

THE EFFECT OF INCREASED CHLORIDE (Cl⁻)
CONTENT IN NUTRIENT SOLUTION ON YIELD AND
QUALITY OF STRAWBERRY
(*Fragaria ananassa* Duch.) FRUITS

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A B S T R A C T

Chloride and sodium are the main ions contributing to soil salinity in many regions but chloride is an essential element necessary for plant growth and development. It also controls the growth of some pathogens in plants. In this experiment, the effect of the chloride ion in nutrient solution on yield and fruit quality of two strawberry cultivars: 'Selva' and 'Camarosa' grown in hydroponic culture, was studied. Three kinds of nutrient solutions were used: 1) Hoagland-Arnon solution as control; 2) Hoagland-Arnon in which potassium nitrate was replaced with potassium chloride and ammonium nitrate was added as a nitrogen source and 3) the previous medium supplemented with 1.5 mmol l⁻¹ magnesium chloride. Plant growth, total fruit yield, fruit firmness and leaf chlorophyll content were higher in plants grown in the second solution than the others, but there was no significant difference between the three solutions in terms of single fruit weight, soluble solids content and fruit dry weight. However, using 1.5 mmol l⁻¹ magnesium chloride in a nutrient solution also increased the height of plants as well as total fruit production. The results showed that adding the chloride ion to the nutrient solution had no negative effects on fruit quality and leaf chlorophyll content.

Key words: strawberries, hydroponic culture, chloride

INTRODUCTION

Chloride was recognised as an essential element for the first time in 1954. It plays a role in photosynthetic

enzyme activation, osmotic regulation, cell division and plant disease prevention. Many workers have studied the effect of chloride in the prevention of some plant diseases.

They used chloride-containing fertilizers plus ammonium chloride and potassium chloride as nitrogen and potassium sources, respectively. Chloride offers some control of rust fungi, mildew, and *Fusarium* and *Septoria* diseases in plants (Halstead et al., 1991; Fixen, 1993). Plants uptake chloride through an active absorption mechanism. The minimum concentration of chloride in plant tissues essential for biochemical processes is about 100 mg/kg dry weight (Fixen, 1993). However, the concentration of this element in plants is usually higher, from about 0.2% to 2.0%, and sometimes rises up to 10%. The amount of chloride that plants take up from the soil varies from 20 kg to 80 kg per hectare depending on the plant type and density in the field (Fixen, 1993). Some non-biochemical roles of chloride (for example, osmotic regulation) need higher concentrations of this element. Unlike other micro-nutrients, chloride is not toxic when it accumulates to high levels in plants. The symptoms of chloride toxicity (higher concentrations) are associated with the osmotic effect of saline soils. Chloride toxicity is also associated with the activity of the nitrate reductase as nitrate and chloride have similar ionic properties and absorption mechanisms. When chloride uptake rises to the toxic level, it is easily converted to toxic compounds (like hypochlorites), before it can be detoxified with the nitrate reductase (Berges et al., 1995; Van Wuk and Hutchinson, 1995).

The use of potassium chloride as a potassium fertilizer is usually not recommended. However, Chapagain

and co-workers (2003) have shown that the quality and appearance of tomato fruit improved when potassium nitrate was replaced with potassium chloride. On the other hand, magnesium and chlorophyll contents, then decreased in the tomato plants. The cumulative usage of chloride increased the chloride concentration in the vascular system of plants, while the concentration of nitrate and total nitrogen in xylem sap was reduced (Liu and Shelp, 1996). Nitrate content of the branches of broccoli plants increases with increasing nitrogen fertilization and decreases after chloride application (Liu and Shelp, 1996). In some studies, the application of calcium chloride has caused a reduction in nitrate uptake as well as nitrate reductase activity. This action is attributed to the role of chloride in plants (Richharia et al., 1997). The chloride ion is possibly involved in aqueous reactions in several agricultural crops. There is some evidence that potato tuber dry weight decreases when potassium chloride is used instead of potassium sulphate as the source of potassium (Dickins et al., 1962). In this study, the effect of chloride added to nutrient solutions on yield and fruit quality of strawberry cultivars 'Selva' and 'Camarosa' was studied expecting some improvement in both quantitative and qualitative characteristics.

