as a source of antioxidants, such as vitamin C, vitamin E, carotenoids and polyphenols, and their flavour and nutritional value is affected by organic acids and sugars (Luning et al. 1994).

With the perspective of increasing the cropped area devoted to ‘Friariello’ pepper, the hydroponic cultivation could be promoted among producers; in fact, the soilless system facilitates harvest, results in earlier production and leads to firmer fruits (López et al. 2013) with thicker flesh (Flores et al. 2009b), compared to the conventional growing system. Notably, closed soilless growing systems cause a negligible environmental contamination stemming from fertigation runoff, compared to open-cycle systems (Van Os 1999). Moreover, the nutrient solution strength affects the water-salt relations in plant as well as the plant growth, and interestingly, salinity increase reduces pepper vegetative growth and yield but it can improve fruit quality (Sonneveld, Vanderburg 1991).

The choice of the crop cycle for pepper cultivation also plays a crucial role, since the environmental factors affect fruit production and quality (Butcher et al. 2012). Notably, pepper plant growth is encouraged by increasing daylight and temperature

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(Nilwik 1981), though yield and fruits size are enhanced by moderate temperature (Thanopoulos et al. 2013); in fact, excessive light intensity and/or temperature cause biomass and yield reductions (Zhu et al. 2012). Light intensity increase also leads to higher fruit sugars and ascorbic acid contents (Lee, Kader 2000), but it may not affect flavonoids or even cause carotenoids decrease (Lee et al. 2005); the latter effect is also produced by a temperature increase.

Although the effects of both salinity and crop cycle have already been documented in the bell pepper type, very little investigation has been carried out on the 'Friariello' pepper.

Therefore, we planned research aimed at defining both the most effective nutrient solution strength (within electronic conductivity (EC) range of 3.5–4.4 mS/cm) and cultural cycle (winter-summer versus spring-autumn) on the yield and quality performances of 'Friariello' pepper grown in hydroponics in southern Italy.

MATERIAL AND METHODS

Plant materials and growth conditions. Research on 'Friariello' pepper (*Capsicum annuum* L.) cv. 'Nocera' was carried out in 2009 and 2010 at the experimental site of the Naples University Federico II in Portici (Naples, southern Italy, 40°49'N, 14°20'E, 63 m a.s.l.), in a Mediterranean, or Csa climate (Peel et al. 2007). Plants were grown in hydroponics using the nutrient film technique (NFT) under a 300 m^2 polyethylene greenhouse. The NFT equipment consisted of rigid PVC gullies (each 12 cm wide, 10 cm deep and 300 cm long), with a 1% slope, settled at 70 cm aboveground level, and each of them was fed by a separate 220 l plastic reservoir tank containing the nutrient solution (NS). Continuous circulation (3 l/min) of the NS was provided by a 90 W submerged pump into each reservoir tank. The NS was daily monitored in all the tanks, which were topped up with water every 15% NS consumption; the EC and pH were adjusted by the addition of nutrients and nitric acid, appropriate to each treatment, and the tanks were completely replaced with fresh NS after being topped up three times.

Plants were exposed to four levels of NS concentration, resulting in electrical conductivities (EC) of 3.5, 3.8, 4.1, 4.4 mS/cm, in factorial combination with two crop cycles (winter-summer and spring-autumn). The experimental treatments were randomized in a split-plot design, assigning the crop cycles to the main plots and the NS concentrations to the sub-plots. Each treatment included 10 plants and it was repeated four times.

The four electrical conductivities (3.5–4.4 mS/cm) tested were achieved by using the following ranges of macronutrient concentrations (mmol/l): 22.3–28.4 of N; 1.9–2.5 of P; 9.6–12.3 of K; 5.7 to 7.1 of Ca; 3.3–4.0 of Mg; 2.7–3.5 of S; 1.0 of Cl; and of micronutrients (μmol/l): 35.0 of Fe; 1.8 of Cu; 24.0 of Mn; 11.0 of Zn; 82.0 of B; 1.0 of Mo; the pH was adjusted to 5.8 and the NH_4/NO_3 ratio was 1:9.

