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ORIGINAL PAPER

EFFECT OF CONCENTRATIONS AND FORMS OF BORON ON THE NUTRITIONAL STATUS OF TOMATO (*LYCOPERSICON ESCULENTUM* MILL.) GROWN ON ROCKWOOL*

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Abstract

Hydroponic systems are very often used for tomato production in the greenhouse. An important role in the diagnosis of a plant nutritional status is played by leaf analysis. Boron toxicity is crop specific, manifesting itself as damage to the tissues where it accumulates, and generally leading to chlorosis and necrosis, first at the edges of mature leaves. The aim of the study was to assess the effect of varying boron levels in the nutrient solution used for fertigation of two tomato cultivars (Alboney F_1 and Emotion F_1), supplied in the form of boric acid and borax. A plant-growing experiment was conducted in 2009 - 2012 (Experiment I) and 2013 - 2014 (Experiment II). A standard nutrient solution for tomato cultivation was used with the following nutrient content (in mg$\cdot$dm^{-3}): N-NH_4 – 2.0, N-NO_3 – 230, P – 50, K – 420, Ca – 140, Mg – 60, Cl – 30, S-SO_4 – 120, Fe –1.80, Mn – 0.3, Zn – 0.50, Cu – 0.07. The following combinations were tested (mg$\cdot$dm^{-3}): Control (0.011), 0.4, 0.8, 1.6 in the form of: $Na_2B_4O_7 \cdot 10H_2O$ (Experiment I) and boric acid H_3BO_3 (Experiment II); (combinations denoted by the symbols B-I, B-II, B-III, and B-IV, respectively). Analyses were conducted on the effect of boron fertigation on the macro- and micronutrient content in leaves of tomato grown on rockwool. Supplied boric acid, the variety significantly differentiated the content of phosphorus (B-III and B-IV), potassium (B-III), magnesium (B-I to B-IV), iron (B-I and B-II), zinc (B-I and B-III), copper (B-IV). When standard borax was used, the variety modified the content of potassium (B-IV), calcium (B-I and B-IV), magnesium (B-I and B-II), iron (B-III), manganese (B-I to B-IV), copper (B-IV).

Keyword: macronutrients, micronutrients, sodium tetraborate, boric acid.

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INTRODUCTION

Boron toxicity is a serious concern that can limit plant growth on soils of arid and semiarid environments throughout the world (Alpaslan, Gunes 2001). The range of boron concentrations optimal for plant growth is very narrow; additionally, this element is toxic to many plant species at levels only slightly above that required for normal growth (Revilla et al. 1985). Boron is accumulated in the leaf cell walls and may penetrate to the cytoplasm, disturbing metabolism and resulting in the development of boron toxicity symptoms (Matoh 1997). While symptoms related to boron deficiency are clear, the primary physiological effect of boron remains unknown (Camacho-Cristobal, Gonzales-Fontes 1999). Boron toxicity is crop specific, manifesting itself as damage to the tissues where it accumulates, and generally leading to chlorosis and necrosis, first at the edges of mature leaves (Brown, Shelp 1997, Nable et al. 1997). Leaf analysis plays an important role in diagnosing a plant nutritional status (Glonek, Komosa 2013).

The aim of the study was to assess the effect of varying boron levels in the nutrient solution used for fertigation of two tomato cultivars, supplied in the form of boric acid as an alternative source of boron, compared to borax, used most commonly in intensive rockwool cultivation systems.

MATERIAL AND METHODS

The plant growing experiment was conducted in 2009-2012 (Experiment I) and 2013 - 2014 (Experiment II). Analyses were conducted on the effect of boron fertigation on the macro- and micronutrient content in leaves of tomato grown on rockwool. The plant growing experiments were run in a specialist culture greenhouse equipped with a modern climate control system. Climate parameters (temperature, CO_2 content, % RH) were recorded using the Synopta software. The facilities were equipped with a modern, computer-controlled fertigation system and energy-conservation curtains. Plants were grown at a density of 2.7 plants m^{-2}.

The experiment was conducted on two tomato cultivars: Alboney F_1 and Emotion F_1 (Markiewicz 2017). Plants were grown on standard rockwool (density of 60 kg m^{-3}, mats of 100x15x7.5 cm). All cultivation measures were performed in accordance with the current recommendations for tomato growing (Adamicki et al. 2005). Seeds were sown into cultivation plugs in the 1^{st} half of March in each year of the study. After 2 weeks seedlings were transplanted to rockwool cubes (10x10x10 cm). Plants were transplanted to permanent beds in the second half of April in each year of the study. The experiment was concluded on 30 September each year. The experiments were conducted according to a two-factor design (factor A: boron concentration, factor B cultivar) in 5 replications, each composed of four plants. Plants were grown in a closed fertigation system with no recirculation of the nutrient solution. A standard nutrient solution for tomato cultivation was used with the following nutrient content (mg dm^{-3}): N-NH_4 – 2.0, N-NO_3 – 230, P – 50, K – 420, Ca – 140, Mg – 60, Cl – 30, S-SO_4 – 120, Fe –1.80, Mn – 0.3, Zn – 0.50, Cu – 0.07. The nutrient solution of boron was prepared and added individually to the respective tanks with a capacity of 1000 dm^3 in the following combinations (mg dm^{-3}): Control (0.011), 0.4, 0.8, 1.6 in the form of: $Na_2B_4O_7 \cdot 10H_2O$ (Experiment I) and boric acid H_3BO_3 (Experiment II); (combinations denoted by the following symbols BI, B-II, B-III, B-IV, respectively). The applied nutrient solution dose depended on the development phase of plants and climatic conditions. In the period of intensive plant yielding and high temperatures (June - July) 3.0 - 3.5 dm^3 nutrient solution per plant were applied daily, in 15 - 20 single doses at 20 - 30% drip from mats.