MATERIAL AND METHODS

System preparation

The plants of the strawberry cultivars 'Selva' and 'Camarosa' were supplied by the Kurdistan Agricultural

Table 1. Chloride and macro-element concentrations [mg l^{-1}] in nutrient solutions

Element	Nutrient solution		
	1	2	3
Nitrogen	237	237	237
Phosphorus	31	31	31
Potassium	234	234	234
Calcium	160	160	160
Magnesium	48.6	48.6	84
Sulphurous	64	64	64
Chloride	–	213	318
pH	6.2±0.1	6.2±0.1	6.2±0.1

Research Centre. The plants were kept in a cold room (4 °C) for two weeks and then cultured in a hydroponic system (pots containing perlite) in the greenhouse of the Hamedan Faculty of Agriculture. The nutrient solutions were supplied to the plants through the piping system. Greenhouse temperatures were adjusted to 24 °C for nights and 18 °C for days and the relative humidity was 60-80%. The project was carried out as a factorial experiment with a completely randomised block design and was done in four replicates. Two experimental factors including nutrient solution (three levels) and strawberry cultivar (two levels) were designated. Four pots, each containing one plant, were considered as an experimental unit, which made up 24 pots for one replicate and 96 pots for the whole experiment. Three different nutrient solutions were applied: 1) Hoagland-Arnon solution as the control; 2) Hoagland-Arnon solution with potassium nitrate replaced with potassium chloride and supplemented with ammonium nitrate as a nitrogen source and 3) the second one supplemented additionally with 1.5 mmol l^{-1} magnesium chloride. The pH of all nutrient

solutions was adjusted to 6.2±0.1 using sulphuric acid. Concentrations of chloride and macro-elements in the solutions are shown in Table 1.

Plant growth and yield estimation

The height of individual plants was measured at the beginning of flowering and considered as an indice of plant growth. The yield of each experimental unit was determined by weighing all the harvested fruit from 10th of March (three months after planting) to 21st of April, at weekly intervals. The yield of each experimental unit was divided by the number of fruit and this number was considered as the average fruit weight.

Fruit firmness

Flesh firmness determination was carried out using an Instron (Hounsfield, H5 KS, England) apparatus through two penetrations and the measurement of the force (Newton) required for a 6.4 mm probe to penetrate 6 mm into fruit flesh. Two measurements were conducted for each fruit and five fruits were used as a replicate.

Leaf chlorophyll content

The Arnon's (1949) spectrophotometric method was employed to determine the leaf chlorophyll content. Chlorophyll was extracted using 80% acetone. The total chlorophyll content as well as of chlorophyll a and b separately were calculated and the results expressed as mg of chlorophyll per g of fresh weight.

Soluble solid content

Total soluble solids content was determined using Atago (Japan) N1 refractometer at 20 °C and expressed as °Brix.

Fruit dry weight

Fruits were put in an oven (70 °C) for 72 hours and their dry weight content was calculated from the difference between the fresh and the dry fruit weight.

Statistical analysis

The data was analyzed using MSTATC statistical software. The means were compared by Duncan's multiple range test.

RESULTS AND DISCUSSION

Plant growth and yield

The height of 'Camarosa' plants was significantly ($p < 0.01$) higher than of 'Selva'. No significant difference was seen between the two cultivars in terms of single fruit weight and total fruit yield in any nutrient solution (Tab. 2). The plant growth in nutrient solution 2 was greater than the growth in the two other solutions, but