Plants were transplanted on 30 January in the winter-summer cycle and on 10 June in the spring-autumn crop. The former cycle ended on 31 July and the latter on 7 November. All plants were transplanted in 12 cm black plastic pots filled with perlite (5–6 mm). Pots were placed on the NFT gullies through a pierced white polyethylene film. The gullies were arranged in double rows which were spaced by 100 cm. Within each double row the plant spacing was of 40 cm between the rows and 30 cm along the row. Fruit harvest began on April 20 and July 29, in the winter-summer and in the spring-autumn cycle, respectively and it continued until the end of the crop cycle.

General analytical methods. Undamaged fruits of regular shape were classified as "marketable". At each harvest, the weight and number of marketable fruits in each plot were recorded. The weight of fruits unsuitable for the market was also recorded in order to monitor total biomass production for each treatment. Cumulative plant biomass was calculated as the sum of the aboveground plant biomass at the end of the experiment plus the total fruit production from the beginning of the harvest period. Dry residue was assessed after dehydration of the fresh samples in an oven at 70°C under vacuum, until they reached constant weight after 72 hours. Leaf area was measured at the cycle end, using a LI-3100 bench top leaf area meter (LI-COR Biosciences, Lincoln, USA).

Plant water consumption and nutrient uptake. Plant water consumption was monitored during the whole cultural cycle. This was calculated in each hydroponics reservoir as the difference between the NS volume at the top level and prior to replenishment.

The uptake of nutrients from the hydroponic solution was assessed in July and in September in the

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winter-summer and in the spring-autumn cycle respectively, when the maximum values of water consumption were also recorded. Nutrient uptake was estimated as the difference between the concentration of each nutrient in the NS at the top volume level and its residual concentration prior to replenishment. The nutrient concentration in the NS was measured by directly analysing samples of the NS using the methods described below for the analyses of cations and of anions.

Analytical determinations of fruit quality and mineral composition. In order to evaluate the quality and mineral composition of fruits harvested in the winter-summer and in the spring-autumn cycles, marketable fruits were sampled on June 10 and on September 16 respectively, then rapidly transferred to the laboratory for analyses.

Soluble solids content. The soluble solids content or SSC (in °Brix) was measured at 20°C on the supernatant obtained from raw homogenate centrifugation, using a Bellingham and Stanley digital refractometer, model RFM 81 (Tunbridge Wells, UK).

Cations. Cation (Ca, Mg, K, Fe and Zn) content in the fruit pulp homogenate was determined by atomic adsorption spectrophotometry as previously described (Conti et al. 2014).

HPLC analysis. Anions, sugars, organic acids and carotenoids were determined by high performance liquid chromatography (HPLC) as previously described (Conti et al. 2014). Tocopherols were determined by high performance liquid chromatography (HPLC) as described by Osuna-Garcia et al. (1998).

Polyphenols. Fifteen-fruit pulp samples per plot were lyophilized and subsequently ground to a fine powder with a blender. Polyphenols were determined as previously described (Caruso et al. 2014).

Statistical analysis. Data were processed by the analysis of variance and mean separations were performed through the Duncan's multiple range test, with reference to 0.05 probability level, using the SPSS software version 17. Data expressed as percentage were subjected to angular transformation before processing.