Leaf samples for chemical analyses were collected on 15.06, 15.07 and 16.08 in each year of the study. Index parts comprised 8 - 9 leaves counting from the top of the plant. One bulk sample was composed of 12 leaves collected from plants within a given combination. Collected plant material was dried at a temperature of 45 - 50°C and then ground. Plant material was mineralized in concentrated sulfuric acid in order to determine total nitrogen, phosphorus, potassium, calcium and magnesium contents. In order to determine total contents of iron, manganese, zinc and copper, the plant material was mineralized in a mixture of acetic and perchloric acids (3:1 v/v). The nutrient content was determined using the following methods: N – total – by the distillation method according to Kjeldahl in a Parnas-Wagner apparatus, P – by colorimetry with ammonium molybdate while K, Ca, Mg, Fe, Mn, Zn and Cu were determined according to AAS.

Results of laboratory analyses were analyzed statistically using the Duncan test, with inference at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Experiment I

Nitrogen. In tomato indicator parts, from 3.48% to 3.72% N were determined (Table 1). There was no effect of the mean concentrations of boron on nitrogen compounds in the combinations B-I to B-IV. There were no significant differences in the nitrogen content between the varieties. The nitrogen content was markedly smaller than that reported by other authors (Jarosz, Horodko 2004, Kowalska 2004, Jarosz, Dzida 2011); however, it was within the content ranges recommended by Kreij et al. (1990), Plank (1999) and Campbell (2000) – Table 2.

Table 1

The influence of borax nutrition on macro- and microelement content in tomato leaves (means from 2009-2012)

Cultivar	B-level (mg dm^{-3})									
	B-I	B-II	B-III	B-IV	mean	B-I	B-II	B-III	B-IV	mean
	N (% in d.m.)					Fe (mg kg^{-1}d.m.)				
Alboney F_1	3.68*a*	3.49*a*	3.52*a*	3.72*a*	3.60*A*	162.2*c*	162.7*c*	151.4*c*	120.1*a*	149.1*B*
Emotion F_1	3.48*a*	3.53*a*	3.61*a*	3.58*a*	3.55*A*	144.1*bc*	143.9*bc*	130.3*ab*	128.8*ab*	136.7*A*
Mean	3.58*A*	3.52*A*	3.57*A*	3.65*A*		153.1*B*	153.3*B*	140.8*B*	124.5*A*	
	P (% in d.m.)					Mn (mg kg^{-1}d.m.)				
Alboney F_1	0.80*bc*	0.65*ab*	0.63*a*	0.59*a*	0.66*A*	191.2*c*	191.3*c*	174.3*b*	147.6*a*	176.1*B*
Emotion F_1	0.84*c*	0.66*ab*	0.73*abc*	0.70*abc*	0.73*A*	169.4*b*	136.0*a*	151.4*a*	171.6*b*	157.1*A*
Mean	0.82*B*	0.65*A*	0.68*A*	0.65*A*		180.3*B*	163.6*A*	162.9*A*	159.6*A*	
	K (% in d.m.)					Zn (mg kg^{-1}d.m.)				
Alboney F_1	3.99*a*	4.24*abc*	4.53*c*	4.33*bc*	4.27*A*	39.96*a*	41.43*a*	50.81*bc*	42.83*ab*	43.75*A*
Emotion F_1	4.09*ab*	4.21*bc*	4.29*abc*	4.82*d*	4.35*A*	42.63*ab*	44.45*ab*	53.85*c*	41.01*a*	45,48*A*
Mean	4.04*A*	4.22*AB*	4.41*BC*	4.57*C*		41.30*A*	42.94*A*	52.33*B*	41.95*A*	
	Ca (% in d.m.)					Cu (mg·kg^{-1}d.m.)				
Alboney F_1	4.60*d*	4.26*c*	4.14*bc*	3.97*b*	4.24*B*	15.60*a*	14.36*a*	21.96*b*	13.78*a*	16.42*A*
Emotion F_1	3.94*b*	4.27*c*	4.05*bc*	3.72*a*	3.99*A*	15.93*a*	15.84*a*	20.76*b*	20.87*b*	18.35*B*
Mean	4.27*C*	4.27*C*	4.09*B*	3.84*A*		15.76*A*	15.10*A*	21.36*B*	17.32*A*	
	Mg (% in d.m.)					Key for Tables 1 and 2: within rows: means marked with different capital letters differ significantly, within rows and columns: means marked with different small letters differ significantly				
Alboney F_1	0.73*a*	0.98*c*	0.78*a*	0.73*a*	0.80A					
Emotion F_1	0.94*bc*	1.11*d*	0.82*ab*	0.84*ab*	0.92B					
Mean	0.82*A*	1.05*B*	0.80*A*	0.78*A*						

