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The impact of mycorrhizal inoculation on the growth and yield of stake tomato under field cultivation

Wpływ szczepionki mikoryzowej na wzrost i plonowanie pomidora palikowego uprawianego w polu

Summary. Seven-week-old potted tomato transplants treated with commercial mycorrhizal inoculum were planted on podzolic soil in the middle of May and trained to one shoot plant at the stakes till August 28th. Mycorrhization did not affect the length and the diameter of tomato stem, infestation of tomato plants by tomato blight or the content of nitrogen, phosphorus, potassium, calcium and magnesium in the dry matter of tomato leaves. Also, it did not affect the course of tomato fruiting, the quantity and the structure of the fruit yield or the fresh weight and the diameter of marketable fruits. However, the fruits harvested from the inoculated plants contained more total sugars, monosaccharides and L-ascorbic acid and their acidity was higher; however, the content of dry matter, total chlorophyll and carotenoids did not differ in comparison to control plants.

Key words: stem length and diameter, macronutrients, dry matter, sugars, tomato blight

INTRODUCTION

Mycorrhiza is a natural phenomenon offering several advantages for the farmers and therefore it can be useful in sustainable plant growing [Conversa *et al*. 2007, Candido *et al*. 2015]. Commercial mycorrhizal preparations most frequently consist of *Glomus* fungi and especially of *G. mosseae*, *G. intraradices* and *G. viscosum* [Colella *et al*. 2013, Candido *et al*. 2015, Pokluda 2015]. Mycorrhizal fungi provide the colonized plants with improved mineral nutrition and, to some extent, higher tolerance to biotic and abiotic stresses [Azcón-Aguilar and Barea 1997, Głuszek *et al*. 2008, Fiorilli *et al*. 2011]. They supply the plants especially with phosphorus and nitrogen [Harrison and Buuren 1995, Hodge *et al*. 2001, Smith *et al*. 2003, Conversa *et al*. 2007, Xu *et al.* 2007] increasing plant growth and altering foliar chemistry [Goverde *et al*. 2000]. Mycorrhiza can induce better resistance against fungal pathogens [Fiorilli *et al*. 2011, Fritz *et al*. 2006]. According to Salvioli *et al*. [2009] ripening process, aroma formation and also sugar and amino-

acid metabolism in tomato fruit seem to be modulated by mycorrhization. Effects of mycorrhizal inoculation vary widely in dependence to the host plant and environmental factors [Azcón-Aguilar and Barea 1997, Głuszek *et al*. 2008]. Authors representing several countries showed a beneficial influence of mycorrhization on growth and yield of tomato. In field studies realized by Candido *et al*. [2015], inoculation of tomato seedlings with commercial microbial formulation containing *Glomus mosseae*, *G. intraradices*, *G. viscosum* and several other microorganisms increased significantly plant growth and biomass and had beneficial effect on marketable yield, mainly as a result of an increased number and weight of fruits but it did not influence fruit quality parameters. Moreover, mycorrhizal treatment improved crop earliness increasing first harvest yield [Candido *et al*. 2013]. Treatment of tomato seedlings with commercial inoculum containing *Glomus mossae*, *G. intraradices* and *G. viscosum* resulted in a positive effect on crop yield and did not show any impact on percentage of waste fruits, fruit mean weight, soluble solids content in fruits or on insect pest sampled in field experiment by Colella *et al*. [2013]. Conversa *et al*. [2007] stated favourable influence of *G. intraradices* strains applied to the soil on growth and on total and marketable yield of processing tomato as well as on phosphorus assimilation by tomato plants. In greenhouse experiment carried out by Dubova *et al*. [2014], mycorrhizal preparation containing *G. mosseae* added under seeds during sowing did not affect the growth of tomato plants, fruit weight and content of dry matter in the fruits and its effect on fruit yield was dependent on tomato cultivar. In field experiments conducted by Makus [2004], cumulative fruit yield obtained at the second and/or third harvest were significantly greater with *G. intraradices* – treated plants, but final season yield, fruit number and average fruit weight were usually similar to untreated control. Smith *et al*. [2003] found that mycorrhizal fungi do not influence growth and phosphorus nutrition of tomato while other plant species showed enhanced growth and phosphorus uptake under comparable conditions. According to Górka [2004], in good growing conditions the effect of mycorrhization can be invisible or even unfavourable. In experiment carried out by Mueller *et al*. [2009], mycorrhizal fungus *G mosseae* mixed into the pot substrate caused no detectable effects on plant growth and nutrient uptake under greenhouse conditions. In field experiment realized by Borowy and Matela [2012], inoculation of transplants of two basil (*Ocimum basilicum* L.) cultivars with commercial mycorrhizal preparation had negative effect on plant growth and on stem height and diameter, however this treatment did not affect the content of dry matter, total sugars, monosaccharides and several other compounds in basil leaves. Until now there is no information about mycorrhization of tomatoes grown in natural conditions of Poland. The purpose of this experiment was to study the effect of tomato transplants inoculation with commercial mycorrhizal preparation on tomato growth and yield under field cultivation in south-eastern part of Poland.