RESULTS AND DISCUSSION

Plant growth and fruit production

Fruit production and plant growth were affected by the "crop cycle" × "nutritive solution EC" interaction (Table 1). In fact, the 3.8 mS/cm EC resulted in the highest yield in the winter-summer crops, whereas the 4.1 mS/cm EC was the most effective under the spring-autumn cycle; in both cycles, the highest NS strength caused the lowest production (Table 1). Notably, in the spring-autumn cycle the lower mean temperature and shorter day during the fructification phase caused a lower plant water consumption (Table 2), whereas in the winter-summer crop the NS concentration increase over 3.8 mS/cm significantly constrained the fruit number and hence the total yield as well. In fact, in winter-summer cycle the lowest monthly temperature at plant level occurred in February (6.0 and 21.0°C) and the highest in July (21.0 and 35.2°C); in spring-autumn cycle the trend was opposite, as the highest values were recorded in August (21.3 and 35.5°C) and the lowest in November (11.3 and 27.9°C). The increasing NS strength from 3.8 to 4.4 mS/cm

Table 1. Effect of the interaction between "crop cycle" and "nutritive solution EC" on yield and plant growth indexes of 'Friariello' pepper

Nutritive solution EC (mS/cm)	Crop cycle	
	winter-summer	spring-autumn
Marketable yield per plant (g)		
3.5	1,787.2^b	1,062.5^c
3.8	2,007.4^a	1,179.4^b
4.1	1,696.0^b	1,294.0^a
4.4	1,357.6^c	1,096.3^{bc}
Fruit number		
3.5	295.3^b	176.5^c
3.8	332.3^a	198.3^b
4.1	283.0^b	214.4^a
4.4	227.8^c	183.5^c
Cumulative dry matter (g/plant)		
3.5	245.0^b	143.2^c
3.8	284.2^a	165.8^b
4.1	247.1^b	190.3^a
4.4	205.0^c	168.2^b
Leaf area per plant (cm^2)		
3.5	6,732.5^b	4,358.3^c
3.8	7,515.1^a	5,143.9^b
4.1	6,347.4^b	5,881.5^a
4.4	5,007.2^c	5,197.3^b

within each column, means followed by different letters are significantly different according to the Duncan's test at $P < 0.05$

Table 2. Values of the maximum water (l/d) and nutrient (mg/d) uptake of ‘Friariello’ pepper

	Water	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulphur	Iron
Crop cycle								
Winter-summer	0.75	266.6	52.5	325.3	191.5	70.3	79.4	1.58
Spring-autumn	0.56	202.5	40.7	249.4	146.4	53.7	59.8	1.21
	*	*	*	*	*	*	*	*
EC (mS/cm)								
3.5	0.68^{ab}	205.1^{c}	37.3^{c}	242.4^{c}	150.2b	51.7^{c}	58.7^{c}	1.34^{bc}
3.8	0.73^{a}	253.2^{a}	52.7^{a}	315.0^{a}	183.3a	68.1^{a}	75.2^{a}	1.55^{a}
4.1	0.67^{b}	254.1^{a}	51.3^{a}	314.2^{a}	179.8a	68.1^{a}	75.4^{a}	1.48^{ab}
4.4	0.55^{c}	225.8^{b}	44.9^{b}	277.8^{b}	162.5b	60.0^{b}	69.0^{b}	1.21^{c}

all data are reported on a “per plant” basis; within each column: *significant difference at $P < 0.05$; means followed by different letters are significantly different according to the Duncan’s test at $P < 0.05$; EC – electrical conductivity

EC also caused the mean fruit weight reduction in both crop cycles (from 6.1 to 5.9 g). In previous research (Sonneveld, Vanderburg 1991), bell pepper yield was adversely affected by nutritive solution over 2.5 mS/cm EC, achieved by the addition of either NaCl or balanced essential salts. In other investigations, yield drop was also caused by NaCl increase in the nutritive solution from 0.8 to 6.0 mol/m^3 (Savvas et al. 2007) or over 10 mmol/l (Chartzoulakis, Klapaki 2000), owing to reduced fruit number and mean weight. Conversely, Urrea-López et al. (2014) found no adverse effect of nutritive solution salinity increase from 4 to 7 dS/m on *C. chinense* yield. In our research, the NS strength also had a significant effect on fruiting precocity, since harvest season started 4.5 days earlier at the highest nutritive solution strength compared to the lowest EC treatment.