Phosphorus. Increasing boron concentrations in the nutrient solution used for fertigation were found to cause greater reduction in the P content in leaves of tomato cv. Alboney F_1. The highest content of phosphorus (0.80% P) in comparison with combinations B-III and B-IV was recorded for the B-I combination. There was no significant effect of boron concentrations in the medium on differences in the phosphorus content between combinations B-I, B-III and B-IV for cv. Emotion F_1. The highest average phosphorus content was recorded in combination B-I (0.82% P).

Potassium. In tomato indicator parts, from 3.99% K to 4.82% K were determined. There were no significant differences in the potassium content in Alboney F_1 leaves at boron concentrations from 0.40 to 1.60 mg dm^{-3}, while for cv. Emotion F_1 the concentrations ranged from 0.011 to 0.80 mg dm^{-3}. Significant differences in the potassium content between varieties were found only at the boron concentration of 1.60 mg dm^{-3}. The potassium content in the indicator parts of tomato plants may be varied depending on the cultivar, substrate and the type of crop, ranging from 3.00% of K (Campbell 2000) to 6.27% of K (Pawlińska, Komosa 2006).

Table 2

Content of macroelements according to other authors (in % in d.m. of leaves)

Source		Nutrient content (average or range)				
		N	P	K	Ca	Mg
Own studies	Borax	3.48-3.72	0.59-0.84	3.99-4.82	3.72-4.27	0.73-0.98
	Boric acid	3.18-3.66	0.68-0.90	3.82-4.78	3.10-4.40	0.51-0.73
Agric. Service... (2001)		3.5-5.0 0.	0.30-0.65	3.50-4.50	1.0-3.0	0.35-1.00
CAMPBEL (2000)		3.5-5.0	0.3-0.7	3.0-4.5	1.0-2.0	0.30-0.80
CHOHURA, KOMOSA (2003)		3.31-3.89	0.36-0.47	5.02-5.54	7.08-7.47	0.45-0.69
JAROSZ (2006)		2.95-2.96	0.82-0.83	4.41-4.42	5.26-5.41	0.55-0.59
JAROSZ, HORODKO (2004)		4.20	0.85	5.32	3.31	0.60
JAROSZ, DZIDA (2011)		3.97-4.27	0.47-0.51	4.30-5.11	2.12-2.98	0.27-0.36
KOWALSKA (2004)		4.83-4.99	0.51-0.74	3.99-4.08	3.13-3.36	0.65-0.69
KREIJ ET AL. (1990)		2.8-4.2	0.30-0.46	3.5-5.1	1.6-3.2	0.36-0.50
NURZYŃSKI (2006)		3.83	0.41	5.45	2.97	0.28
PAWLIŃSKA, KOMOSA (2006)		4.22-4.27	0.74-0.78	6.15-6.27	-	-
PLANK (1999)		3.5-5.0	0.5-1.0	3.5-5.0	0.9-1.8	0.5-1.0

Calcium. The boron level in the nutrient solution affected the calcium content in the indicator parts of tomato plants. The lowest statistically significant Ca content (3.72%) was recorded in the leaves of cv. Emotion F_1 in combination B-IV as compared with combinations B-I to B-III, and B-IV in comparison with B-I and B-II of Alboney F_1. Significant differences in the calcium content between the cultivars were demonstrated in the combinations of B-I and B-IV. The variety significantly differentiated the mean content of calcium. The highest mean content was found in Alboney F_1 leaves (4.24% Ca).

Magnesium. The highest magnesium content was recorded in the tomato leaves of cv. Alboney F_1 and Emotion F_1 at a boron concentration in the nutrient solution of 0.40 mg dm^{-3}. There were no significant differences in the magnesium content between combinations B-I and B-III and B-IV. The variety significantly differentiated the mean content of magnesium (0.80% and 0.92%).

Iron. Significant variation was found in the iron content in tomato leaves at a boron concentration in the nutrient solution of 0.80 mg dm^{-3}. The lowest iron content was found in leaves of cv. Alboney F_1 when grown with the nutrient solution 1.60 mg B dm^{-3} (120.1 mg kg^{-1}). Boron fertigation influenced the average iron content in the indicator plant parts. An increase in the boron content in the medium to 1.60 mg dm^{-3} (B-IV) caused a significant reduction in the mean iron content in tomato leaves.

