MIXTURE OPTIMISATION OF THE MINERAL NUTRITION OF TOMATOES IN RELATION TO MINERAL CONTENT OF THE FRUIT: EFFECTS OF PREHARVEST FACTORS ON FRUIT QUALITY

G. De Rijck[1] and E. Schrevens[1]

[1] Department of Applied Plant Sciences, Katholieke Universiteit Leuven, W. de Croylaan 42, 3001 Heverlee, Belgium

Abstract

The mineral composition of tomatoes is an important intrinsic quality parameter, concerning both the conservation and the nutritional value of the product. This study investigates the effects of the mineral composition of the nutrient solution and the moisture content of the substrate on the mineral content of hydroponically grown tomato fruits.

Using "design and analysis of mixture systems", a {3.1} simplex lattice design extended with the overall centroid was set-up in the cation factor space (K^+, Ca^{2+} and Mg^{2+}) of the nutrient solution. For each nutritional composition two moisture contents (40 and 80 volume %) of the substrates were investigated.

Higher moisture content of the substrate yielded a higher production, due to the production of more tomatoes of the same weight.

Increasing the K^+, Ca^{2+} and Mg^{2+} concentration of the nutrient solution resulted in a higher potassium, calcium and magnesium content of the fruit respectively. No interaction effect on fruit mineral content between moisture content of the substrate and mineral content of the nutrient solution was found.

This study demonstrates the usefulness of mixture theory for investigating the effect of preharvest mineral nutritional factors on fruit quality.

1. Introduction

The taste and the mineral content of tomatoes are both important intrinsic quality parameters. The taste of tomatoes is influenced by factors like the content of acids and sugars. The good taste of tomatoes is associated with a higher dry weight (Adams, 1989). The mineral content of tomatoes is important for both the conservation and the nutritional value of the product. The cultivation of tomatoes on a nutrient solution with high electric conductivity (EC) improves the taste but negatively influences the uptake of calcium and magnesium (Janse, 1986).

The effect of the mineral composition of the nutrient solution and the moisture content of the substrate on the mineral content of hydroponically grown tomato fruits is investigated using "design and analysis of mixture systems" (Cornell, 1981 and Schrevens, 1988). Preharvest factors like mineral composition of the nutrient solution and moisture content of the substrate change intrinsic quality properties of the product, influencing the postharvest behaviour of the tomato fruits.

For the cultivation of tomatoes on rockwool with a moisture content of 40 and 80 volume %, a {3.1} simplex lattice design (Cornell, 1981, 1990, Schrevens, 1988 and Schrevens *et al.*, 1993) extended with the overall centroid was set-up in the cation factor space (K^+, Ca^{2+} and Mg^{2+}).

2. Materials and methods

2.1. Experimental design

Two tomato plants of the variety “Trust” were planted the 18th of January ‘95 per rockwoolslab (Grodan: 1 m x 0.15 m x 0.075 m). Five slabs were placed in each NFT gully (25 cm wide, 5 m long). The gullies were grouped by two, with 50 cm between the gullies and 75 cm between the groups and placed in a climatised greenhouse. Per experimental unit the overdrain was collected in a barrel (100 litre) and recycled after adjusting pH and EC. To prevent depletion of some ions with more than 5 % the nutrient solutions were completely renewed every 2 weeks.

The plants were fertigated at 8.00, 12.00 and 16.00 hours during 15 minutes with 350 ml nutrient solution with an EC of 3 mS/cm and a pH of 5.5. Four nutrient solutions with the same anion - and micronutrient composition were investigated (Table 1).

Table 1. Anion and micronutrient composition at a total milli-equivalent concentration of 50 mval/l

Anion	**mmol/l**	**Micronutrient**	**µmol/l**
NO_3^-	17.25	**$ZnSO_4.7H_2O$**	1.875
$H_2PO_4^-$	2.25	**$CuSO_4.5H_2O$**	0.625
SO_4^{2-}	2.75	**$MnSO_4.H_2O$**	43.75
		H_3BO_3	31.25
		$(NH_4)_6Mo_7O_{24}.4H_2O$	0.625
		FeHEDTA 4.5 %	125

The cation composition of the nutrient solutions was set-up as a {3.1} simplex lattice design in the cation factor space K^+, Ca^{2+} and Mg^{2+}, extended with the overall centroid (Cornell, 1981 and Schrevens, 1988). Figure 1 represents the proportions of the cations of the investigated nutrient solutions in a simplex co-ordinate system.