As for the season, yield recorded in the winter-summer crops was higher than that obtained from the spring-autumn ones at any NS strength (Table 1), as a consequence of the higher number of fruits (+47% on average); the mean fruit weight did not significantly change (6 g on average). Conversely, harvest season began thirty-one days earlier with the spring-autumn crops than with the winter-summer ones.

The effect of the “crop cycle” × “nutritive solution EC” interaction was also significant on the number of fruits per plant, plant cumulative dry matter and leaf area (Tables 1) and the trend of these variables was similar to that of yield. Notably, the longer winter-summer cycle allowed the plants to develop a larger leaf area and a higher biomass, compared to the shorter spring-autumn crop, and it also benefited from increasing temperature and day length during the fructification phase. Moreover, depressing effects of salt stress on bell pepper vegetative growth (Lycoskoufis et al. 2005) and in particular on leaf area (Chartzoulakis, Klapaki 2000) corresponds to the rapid plant adaptation to water deficit (Munns 2002).

Plant water consumption and mineral nutrient uptake

The peak of crop water requirements, recorded when the plants were in their full fruiting stage, occurred in late July in the winter-summer crops and in early October under the spring-autumn cycle (Table 2). The water consumption recorded in winter-summer cycle was 34% higher than the one assessed in the spring-autumn one.

The 3.8 mS/cm EC of nutrient solution caused the highest water consumption, whereas the latter showed a 25% reduction under the 4.4 mS/cm EC. A similar response to water deficit was reported for bell pepper, where the increased salt concentration in the nutrient solution caused the reduction of plant water absorption (Savvas et al. 2007). Interestingly, the decrease of leaf area and stomata contribute to reducing transpiration and increasing water use efficiency, as a salinity adaptation response of plants (Chartzoulakis, Klapaki 2000).

The higher water requirements of the winter-summer crop compared to the spring-autumn crop

(Table 2) are in accordance with the larger leaf area developed by the winter-summer plants (Table 1).

The cultural cycle also had a significant effect on the plant nutrient requirements (Table 2), since the winter-summer crops displayed a higher nutrient uptake than the spring-autumn ones. The absorption of all macronutrients (N, P, K, Ca, Mg, S) was highest at the two intermediate NS strengths in both cultural cycles and lowest at the 3.5 mS/cm EC. However, the plant iron uptake showed the lowest value at the 4.4 mS/cm EC treatment.

Interestingly, within the same range of NS strengths the increased absorption of mineral nutrients corresponded to a higher water consumption (Table 2), suggesting that the water deficit effect caused both a decrease in water consumption and in nutrient uptake. These trends are also in agreement with those recorded for dry matter and leaf area (Tables 1), which therefore showed a dependence on the mineral nutrient absorption.

Fruit quality and chemical composition

The value of most fruit quality indicators was significantly different between the two crop cycles (Table 3). Notably, late summer fruits had higher levels of dry residue, soluble solids, reducing sugars and citric acid compared to the late spring berries; this was maybe a consequence of the higher summer temperature, allowing for an increased nutrient uptake and plant metabolism. Similar results were reported by Flores et al. (2009a) in south-eastern Spain, though they found higher fruit dry residue in spring than in summer.

The fruit quality indicators were all significantly affected by the NS strength, as they generally attained the highest values at 4.4 mS/cm EC of nutrient solution and the lowest ones at 3.5 mS/cm EC. In fact, the higher availability of nutrients corresponding to increased NS strengths resulted in higher dry residue and soluble solids in the berries (Table 3). Similar effect of nutritive salt solution increase on most fruit quality indicators in bell pepper was reported by Sonneveld and Vanderburg (1991). Conversely, in other research (Savvas et al. 2007) the berry marketable quality was adversely affected by salt concentration increase in the nutritive solution from 0.8 to 6.0 mol/m^3.