significant differences were found only between plants grown in solutions 1 and 2. The plants of both cultivars fed with the nutrient solutions 2 and 3, significantly ($p < 0.01$) produced more fruit compared with the control. The two solutions: 1 and 2 also had a significant effect on total fruit production (Tab. 2). These results show that fruit production increased when strawberry plants were treated with higher levels of chloride. This is probably due to the higher rate of plant growth in nutrient solutions containing more chloride. One of the most important factors affecting the uptake of nutrient elements by plants is the pH of the nutrient solutions. The pH of all nutrient solutions in this study was adjusted to 6.2 (± 0.1). The amount of nitrogen was the same in all solutions, but they were different in terms of the NH_4/NO_3 ratio. We did not measure EC of nutrient solutions. As the pH of all nutrient solutions was the same, we assumed that the uptake of nutrients should not be aggravated by any other factor in the study. The question of whether it is pH or EC that most affect the uptake of nutrients is still open. As the ratio of NH_4/NO_3 was different in nutrient solutions, there is a possibility that a higher strawberry yield is due not only to the addition of Cl^- , but also to N-form. This, of course, needs to be investigated further. Increasing plant growth and fruit production by adding potassium chloride to the nutrient solutions observed in this experiment is in agreement with the results of Capagin and co-workers (2003), who reported a better quality of tomatoes

Table 2. Effect of adding chloride to the nutrient solutions on some properties of the strawberry cultivars

Parameter	Cultivar		Nutrient solution			
	Selva	Camarosa	1	2	3	
Plant height [cm]	9.27 b*	13.36 a	10.14 b	11.92 a	11.00ab	
Average fruit weight [g]	7.60 a	6.82 a	6.59 a	6.28 a	7.14 a	
Fruit yield per plant [g]	155.96a	173.18 a	128.67 b	161.53 a	155.05 a	
Fruit soluble solids content [°Brix]	5.58 a	5.77 a	5.47 a	6.32 a	5.58 a	
Fruit dry weight [%]	9.04 a	10.16 a	10.56 a	9.32 a	9.61 a	
Fruit firmness [Newton]	2.58 b	3.17 a	2.69 b	3.66 a	3.11 ab	
Leaf chlorophyll content [mg g ⁻¹ f. w.]	Total	1.377 a	1.403 a	1.272 b	1.467 a	1.423 ab
	Chlorophyll a	0.840 a	0.832 a	0.775 a	0.873 a	0.852 a
	Chlorophyll b	0.538 a	0.586 a	0.498 a	0.594 a	0.610 a
	Chlorophyll a to b ratio	1.612 a	1.493 a	1.639 a	1.505 a	1.473 a

*Data represent means of four replicates compared by Duncan's multiple range test ($p < 0.01$)

when treated with potassium chloride instead of potassium nitrate. The chloride ion is found together with sodium in saline soils. The chloride ion is known as a toxic element for plants, although its toxicity is associated with the osmotic effect in saline soils. In other cases chloride is not toxic even when it is in higher concentrations compared to the other micronutrients. This fact is confirmed by the present study.

Fruit firmness

The 'Camarosa' strawberry cultivar showed significantly ($p < 0.01$) higher fruit tissue firmness in any of the nutrient solutions compared with the 'Selva'. Strawberry plants nourished with the nutrient solution 2 had firmer fruit than the two other solutions, but statistically, only solutions 1 and 2 showed significant effect (Tab. 2). The difference between the fruit

firmness of 'Selva' and 'Camarosa' strawberries could be interpreted as the natural diversity of the plant cultivars. When an individual plant cultivar is nourished with various nutrient solutions, it may show different properties as was confirmed in the present study. How adding chloride to the nutrient solution could improve the quality of strawberry fruit is not clearly understood. Further studies, perhaps at the molecular level, are necessary to gain a better understanding. Increasing the firmness of strawberry fruit tissues is one of the important factors needed for prolonged post-harvest storage life of this delicate fruit, which is greatly demanded by both producers and consumers.

Chlorophyll content

There was no significant difference between the two strawberry cultivars in terms of total amount of chlorophyll,