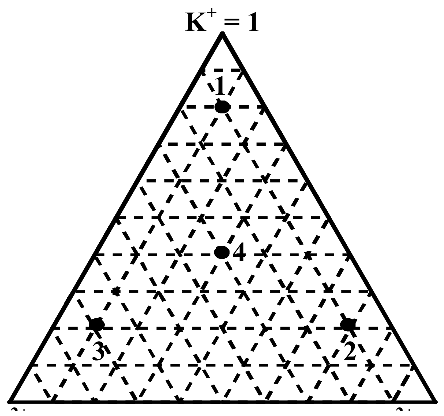


Figure 1 - {3,2} simplex lattice design

The cation concentrations of the investigated nutrient solutions at a total milli-equivalent concentration of 50 mval/l are represented in table 2. These concentrations are obtained by multiplying the proportion of each cation (Figure 1) with the total milli-equivalent concentration of the cations (25 mval/l) divided by the charge of the cation.

Table 2. Cation composition of the investigated nutrient solutions at a total milli-equivalent concentration of 50 mval/l

Nutrient solution	Potassium (mmol/l)	Calcium (mmol/l)	Magnesium (mmol/l)
1	20	1.25	1.25
2	5.25	8.625	1.25
3	5.25	1.25	8.625
4	10.167	3.708	3.708

After 20 days (8th of February ‘95) two moisture contents were imposed on each nutrient solution, resulting in a total of 8 experimental units. Each experimental unit consisted of 2 gullies with 10 slabs and 20 tomato plants. The moisture content of 80 volume percent is the saturated moisture content of rockwool slabs. The moisture content of 40 volume percent was realised using the active drainage system of Grodan, based on siphon action (De Rijck *et al*., 1994).

2.2. Production

From the 2nd of April ‘95 until the 24th of May ‘95 the tomatoes of ten plants per experimental unit were harvested. Each tomato was associated with its truss and weighted individually. Per experimental unit the dry weight of 5 tomatoes of the first, the second and the third truss was determined, after 5 days drying in a ventilated oven at 70 °C.

2.3. Chemical characterisation of the tomatoes

Per experimental unit the mineral content of 5 tomatoes was measured for the first, the second and the third truss. The mineral content was determined on 0.5 g ground dry plant material after a wet extraction during 30 minutes at 70 °C with 25 ml $NaHCO_3$ (1.7 mmol/l) and 25 ml Na_2CO_3 (1.8 mmol/l). After filtration the mineral content of the supernatant was measured. The potassium, calcium and magnesium content was determined with atomic absorption spectrophotometry (Varian SpectrAA plus).

2.4. Statistical analysis

The calculations were carried out with the SAS (Statistical Analysis System, 1991) System for windows 3.1, release 6.08. A detailed analysis was carried out using Duncan multiple range tests. The Duncan tests at a confidence level of 95 % are represented in the tables 3 and 4. A first degree canonical polynomial (Cornell, 1981, 1991, Schrevens, 1988 and Schrevens *et al*., 1993) was fitted to the results for the mineral content of the tomatoes. The obtained model was used to represent the response surface over the experimental region.

3. Results

3.1. Production

A high magnesium concentration in the nutrient solution and thus a low potassium and a low calcium concentration yields a significant lower mean weight per tomato fruit (Table 3). This resulted in a significant lower total weight of tomato fruits per plant. A high potassium concentration in the nutrient solution yielded a low total production, due to a significant lower number of tomato fruits per plant. The percentage dry weight is significantly lower for the tomato fruits fertigated with solution 4. Nutrient solution 1 and 4 yield the highest production.

Table 3. Effect of the nutrient solutions on production

Nutrient solution	Mean weight tomato fruits per plant (g)		Total weight tomato fruits per plant (g)		Number of tomato fruits per plant		% dry weight tomato fruits	
1	155.8	A	2384.5	B	15.6	C	4.5	A
2	155.5	A	3313.8	A	21.4	A	4.4	A
3	132.8	B	2435.7	B	18.3	B	4.4	A
4	148.6	A	3480.2	A	23.4	A	4.2	B

The moisture content of the substrate has no significant influence on the mean tomato fruit weight per plant (Table 4). A high moisture content results in a significantly higher total weight of tomato fruits per plant due to the production of more tomatoes. The percentage dry weight is significantly higher at a lower moisture content. There exists no significant interaction between the mineral content of the nutrient solution and the moisture content of the substrate.

Table 4. Effect of the moisture content of the substrate on production

Moisture content (vol %)	Mean weight tomato fruits per plant (g)		Total weight tomato fruits per plant (g)		Number of tomato fruits per plant		% dry weight tomato fruits	
40	151.7	A	2645.5	B	17.4	B	4.5	A
80	144.5	A	2996.8	A	20.8	A	4.3	B

3.2. Chemical characterisation of the tomatoes

The mineral composition of the nutrient solution significantly influences the potassium, calcium and magnesium content of the tomatoes, while the moisture content has only a significant effect on the magnesium content of the tomatoes (Table 5). There exists no significant interaction between the mineral composition of the nutrient solution and the moisture content of the substrate for the mineral composition of the tomatoes. For potassium, calcium and magnesium a multiple regression was carried out in function of the mixture variables.