Similarly to the trend of dry residue and soluble solids, the sugar content of pepper fruits also followed the increasing NS strength (Table 3). This result is in agreement with previous investigation in tomato fruits (Adams, Ho 1989), reporting an enhancement in sugar content and titratable acidity as a consequence of salinity increase or water deficit. Conversely, Navarro et al. (2006) found a slight decrease of sugar concentration in pepper fruits, which is reportedly a consequence of fruit respiration enhancement caused by the ionic strength rise in the nutrient solution (Tadesse et al. 1999).

Among the organic acids, malic acid was more abundant than succinic and citric acids and its content increased with the increasing NS strength (Table 3).

Table 3. Fruit quality indicators of 'Friariello' pepper grown in hydroponics

	DR (mg)	OR (°Brix)	Suc	Glc	Fru	Citr	Mal	Sad
			(mg)					
Crop cycle								
Winter-summer	122	6.6	9.9	128	124	10.3	43.7	17.9
Spring-autumn	134	7.4	11.2	137	131	11.1	45.6	18.3
	*	*	*	*	*	*	n.s.	n.s.
EC (mS/cm)								
3.5	116^c	6.3^c	10.3^b	119^b	116^b	10.0^b	40.6^c	16.5^b
3.8	126^b	7.0^b	10.3^b	133^a	129^a	10.7^a	44.6^b	18.2^a
4.1	133^{ab}	7.3^{ab}	10.5^{ab}	138^a	132^a	11.0^a	46.0^{ab}	18.6^a
4.4	135^a	7.5^a	11.1^a	140^a	134^a	11.2^a	47.1^a	18.8^a

DR data are per g of fruit fresh weight; other data are per g of fruit dry weight; within each column: *significant difference at $P < 0.05$; n.s. – not significant; means followed by different letters are significantly different according to the Duncan's test at $P < 0.05$; DR – dry residue; OR – optical residue; Suc – sucrose; Glc – glucose; Fru – fructose; Citr – citric acid; Mal – malic acid; Sad – succinic acid; EC – electrical conductivity

Table 4. Fruit mineral composition of 'Friariello' pepper grown in hydroponics (per g of fruit dry weight)

Treatment	Calcium (mg)	Magnesium (mg)	Potassium (mg)	Iron (µg)	Zinc (µg)	Nitrates (mg)	Phosphates (mg)	Sulphates (mg)	Chlorides (mg)
Crop cycle									
Winter-summer	0.59	0.81	21.0	36.2	20.0	3.29	7.19	0.59	2.25
Spring-autumn	0.62	0.89	21.2	41.9	22.2	3.48	8.25	0.64	2.32
	n.s.	*	n.s.	*	*	n.s.	*	n.s.	n.s.
EC (mS/cm)									
3.5	0.56b	0.80^{b}	19.9^{b}	38.2	21.0	2.93^{c}	6.94^{b}	0.51^{c}	2.26
3.8	0.59^{ab}	0.85^{ab}	20.8^{ab}	38.6	21.1	3.30^{b}	7.65^{a}	0.60^{b}	2.29
4.1	0.62^{ab}	0.87^{ab}	21.5^{ab}	39.3	21.1	3.54^{ab}	8.03^{a}	0.65^{ab}	2.30
4.4	0.63^{a}	0.88^{a}	21.9^{a}	39.1	21.3	3.69^{a}	8.19^{a}	0.68^{a}	2.29
				n.s.	n.s.				n.s.

all data are per g of fruit dry weight; within each column: *significant difference at $P < 0.05$; n.s. – not significant; means followed by different letters are significantly different according to the Duncan´s test at $P < 0.05$; EC – ellectrical conductivity

The fruit mineral composition was also significantly affected by the crop cycle (Table 4). Fruits harvested in the spring-autumn cycle contained a significantly higher amount of magnesium, phosphates, iron and zinc. Flores et al. (2009b) also reported a higher concentration of potassium, magnesium and phosphorus in bell pepper fruits harvested in summer than in those obtained in spring.

Notably, the fruit nitrate content was not significantly different between the fruits harvested in late spring and those detached in late summer. However, either content was interestingly low, as 'Friariello' fruits consumption should not exceed 500 g per day, based on the Acceptable Daily Intake for nitrate (222 mg/day for 60 kg adult) (Authority EFS 2008).