Manganese. An increase in boron concentrations in the nutrient solution had an effect on the Mn content in tomato leaves. The highest manganese content in Alboney F_1 leaves was found in combinations B-I and B-II (191.2 and 191.3 mg kg^{-1}). The highest manganese content in the leaves of cv. Emotion F_1 variety was recorded at boron concentrations of 0.011 and 1.60 mg dm^{-3} (169.4 and 171.6 mg kg^{-1}). The cultivar differentiated the content of manganese in the leaves. Contents of iron and manganese in the indicator parts of tomato plants reported in this study fell within a broad range of contents provided by other authors (CAMPBEL 2000, UCHIDA 2000, AGRIC SERVICE 2001) – Table 3. The highest mean content of iron and manganese in Alboney F_1 leaves was found (149.1 mg kg^{-1} Fe, 176.1 mg kg^{-1} Mn).

Table 3

Content of microelements according to other authors (in mg kg^{-1} d.m. of leaves)

Source		Nutrient content (average or range)			
		Fe	Mn	Zn	Cu
Own studies	borax	120.1-162.7	136.0-191.2	39.96-53.85	13.78-21.96
	Boric acid	115.4-164.6	141.1-193.5	39.25-98.27	15.15-22.07
AGRIC. SERVICE. (2001)		50-300	25-200	18-80	5-35
BREŚ, RUPRIK (2007)		80.0-120.4	70.6-190.9	66.9-102.1	8.70-15.62
CHOHURA, KOMOSA (2003)		85.5-161.9	252.0-273.3	33.8-75.8	10.23-13.84
CHOHURA ET AL. (2006)		97.1-205.3	338.9	28.3-53.7	7.73-12.65
CAMPBEL (2000)		45-300	30-300	18-75	5-30
KOWALSKA (2004)		136.7-141.6	115.6-137.0	40.6-47.5	33.02-36.60
KREIJ ET AL. (1990)		84-112	54-165	54-76	6
PLANK (1999)		50-300	50-100	20-100	8-20

Zinc. The highest average zinc content was recorded in combination B-III (52.3 mg kg^{-1}) compared to the other combinations. The cultivar did not differentiate the average zinc content in the indicator plant parts. The results obtained in our study did not exceed the values reported by other authors.

Copper. The highest copper content was detected in the leaves of cv. Emotion in combinations B-III and B-IV, whereas in cv. Alboney F_1 it was in combination B-III. The greatest mean copper content was recorded in combination B-III (21.36 mg kg^{-1}). The cultivar had a significant effect on the zinc content at concentrations of 0.80 and 1.60 mg dm^{-3}. The highest mean content of copper was found in Alboney F_1 leaves (18.35 mg kg^{-1}).

The recorded copper content in the leaves was greater than those obtained by ATHERTHON et al. (1986), BREŚ, RUPRIK (2007), CHOHURA et al. (2006), JAROSZ (2014), but lower than the content obtained by KOWALSKA (2004). All recorded contents fell within the range given by PLANK (1999), AGRIC SERVICE (2001).

Experiment II

Nitrogen. Boron has been implicated in N metabolism. In tomato plants deficient in B, nitrate levels rise as a consequences of reduced nitrate reductase (NR) activity (Bonilla et al. 1988). In nitrogen fixing plants (pea and soybean) the activity of nitrogenase is sensitive to both B deficiency and B toxicity (Bolanos et al. 1994, Carpena et al. 2000). Significant differences were found in the mean nitrogen content in combination B-I (3.17% N) compared to B-III (3.53% N) – Table 4. The cultivar, as in the case of the use of

Table 4

The influence of boric acid nutrition on macro- and microelement content in tomato leaves (means from 2013-2014)