Table 5. Effect of the mineral composition of the nutrient solution and the moisture content of the substrate on the mineral composition of the tomato fruits

Dependent variable	Prob value nutrient solution	Prob value moisture content	Prob value interaction
potassium	**0.0001**	0.6355	0.2212
calcium	**0.0228**	0.9612	0.9406
magnesium	**0.0001**	**0.0193**	0.1275

Since the experimental set-up consists of 4 experimental units, it is possible to add one interaction term (ca*mg) to the linear model. The obtained models were used to represent the response surface over the experimental region.

3.2.1. Potassium

The potassium content of the tomatoes in mmol/kg dry weight can be calculated in function of the mineral composition of the nutrient solution with the following model:

Potassium = 1951.1*K + 8.7*Ca + 454.3*Mg +8940.9*Ca*Mg $R^2 = 0.98$

with K, Ca and Mg in proportions

The vertical axis in figure 2 represents the potassium content of the tomato fruits. The left and the right horizontal axis represents respectively the potassium and the magnesium proportion in the nutrient solution (Figure 1). Since for each nutritional composition the sum of the proportions of potassium, calcium and magnesium equals 1, the calcium proportion can be calculated in each point of the experimental region as 1 minus the potassium and minus the magnesium proportion. As indicated by the model, the potassium proportion of the nutrient solution has a strong positive influence on the potassium content of the tomatoes (Figure 2). At a low potassium proportion there exists a strong synergistic interaction between the magnesium and the calcium proportion in the nutrient solution for the potassium content of the tomatoes.

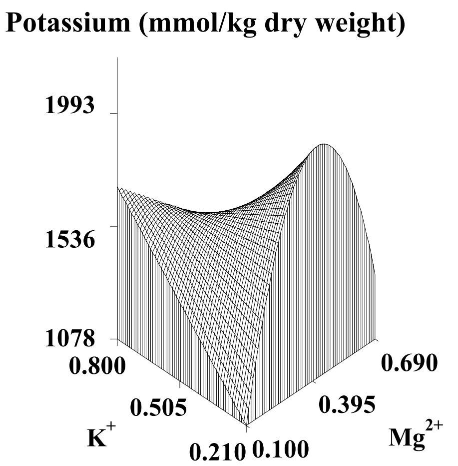
3.2.2. Calcium

The calcium content of the tomatoes in mmol/kg dry weight can be calculated with the following model:

Calcium = 26.6*K + 29.2*Ca + 14.0*Mg + 172.5*Ca*Mg $R^2 = 0.97$

with K, Ca and Mg in proportions

Increasing the calcium proportion of the nutrient solution increases the calcium content of the tomatoes (Figure 3). Replacing at a low calcium proportion magnesium with potassium yields a higher calcium content in the tomatoes.



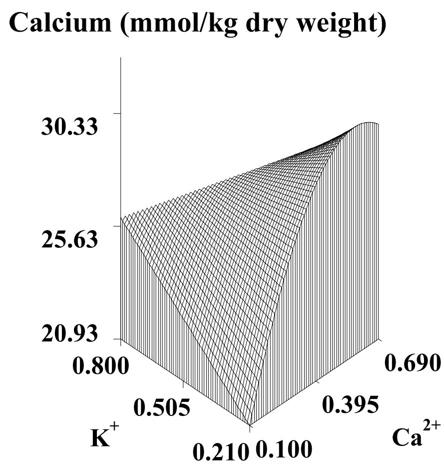


Figure 2 - Potassium content of the tomatoes

Figure 3 - Calcium content of the tomatoes

3.2.3. Magnesium

Both the mineral composition of the nutrient solution and the moisture content of the substrate significantly influence the magnesium content of the tomatoes (Table 5). The following models represent the magnesium content of the tomatoes in mmol/kg dry in function of the nutritional composition at a moisture content of respectively 40 and 80 volume percent:

magnesium (40 vol %) = 113.1*K + 10.9*Ca + 113.6*Mg + 172.5*Ca*Mg $R^2 = 0.98$

magnesium (80 vol %) = 109.5*K + 8.1*Ca + 76.7*Mg + 272.3*Ca*Mg $R^2 = 0.96$

with K, Ca and Mg in proportions

At a moisture content of 40 volume percent the magnesium content of the tomatoes is highest at a high magnesium proportion in the nutrient solution (Figure 4). Reducing the magnesium proportion in the nutrient solution reduces the magnesium content of the tomatoes and this the strongest in the calcium direction. Calcium and magnesium interact synergistically for the magnesium content of the tomatoes.