MATERIAL AND METHODS

The field studies were carried out in the Felin Experimental Farm belonging to the University of Life Sciences in Lublin in 2009. The experiment was established on podzolic soil developed from dusty medium loam containing 1.7% of organic matter and

with pH (in H_2O) of 6.5. Seeds of tomato (*Lycopersicon esculentum* L.) 'Malinowy Ożarowski' (POLAN Seeds Co., Poland) were seeded to seeding boxes in the greenhouse on March 27th and two-week-old seedlings were transplanted to plastic pots of 6 cm diameter filled with peat substrate. On May 8th the transplants were taken out of pots and the whole root block was dipped for 30 seconds in a mycorrhizal inoculum containing several *Glomus* species appropriated for vegetable plants and produced in a hydrogel form by Mycoflor® Szalanski Wlodzimierz Co. in Rudki near Końskowola. About 20 ml of inoculum was absorbed by one root block. Then the plants were put again into the pots and stayed in the greenhouse till planting in the field. On May 16th experimental field was fertilized with 20 kg N · ha^{-1} (ammonium nitrate), 150 kg P_2O_5 · ha^{-1} (superphosphate) and 250 kg K_2O · ha^{-1} (potassium salt) and then it was cultivated with rototiller. On May 19th eight 13.5 m^{-2} (3.5 × 3.75 m) plots were established and four of them were appropriated for cultivation of control plants and the other four plots were appropriated for cultivation of inoculated plants. Six tomato plants were planted in two rows on each plot with the 0.8 m distance between plants in the row and 1.0 m distance between rows and one plot was considered as one replication. The experiment was established in randomized blocks design with one experimental factor.

The transplants were watered immediately after planting. On June 7th, soil samples were taken and then the soil salinity and the content of nitrogen, phosphorus, potassium, calcium and magnesium in the soil were determined in the Regional Chemical-Agricultural Station in Lublin. Following results were obtained (in mg · dm^{-3} of soil): N – 86.7, P – 168.0, K – 320.0, Ca – 695.0, Mg – 80.0 and soil salinity – 0.53 g NaCl · dm^{-3}. On June 9th, 50 kg N · ha^{-1} (ammonium nitrate) was applied as a top dressing and two days later the stakes were inserted near the plants and tomato stems were tied up to them. Then the tomatoes were pruned leaving one main shoot which was topped on August 19th. Until this time the stem length of all plants was measured every week. Moreover, the diameter of stem base was measured every week started from the beginning of June till August 19th.