Cultivar	B-level (mg dm^{-3})									
	B-I	B-II	B-III	B-IV	mean	B-I	B-II	B-III	B-IV	mean
	N (% in d.m.)					Fe (mg kg^{-1}d.m.)				
Alboney F_1	3.18*ab*	3.36*ab*	3.66*b*	3.47*ab*	3.41*A*	138.5*bc*	138.2*bc*	126.5*abc*	123.5*ab*	131.7*A*
Emotion F_1	3.17*a*	3.37*ab*	3.40*ab*	3.38*ab*	3.33*A*	159.3*de*	164.6*e*	143.5*cd*	115.4*a*	145.7*B*
Mean	3.17*A*	3.36*AB*	3.53*B*	3.43*AB*		148.9*C*	151.4*C*	133.0*B*	119.4*A*	
	P (% in d.m.)					Mn (mg kg^{-1}d.m.)				
Alboney F_1	0.85*bc*	0.85*bc*	0.90*c*	0.83*bc*	0.85*B*	166.1*b*	141.1*a*	151.0*a*	169.0*b*	155.5*A*
Emotion F_1	0.81*bc*	0.75*ab*	0.75*ab*	0.68*a*	0.74*A*	193.5*d*	182.9*c*	168.6*b*	178.0*b*	180.7*B*
Mean	0.83*B*	0.80*AB*	0.82*AB*	0.75*A*		179.8*B*	162.0*A*	159.8*A*	159.8*A*	
	K (% in d.m.)					Zn (mg kg^{-1}d.m.)				
Alboney F_1	3.91*a*	4.78*c*	4.64*c*	4.65*c*	4.49*A*	46.66*b*	50.23*b*	47.99*b*	39.83*a*	45.67*B*
Emotion F_1	3.82*a*	4.60*bc*	4.38*b*	4.59*bc*	4.34*A*	39.25*a*	48.27*b*	40.58*a*	40.91*a*	42.25*A*
Mean	3.86*A*	4.69*C*	4.51*B*	4.62*BC*		42.95*A*	49.25*B*	44.28*AB*	40.37*A*	
	Ca (% in d.m.)					Cu (mg kg^{-1}d.m.)				
Alboney F_1	4.40*b*	3.41*a*	3.34*a*	3.47*a*	3.65*B*	18.22*ab*	20.65*c*	18.20*ab*	22.07*c*	19.78*B*
Emotion F_1	4.26*b*	3.11*a*	3.10*a*	3.48*a*	3.48*A*	16.08*a*	21.94*c*	15.39*a*	15.15*a*	17.14*A*
Mean	4.35*B*	3.26*A*	3.22*A*	3.48*A*		17.15*A*	21.30*B*	16.80*A*	18.61*A*	
	Mg (% in d.m.)					Explanations see Table 1				
Alboney F_1	0.61*b*	0.57*b*	0.64*c*	0.51*a*	0.58A					
Emotion F_1	0.73*d*	0.69*c*	0.62*b*	0.61*b*	0.66B					
Mean	0.67*B*	0.63*B*	0.63*B*	0.56*A*						

borax, had no effect on nitrogen contents in tomato leaves. The nitrogen contents obtained in our study were similar to those reported by Kleiber (2015) in experiments conducted using the same tomato cultivars. According to other authors, the optimal range of nitrogen content in tomato leaves is quite wide (Kreij et al. 1990, Plank 1999, Campbel 2000, Agric Service… 2001).

Phosphorus. An increase in the boron content in the nutrient solution used for fertigation in the range of 0.011 - 1.60 had no significant effect on the phosphorus content in leaves of tomato cv. Alboney F_1. No relationships with borax as a source of boron have been confirmed. In the case of cv. Emotion F_1, the highest phosphorus content was recorded in combination B-I (0.81% P) compared to B-IV (0.68% P). Increasing the boron content in the nutrient solution to 1.60 (B-IV) had a significant effect on the average phosphorus content compared to the control combination (B-I). The cultivar significantly differentiated the content of phosphorus in tomato leaves in combinations B-III and B-IV. The highest mean content of phosphorus was recorded in leaves of tomato cv. Alboney F_1 (0.85% B). The range of P contents in tomato indicator parts was similar to that reported for boric acid. All the recorded phosphorus contents were found within the range given by Plank (1999) and were comparable to the results obtained by Jarosz (2006), Pawlińska, Komosa (2006), Komosa et al. (2014). The range of P contents in the indicator parts of tomato plants was similar to that obtained using tetraborate sodium. P and B are essential nutrients for higher plants. The interaction between these two nutrients is highly significant for many crop plants (Yamanouchi 1980, Gunes, Alpaslan 2000). According to Kaya et al. (2009), phosphorus could mitigate boron toxicity in tomato plants by regulating the uptake of essential nutrients and activities of some vital antioxidant enzymes. The boron concentration increased in plant tissues with an increasing B concentration in the nutrient solution; however, the P content decreased in plants grown at high boron levels. The high boron concentrations reduced dry weight, fruit yield and P concentration in tomato plants.

Potassium. Significantly the lowest potassium content in leaves of both tomato cultivars was recorded in the control combination (3.91% and 3.82%). Boron nutrition affected the mean potassium content. Plant cultivation with natural boron contents in water (0.011) and its increase in the nutrient solution to 0.80 mg dm^{-3} (B-III) had a significant effect on the mean potassium content in tomato leaves as compared to combination B-II. Significant differences were found in the mean potassium content in tomato leaves between cv. Alboney F_1 and Emotion F_1 (0.85% and 074%). Despite the confirmed effect of boron fertigation on the mean potassium content, all obtained results were within the range recommended by other authors (Kreij et al. 1990, Plank 1999). According to Ekbic et al. (2018), the K content in leaf was reduced by increased boric acid doses.

Calcium. The effect of boron nutrition on calcium contents in indicator parts of tomato plants was demonstrated. Significantly the highest calcium content was recorded in the control combination (B-I). No significant differences were found in the calcium content in leaves between combinations B-II, B-III and B-IV. No differences were found between the cultivars in terms of the mean calcium content in tomato leaves. Significantly the highest mean content of calcium was obtained in cv. Alboney F_1 (3.65% Ca). Calcium contents in the indicator plant parts recorded in our study were greater than those given by other authors (Plank 1999, Campbel 2000, Agric Service 2001, Nurzyński 2006, Jarosz, Dzida 2011). Higher calcium contents in tomato indicator parts were recorded by Chohura, Komosa (2003), Jarosz (2006), Haghighi et al. (2012). According to Kaya and Ashraf (2015), high boron concentrations decrease the leaf Ca, N and K content in tomato plants.