Similarly to the trend shown by quality indicators, the mineral nutrient content in pepper fruits was generally highest at the highest NS strength and lowest at 3.5 mS/cm (Table 4). Notably, the primary physiological response of pepper plants to salts occurrence in the external solution involves active exclusion (Bethke, Drew 1992); thus, salt ions tend to accumulate in the rizhosphere, causing the increase of K, Ca, and Mg concentration in the plant tissues (Sonneveld 2002).

Fruit antioxidant content

The seasonal factor significantly affected the fruit ascorbic acid and α-carotene content,

Table 5. Fruit antioxidant content of 'Friariello' pepper grown in hydroponics

	Ascorbic acid (mg)	α-carotene (µg)	β-carotene (µg)	Lutein (µg)	α-tocopherol (µg)	Polyphenols (mg)
Crop cycle						
Winter-summer	17.6	2.14	11.0	0.91	3.46	2.50
Spring-autumn	19.5	2.35	11.2	0.97	3.60	2.58
	*	*	n.s.	n.s.	n.s.	n.s.
EC (mS/cm)						
3.5	13.1^{c}	1.98^{c}	10.0^{b}	0.86^{c}	3.28^{b}	2.35^{c}
3.8	18.3^{b}	2.22^{b}	11.0^{a}	0.95^{b}	3.57^{a}	2.43^{bc}
4.1	20.9^{a}	2.33^{ab}	11.4^{a}	0.98^{ab}	3.61^{a}	2.65^{ab}
4.4	22.0^{a}	2.37^{a}	11.6^{a}	1.04^{a}	3.70^{a}	2.73^{a}

all data are per g of fruit dry weight; within each column: *significant difference at $P < 0.05$; n.s. not significant; means followed by different letters are significantly different according to the Duncan's test at $P < 0.05$

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which was higher in the berries harvested in late summer than in those removed in late spring; β-carotene, lutein, α-tocopherol and polyphenols did not vary (Table 5). In previous research (Thanopoulos et al. 2013), the ascorbic acid content of pepper green fruits attained higher values in summer than in autumn in one cultivar, whereas no difference was recorded in other two hybrids. Moreover, Flores et al. (2009a) found no significant effect of harvest season both on ascorbate and carotenoid content (on dry matter basis) in green fruits of bell pepper.

The α-tocopherol average concentration of 3.5 mg/100 g of dry weight found in 'Friariello' pepper fruits in our research falls within the range of 2 to 7 mg/100 g of dry weight assessed in Mexican chili green fruits (Osuna-Garcia et al. 1998).

The fruit content of all the analysed antioxidants was significantly affected by the NS strength, since the highest values were attained at 4.4 mS/cm EC of nutrient solution and the lowest at 3.5 mS/cm EC. In previous research (Navarro et al. 2006), the ascorbate concentration in pepper green fruits was reduced by salinity increase, whereas the carotenoids and total phenolics content were not affected by salt application.

CONCLUSION

In the research carried out in southern Italy, 'Friariello' pepper grown in hydroponics showed to benefit from much higher electrical conductivity of the nutrient solution compared to bell pepper. In fact, the highest yield was obtained in the 3.8–4.1 mS/cm EC range, whereas bell pepper best reacts to 1.5–2.0 mS/cm EC (Tadesse et al. 1999) or even up to 3.0 mS/cm EC (Kläring, Cierpinski 1998). Moreover, the cooler climate conditions characterising the harvest time in the spring-autumn cycle allowed the crops for better production performance under 4.1 mS/cm EC, whereas in the warmer spring-summer season the salt concentration exceeding the 3.8 mS/cm electrical conductivity caused yield decrease. However, the overall fruit quality was better affected by climate conditions occurring in September than in May and in both times increasing salinity up to 4.4 mS/cm EC resulted in enhanced accumulation of quality-related substances in the berries.

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