On July 28th, the samples of tomato leaves (first fully developed leaf on shoot top) were taken and then after drying the content of total nitrogen (distillation method), phosphorus (colorimetric method), potassium (flame photometry), magnesium (atomic absorption spectrometry) and calcium (flame photometry) in the leaves was determined in the Regional Chemical-Agricultural Station in Lublin. The fruits were harvested five times starting on July 29th and ending on August 28th. At harvest they were classified as marketable (fruit diameter > 35 mm), nonmarketable (healthy fruits with diameter < 35 mm) and infested by tomato blight (*Phytophthora infestans*) and then the diameter and the fresh weight of each marketable fruit were measured. During last harvest the unripe fruits were also harvested. Moreover, on August 14th (tomato full fruiting), the content of dry matter (oven dry method), monosaccharides and total sugars (Luff-Schoorl's method), L-ascorbic acid (Tillmans' method modified by Pijanowski), total chlorophyll and carotenoids (Mac Kinney's method) in marketable fruits was determined in the Laboratory of Vegetable and Herbal Material Quality, Dept. of Vegetable Crops and Medicinal Plants, Univ. of Life Sciences in Lublin. During whole vegetation period the infestation of tomatoes by tomato blight was monitored. No chemical plant protection was applied in the experiment with the aim to avoid its influence on mycorrhizal fungi and their effects on tomato plants health condition.

Average monthly air temperatures and monthly sums of rainfalls noted in a meteorological station situated in the Felin Experimental Farm in 2009 and also many years averages are presented in table 1.

Table 1. Average monthly air temperatures and monthly sums of rainfalls noted in a meteorological station in the Felin Experimental Farm in 2009 (1951–2005 many years averages and sums)
Tabela 1. Średnie miesięczne temperatury powietrza i miesięczne sumy opadów zanotowane w stacji meteorologicznej w Gospodarstwie Doświadczalnym Felin w roku 2009 (średnie wieloletnie dla lat 1951–2005)

Month Miesiąc	Temperature (°C) Temperatura		Rainfalls (mm) Opady	
	monthly averages/ średnie miesięczne	many years averages/ średnie wieloletnie	monthly sums/ sumy miesięczne	many years monthly sums/ średnie wieloletnie sumy miesięczne
May / Maj	13.5	13.0	71.3	57.7
June/ Czerwiec	16.4	16.2	125.5	65.7
July/ Lipiec	19.9	17.8	57.1	83.5
August/ Sierpień	19.0	17.1	54.7	68.6

Results obtained in the experiment were studied by analysis of variance and the significance of differences was determined using Tukey's test at 0.05 probability level.

RESULTS

After planting in the field, all tomato transplants took roots well and grew fast till end of July. In this time an average increase of tomato stem diameter and length amounted to 1.4 mm and 98 mm per week on an average respectively. At the time of fruit ripening the vegetative growth of tomato plants was slower. Mycorrhization did not affect this process (tab. 2). Content of nitrogen, phosphorus, potassium, magnesium and calcium in tomato leaves measured in the middle of full vegetation made 3.96, 0.44, 4.41, 0.31 and 2.77% on an average respectively and was independent on mycorrhization (tab. 3). Fruit ripening started in both treatments at the same time in the last week of July and continued till end of August (tab. 4). Mycorrhization did not influence the course of fruit ripening or the quantity and quality of fruit yield. An average yield of fruits harvested from one plant made about 2.93 kg and majority of the fruits (67.9%) was infested by tomato blight. First symptoms of this disease appeared on the lowest, oldest leaves in the first half of July and then they moved gradually towards plant top. At the last harvest, about 85% of leaves was infested by this disease and only the youngest top leaves did not show disease symptoms. In dependence on date of harvest, an average weight of marketable fruit ranged from 84.2 to 141.8 g and its average diameter ranged from 50.2 to 60.1 mm being independent on mycorrhizal inoculation (tab. 5). Marketable fruits harvested from inoculated plants contained total sugars, monosaccharides and L-ascorbic acid more and their acidity was higher, however content of dry matter, carotenoids and total chlorophyll did not differ in comparison to those from control plants (tab. 6).

Table 2. Effect of mycorrhizal inoculation on tomato stem diameter and length in dependence on time of measurement
Tabela 2. Wpływ inokulacji szczepionką mikoryzową na średnicę i długość łodygi pomidora w zależności od terminu pomiaru