Magnesium. The highest magnesium content (0.73% Mg) was found in the tomato leaves of cv. Emotion in the control combination (B-I). In cv. Alboney F_1 the greatest magnesium content was recorded in indicator parts of plants cultivated using 0.80 mg B dm^{-3} (0.64% Mg). The lowest mean magnesium content was found in combination B-IV (0.56% Mg) in comparison with B-I, B-II and B-III. Increasing the content of boron in the nutrient solution had an impact on the nutritional status of plants in the case of magnesium. Other authors recommend lower magnesium content in tomato indicator parts (Kreij et al. 1990, Jarosz, Dzida 2011). The magnesium contents obtained in our study were consistent with the range given by Plank (1999) and Agric Service… (2001).

Iron. Significant variations were found in the iron content in tomato leaves in combinations B-I and B-II. The lowest iron content was recorded in the leaves of cv. Emotion F_1 at the application of 1.60 mg dm^{-3} (115.4 mg kg^{-1}) in the nutrient solution. The effect of boron-supplemented fertigation on the average iron content was found. Increasing the content of boron in the nutrient solution caused a significant reduction in the average iron content in tomato leaves.

Manganese. Analyses showed the effect of the boric acid level on the content of manganese in tomato leaves. The highest manganese content was recorded in the leaves of cv. Emotion F_1 variety in combination B-I (193.5 mg kg^{-1}). The boron content in the nutrient solution was found to influence the mean manganese content in plant parts. Differences between the tested cultivars were found in the manganese contents in leaves. In the conducted experiments, a cultivar-specific plant response to the increasing boron concentration in the nutrient solution was shown for the content of iron and manganese in indicator parts. When analysing the mean Fe and Mn content depending on boron concentrations, the same relationships were found for borax and boric acid. The iron and manganese content detected in the indicator parts of tomato plants in our study fell within a wide range of contents provided by other authors (Campbel 2000, Uchida 2000, Agric Service 2001). The highest mean content of iron and manganese was obtained in cv. Emotion F_1.

Zinc. Significantly the highest zinc content was reported in leaves of cv. Alboney F_1 for the boron content in the nutrient solution ranging from 0.011 to 0.80 mg dm^{-3}. The highest mean zinc content was found in combination B-II (49.25 mg kg^{-1}) in comparison with BI and B-IV. The cultivar differentiated the zinc content in the indicator parts in the control combination and at the boron level in the nutrient solution of 0.80 mg dm^{-3}. The results obtained in our study did not exceed the values reported by other authors.

Copper. The highest copper content was found in leaves of cv. Alboney F_1 in combinations B-II and B-IV, whereas in cv. Emotion F_1 it was in B-II.

In the case of cv. Emotion F_1 both a reduction and an increase in the boron content in the nutrient solution had a significant effect on the copper content in tomato leaves. The cultivar had a significant effect on the mean zinc content. The highest mean content of zinc and copper was obtained in cv. Alboney F_1.

According to Kabata-Pendias, Pendias (1999), an admissible boron content for tomato plants is 100 mg kg^{-1} B in d.m. An optimal content of boron in tomato leaves should be 54.0-75.6 mg kg^{-1} B d.m. (Kreij De et al. 1990). In our study (Experiment I), plants of cv. Alboney F_1 yielded the best (5.55 and 5.52 kg $plant^{-1}$) at the boron content in index parts of 33.24 - 78.58 mg kg^{-1}, while cv. Emotion F_1 yielded the best at 79.44 mg kg^{-1} (5.57 kg $plant^{-1}$). In Experiment II cv. Alboney F_1 yielded the best at the boron content in index parts of 32.80 - 80.62 mg kg^{-1}, (5.73 and 5.87 kg $plant^{-1}$) while the best yields were produced by cv. Emotion F_1 at 83.89 mg kg^{-1} (5.85 kg $plant^{-1}$) – Markiewicz et al. (2016).

Alboney F_1 Emotion F_2

Fig 1. Symptoms of boron toxicity on tomato leaves. Alboney F_1 and Emotion F_1 using 1.60 mg dm^{-3} in the form of borax

Alboney F_1 Emotion F_2

Fig 2. Symptoms of boron toxicity on tomato leaves: Alboney F_1 and Emotion F_1 using 1.60 mg dm^{-3} in the form of boric acid

Based on the experiments carried out, the symptoms of boron toxicity described by other authors have been demonstrated on tomato leaves (Brown, Shelp 1997, Nable et al. 1997) at the boron content in the nutrient solution of 1.60 mg·dm^{-3} (Figures 1, 2). Plants showed no signs of boron toxicity when supplied boron at 0.80 mg B dm^{-3} medium in the form of borax and boric acid.

CONLUSIONS

1. The effect of a boron concentration and form on the nutrient content in indicator parts of tomato was demonstrated.

2. The different levels of boron in the nutrient solution within the range of 0.011 to 1.60 mg dm^{-3} supplied in the form of borax and boric acid do not change the chemical composition of leaves indicative of an inadequate or toxic nutritional status of plants.