Increasing the moisture content of the substrate to 80 volume percent, results in the same strong negative effect of the calcium proportion of the nutrient solution on the magnesium content of the tomatoes, while the negative effect of the potassium proportion on the magnesium content diminishes (Figure 5). The synergistic interaction between calcium and magnesium increases as the moisture content of the substrate increases

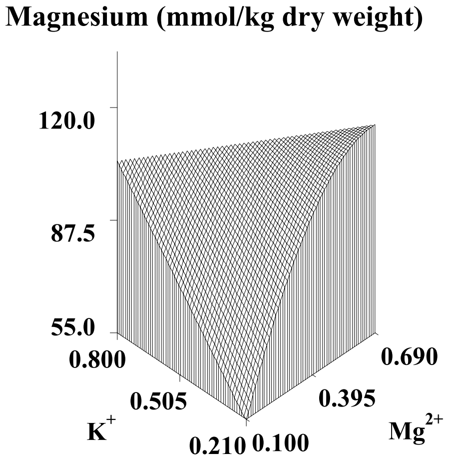


Figure 4 - Magnesium content of the tomatoes at a moisture content of 40 volume percent

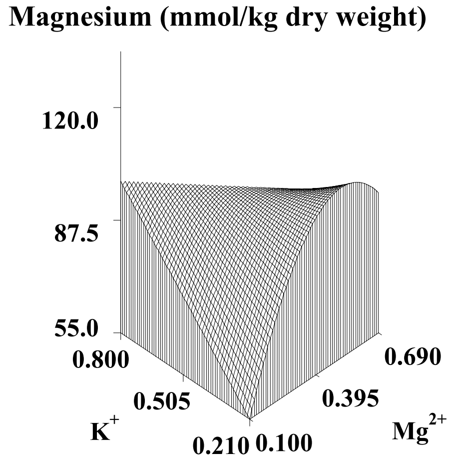


Figure 5 - Magnesium content of the tomatoes at a moisture content of 80 volume percent

4. Discussion

The mineral composition of the nutrient solution and the moisture content of the substrate significantly influence the total weight of tomatoes produced per plant, the number of tomatoes per plant and the percentage dry weight of the tomatoes. Increasing the moisture content of the substrate from 40 to 80 volume percent yields a higher production, due to the production of more tomatoes of the same weight. This results in a lower percentage dry weight of the tomatoes, an important intrinsic quality parameter (Adams, 1989).

Increasing the K^{+}, Ca^{2+} and Mg^{2+} concentration in the nutrient solution increases the content of the respective cation in the tomatoes. The mineral composition used to cultivate tomatoes not only affects the production but also the mineral content of the fruits. In this way the mineral content of the tomatoes, an intrinsic quality parameter is influenced on a preharvest base. No interaction effect on mineral content of the tomatoes, between the moisture content of the substrate and the nutritional composition was found.

In the interpretation of the results of postharvest experiments it is important to take also the preharvest factors into account. Tomatoes with the same external quality properties can differ considerably in their intrinsic quality parameters, resulting in a different postharvest behaviour.

References

Adams, P. and HO, L.C., 1989. Effects of constant and fluctuating salanity on the yield, quality and calcium status of tomatoes. Journal of Horticultural Science, 64 (6), p. 725-732.

Cornell, J.A., 1981. Experiments with mixtures. Designs, models and the analysis of mixture data. John Wiley and sons, New York.

Cornell, J.A., 1990. Experiments with mixtures. Designs, models and the analysis of mixture data. John Wiley and sons, New York.

De Rijck, G., Schrevens, E. and De Baerdemaeker, J., 1994. Application of thermal conductivity sensing for on-line monitoring and control of moisture content in hydroponic tomato cropping on rockwool, and critical evaluation of the active drainage system using thermal conductivity sensing. “International Symposium on growing media and plant nutrition in horticulture”. I.S.H.S. 10-16 september 1994. Naaldwijk, The Netherlands. Acta Horticulturae. 401. 8 p.

Janse, J., 1986. Smaak van tomaat voor verbetering vatbaar. Groenten en fruit, 41 (27), p. 40-41.

SAS, 1991. Statistical Analysis System for Windows 3.10, release 6.08.

Schrevens, E., 1988. Design and analysis of mixture systems. Application in hydroponic plant nutritional research. PhD thesis. Katholieke Universiteit Leuven.

Schrevens, E. and Cornell, J. 1993. Design and analysis of mixture systems. Applications in hydroponic plant nutritional research. Plant and Soil 154: 45-52.