chlorophyll a, chlorophyll b and the ratio of a to b in any nutrient solution. In this respect, comparison of the three solutions showed that only solutions 1 and 2 had significant ($p < 0.01$) differences in total amount of chlorophyll only. The highest rate of chlorophyll was obtained from the plants grown in solution 2, while the lowest rate of chlorophyll was from the control. Chlorophyll content in plants is greatly affected by nutrition. The results of this study showed that the use of chloride in a nutrient solution not only did not cause chlorophyll reduction which disagrees with the report of Chapagain and co-workers (2003), but also resulted in an increase in total chlorophyll content in solution 2. Since chlorophyll contains nitrogen, the chloride ion may possibly play a role in nitrogen metabolism. However, even if this is not the case, the amount of chloride in solution 2 has no negative effect on normal nitrogen metabolism. Chlorophyll also contains magnesium and the amount of this element in solution 3 is more than the amount in the two other solutions. It might therefore be expected that the plants grown in solution 3 should have even more chlorophyll than those in solution 2. This anticipation may not be reasonable, because the chloride concentration of solution 3 is considerably higher than that of solution 2. The chloride concentration of solution 3 was probably at the critical level that the strawberry plants were able to tolerate in this experiment. In other words, the amount of chloride in solution 3 is possibly more than

enough to promote the chlorophyll synthesis. Because the strawberry plant growth and yielding in nutrient solution 2 were also higher than in the two other solutions in this work, such comparison of solutions 2 and 3 may be logical. However, for better understanding of these findings, further, more detailed studies are necessary.

Soluble solid content and dry weight

There was no significant difference between the two cultivars and the three nutrient solutions in terms of fruit soluble solids and dry weight contents (Tab. 2). However, Dickins and co-workers (1962) reported that potato tuber dry weight was reduced when potassium chloride was used instead of potassium sulphate; both as sources of potassium. Sensitivity and reaction of plants and their organs to chloride may possibly be varied.

CONCLUSIONS

The results of this study showed that adding chloride to the nutrient solution at a well-defined level not only increases strawberry plant growth, leaf chlorophyll content and yield, but also improves firmness of fruit tissue. On the other hand, this element has no negative effect on some fruit properties such as dry weight, soluble solid content and fruit weight. As we discussed earlier, the ratio of NH_4/NO_3 was different in the different nutrient solutions. This difference means that there is a possibility that a higher strawberry yield is

due not only to the addition of Cl⁻, but also to N-form. This assumption, of course, needs to be investigated further. The above improvements are greatly demanded by both strawberry producers and consumers. The findings of the present study could also be important for producers who intend to exploit saline water and soil resources with a high level of chloride in both a hydroponic system and a field and greenhouse culture.

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The effect of increased chloride (Cl⁻).....

WPLYW ZWIĘKSZONEJ ZAWARTOŚCI CHLORKU W POŻYWCIE NA PLON ORAZ JAKOŚĆ TRUSKAWEK (*Fragaria ananassa* Duch.)

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S T R E S Z C Z E N I E

Chlorek i sód są głównymi jonami mającymi wpływ na zasolenie gleby w wielu regionach, ale to chlorek jest niezbędnym elementem potrzebnym do wzrostu i rozwoju roślin. Chlorek jest również odpowiedzialny za kontrolowanie wzrostu niektórych patogenów roślin. Doświadczenie miało na celu określenie wpływu jonu chlorkowego zawartego w pożywce na plon oraz jakość truskawek dwóch odmian: 'Selva' i 'Camarosa' hodowanych w kulturze hydroponicznej. Zastosowano trzy rodzaje pożywek: 1) pożywkę Hoagland-Arnon jako kontrolę, 2) pożywkę Hoagland-Arnon, w której azotan potasu został zastąpiony chlorkiem potasu a azotan amonu dodany jako źródło azotu, oraz 3) drugą pożywkę uzupełnioną chlorkiem magnezu w dawce $1,5 \text{ mmol l}^{-1}$. Wzrost roślin, całkowity plon, jędrność owoców i zawartość chlorofilu w liściach były najwyższe wśród roślin hodowanych na drugiej pożywce. Nie zaobserwowano jednak znacznych różnic między pożywkami pod względem masy pojedynczych owoców, zawartości ekstraktu oraz suchej masy owoców. Zastosowanie $1,5 \text{ mmol l}^{-1}$ chlorku magnezu w pożywce zwiększyło natomiast wysokość roślin oraz całkowity plon owoców. Wyniki wykazały, że jon chlorkowy dodany do pożywki nie wpływa negatywnie na jakość owoców oraz zawartość chlorofilu w liściach.

Słowa kluczowe: truskawki, kultura hydroponiczna, chlorek