3. The use of different concentrations of boron in the boric acid medium significantly increased the nitrogen content in tomato leaves at 0.80 mg B dm^{-3} compared to the control combination. The concentration of boron in the form of borax did not modify the nitrogen content.

4. Differentiated levels of boron in the nutrient solution had a significant effect on the phosphorus content in tomato leaves. The use of two boron forms showed a different response of tomato varieties to boron nutrition.

5. The use of increasing concentrations of boron in the boric acid medium had no effect on the calcium content in the indicator parts, compared to borax, which caused a significant reduction in Ca in the leaves along with the increase in the boron content in the medium.

6. Supplied boric acid, the variety significantly differentiated the mean content of phosphorus, calcium, magnesium, iron, zinc and copper. When standard borax was used, the variety modified the mean content of calcium, magnesium, iron, manganese and copper.

7. Supplied boric acid, the variety significantly differentiated the content of phosphorus (B-III and B-IV), potassium (B-III), magnesium (BI to B-IV), iron (BI and B-II), zinc (BI and B-III)), copper (B-IV). When standard borax was used, the variety modified the content of potassium (B-IV), calcium (BI and B-IV), magnesium (BI and B-II), iron (B-III), manganese (BI to B-IV), copper (B-IV).

REFERENCES

Adamicki F., Dyśko J., Nawrocka B., Ślusarski C., Wysocka-Owczarek M. 2005. *Methodology of integrated production of tomatoes under cover*. PIORIN, Warszawa. (in Polish).

Agric. Service Laboratory Clemson Extension. 2001. *Guidelines for sampling and interpreting results*. http://www.agr.state.nc.us/agronomi/saaesd

ALPASLAN M., GUNES A. 2001. *Interactive effects of boron and salinity stress on the growth, membrane permeability and mineral composition of tomato and cucumber plants*. Plant Soil, 236: 123-128. https://doi.org/10.1023/A:1011931831273

ATHERTON J.G., RUDICH J., ADAMS P. 1986. *The tomato crop. A scientific basis for improvement*. Champman and Hall., London, New York, 281-334.

BREŚ W., RUPRIK B. 2007.*Growing of greenhouse cherry tomato in coconut fibre with differentiated nitrogen and potassium fertilization*. Part IV. *Assessment of nutritional status of plants*. Acta Agroph., 9(2): 297-305. (in Polish)

BOLANOS L., ESTEBAN E., DE LORENZO C., FERNANDES-PASCUAL M., DE FELIPE M., R.,

BONILLA I., MATEO P., GARATE A. 1988. *Accion del boro sobre El metabolismo nitrogenado en Lycopersicum esculentum cv. Dombo , cultivado en hidroponia*. Agrochimica, 32: 276-284.

BROWN P.H., SHELP B.J. 1997. *Boron mobility in plants*. Plants Soil, 193: 85-101. https://doi.org/10.1023/A:1004211925160

CAMACHO-CRISTOBAL JJ., GONZALEZ-FONTES A. 1999. *Boron deficiency causes a drastic decrease in nitrate content and nitrate reductase activity, and increases the content of carbohydrates in leaves from tobacco plants*. Planta. 209(4): 528-36. DOI: 10.1007/s004250050757

CAMPBEL C.R. 2000. *References sufficiency ranges for plant analysis in the southern region. References sufficiency ranges vegetable crops*. Southern Cooperative Ser., Bull., 394.

CARPENA R.O., GARATE A., ZORNOZA P. 2000. *Boron and calcium distribution in nitrogen-fixing pea plants*. Plant Sci., 151: 163-170.

CHOHURA P., KOMOSA A., KOŁOTA E. 2006.*Effect of iron chelates of Librel Fe-DP7, Pionier Fe 13 and Top 12 on nutritional status of microelements of greenhouse tomato grown in rockwool*. Acta Agroph.,7(3): 549-555.

CHOHURA P., KOMOSA A. 2003. *Nutrition status of greenhouse tomato grown in inert media*. Part I. *Macroelements*. Acta Sci. Pol. Hort. Cult., 2(2): 3-13.

EKBIC H. B., GOGDEMIR N., ERDEM H. 2018. *Effects of boron on yield, quality and leaf nutrients of Isabella (Vitis labrusca* L.*) grape cultivar*. Acta Sci. Pol. Hort. Cult., 17(1): 149-157.

GARATE A., BONILLA I. 1994. *Essentiality of boron for symbiotic dinitrogen fixation in pea (Pisum sativum) rhizobium nodules*. Plant Physiol., 142: 513-517.

GLONEK J., KOMOSA A. 2013. *Fertigation of highbush blueberry (Vaccinium corymbosum* L.*)*. Part I. *The effect on growth and yield*. Acta Sci. Pol. Hort. Cult., 12(3): 59-68.

GUNES A., ALPASLAN M. 2000. *Boron uptake and toxicity in maize genotypes in relation to boron and phosphorus supply*. J. Plant Nut., 23(4): 541-550 DOI: 10.1080/01904160009382038

HAGHIGHI M., HEIDARIAN S., TEIXEIRA DA SILVA J.A. 2012. *The effect of titanium amendment in n-withholding nutrient solution on physiological and photosynthesis attributes and micronutrient uptake of tomato*. Biol Trace Elem Res., 150: 381. https://doi.org/10.1007/ /s12011-012-9481-y

JAROSZ Z. 2006. *Effect of differents types of potassium fertilisation on the chemical composition of leaves and fruits of greenhouse tomatoes grown in various substrates*. Acta Sci. Pol. Hort. Cult., 5(1): 11-18.

JAROSZ Z., HORODKO K. 2004. *The yielding and mineral composition of greenhouse tomato grown in inert media*. Rocz. AR Pozn., 356, Ogrodnictwo, 37: 81-86. (in Polish)

JAROSZ Z., DZIDA K. 2011. *Effect of substratum and nutrient solution upon yielding and chemical composition of leaves and fruits of glasshouse tomato grown in prolonged cycle*. Acta Sci. Pol. Hort. Cult., 10(3): 247-258.

JAROSZ Z. 2014. *The effect of silicon application and type of medium on yielding and chemical composition of tomato*. Acta Sci. Pol. Hort. Cult., 13(4): 171-183.

KABATA-PENDIAS A., PENDIAS H. 1999. *Biogeochemistry of trace elements*. Wyd. Nauk. PWN, Warszawa. (in Polish)

Kaya C., Tuna L., Dikilitas M., Ashraf M., Koskeroglu S., Guneri M. 2009. *Supplementary phosphorus can alleviate boron toxicity in tomato.* Sci Hort., 121: 284-288.

Kaya C., Ashraf M. 2015. *Exogenous application of nitric oxide promotes growth and oxidative defense system in highly boron stressed tomato plants bearing fruit.* Sci. Hortic., 185: 43-47.

Kleiber T. 2015. *Effect of manganese on nutrient content in tomato (Lycopersicon esculentum* Mill.*) leaves.* J. Elem., 115-126. DOI: 10.5601/jelem.2014.19.2.580.

Komosa A., Kleiber T., Markiewicz B. 2014. *The effect of nutrient solutions on field and macronutrient status of greenhouse tomato (Lycopersicon esculentum* Mill.*) grown in aeroponic and rockwool culture with or without recirculation of nutrient solution.* Acta Sci. Pol. Hort. Cult., 13(2): 163-177.

Kowalska I. 2004. *The effect of different sulphate levels in the nutrient solution and type of medium on the yield, mineral composition and quality of tomato grown in the NFT.* Acta Sci. Pol. Hort. Cult., 3(1): 153-164. (in Polish)

Kreij de C., Sonneveld C., Warmenhoven M.G., Straver N. 1990. *Guide values for nutrient element content of vegetables and flowers under glass.* Voedingsoplossingen Glastuinbouw 15.

Markiewicz B., Kleiber T., Bosiacki M. 2016. *Hydroponic cultivation of tomato*; „Alternative Crops and Cropping Systems", book edited by Petr Konvalina, ISBN 978-953-51-2279-1.

Markiewicz B. 2017. *Effect of boron concentration and form on the chemical composition of the rhizospehere of tomato (Lycopersicon esculentum* Mill.*) grown on rockwool.* Aparatura Badawcza i Dydaktyczna, 22: 174-182. (in Polish)

Matoh T. 1997. *Boron in plant cell wall.* Plant Soil, 193: 59-70. https://doi.org/10.1023/A:1004207824251

Nable R.O., Banuelos G.,S., Paull J.G. 1997. *Boron toxity.* Plant Soil, 193: 181-198. https://doi.org/10.1023/A:1004272227886

Nurzyński J. 2006. *Yielding and chemical composition of greenhouse tomato grown in ecological substrates*. Acta Agroph., 7(3): 681-690. (in Polish)

Pawlińska A., Komosa A. 2006. *Effect of substrates and nutrient solutions on the status of nitrogen, phosphorus and potassium in greenhouse tomato.* Acta Agroph., 7(3): 691-698. (in Polish)

Plank C.O. 1999. *Plant Analysis Handbook for Georgia*. University of Georgia.

Revilla E, Ciruelos, A. Apaolaza A., Sarro M.,J. 1985. *Influence of boron toxicity on single phenols of tomato leaves.* Plant Soil., 88: 295-297. https://doi.org/10.1007/BF02182458

Uchida R. 2000. *Recommended plant tissue nutrient levels for some vegetable, fruit and ornament al foliage and flowering plants in Hawaii. Plant nutrient management in Hawaii's soils.* College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, 57-64.

Yamanouchi M. 1980. *Effect of phosphorus, potassium, calcium, magnesium and iron treatment on the absorption and translocation of boron in several crop grown in high concentration of boron.* Nippon Dojo Hiryogaku Zasshi., 51: 126-130.