Date of measurement Termin pomiaru	Stem diameter (mm) Średnica łodygi			Stem length (cm) Długość łodygi		
	inoculated/ rozsada inoculowana	non inoculated/ rozsada nieinoku-lowana	mean/ średnio	inoculated/ rozsada inoculowana	non inoculated/ rozsada nieinokulowana	mean/ średnio
May 28thd 28 maja	6.1	6.5	6.3	15.9	17.4	16.7
June 4th 4 czerwca	8.0	8.1	8.1	22.8	24.0	23.4
June 11th 11 czerwca	9.9	9.8	9.9	28.8	29.9	29.4
June 18th 18 czerwca	11.9	11.3	11.6	34.2	35.1	34.7
June 26th 26 czerwca	13.2	12.9	13.1	45.5	45.9	45.7
July 2nd 2 lipca	14.4	14.2	14.3	56.6	57.6	57.1
July 9th 9 lipca	14.8	14.9	14.9	64.8	66.7	65.8
July 15th 15 lipca	16.0	16.1	16.1	78.4	80.3	79.4
July 22nd 22 lipca	17.8	17.6	17.7	87.6	93.3	90.5
July 29th 29 lipca	18.7	18.3	18.5	103.5	106.0	104.8
August 5th 5 sierpnia	18.9	18.5	18.7	107.2	109.6	108.4
August 14th 14 sierpnia	19.9	19.5	19.7	112.8	114.5	113.7
August 19th 19 sierpnia	19.7	19.6	19.7	115.4	116.1	115.8
$LSD_{0.05}$ (for last measurement)		n.s.			n.s.	
$NIR_{0,05}$ (dla ostatniego pomiaru)		n.i.			n.i.	

Table 3. Effect of mycorrhizal inoculation on the content of macronutrients leaves (in % of dry matter)
Tabela 3. Wpływ inokulacji szczepionką mikoryzową na zawartość makroelementów w liściach pomidora (w % suchej masy)

Macronutrient Makroelement	Inoculated plants Rośliny inokulowane	Non inoculated plants Rośliny nieinokulowane	Mean Średnio	$LSD_{0.05}$ $NIR_{0,05}$
Nitrogen (N)	3.94	3.98	3.96	
Phosphorus (P)	0.43	0.44	0.44	
Potassium (K)	4.42	4.40	4.41	n.s./n.i.
Magnesium (Mg)	0.30	0.32	0.31	
Calcium (Ca)	2.78	2.76	2.77	

Table 4. Effect of mycorrhizal inoculation on course of fruiting and structure of tomato yield (g · plant^{-1})
Tabela 4. Wpływ szczepionki mikoryzowej na przebieg plonowania i strukturę plonu owoców pomidora (g · roślina^{-1})

Date of harvest Data zbioru	Ripe, healthy, Ø > 35 mm Dojrzałe, zdrowe			Ripe, healthy, Ø < 35 mm Dojrzałe, zdrowe			Unripe, healthy Niedojrzałe, zdrowe			Diseased Chore			Total yield Plon ogółem		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
July 29th 29 lipca	110.3	93.4	101.9	0.0	20.6	10.3	0.0	0.0	0.0	49.8	45.4	47.6	160.1	159.4	159.8
August 5th 5 sierpnia	212.6	205.2	208.9	28.9	0.0	14.5	0.0	0.0	0.0	560.3	486.1	523.2	801.8	691.3	746.6
August 13th 13 sierpnia	220.1	170.3	195.2	0.0	0.0	0.0	0.0	0.0	0.0	385.9	498.9	442.4	606.0	669.2	637.6
August 20th 20 sierpnia	128.7	106.5	117.6	53.6	59.5	56.6	0.0	0.0	0.0	494.1	453.1	473.6	676.4	619.1	647.7
August 28th 28 sierpnia	71.0	93.6	82.3	0.0	0.0	0.0	148.3	159.4	153.9	542.2	465.0	503.6	761.5	718.0	739.7
Total Suma	742.7	669.0	705.9	82.5	80.1	81.3	148.3	159.4	153.9	2032.3	1948.5	1990.4	3005.8	2857.0	2931.4
$LSD_{0.05}$ (total) $NIR_{0.05}$ (suma)	n.s./n.i.			n.s./n.i.			n.s./n.i.			n.s./n.i.			n.s./n.i.		

I – inoculated plants/ rośliny inokulowane
II – non inoculated plants/ rośliny nieinokulowane
III – mean/ średnio

Table 5. Effect of mycorrhizal inoculation and date of harvest on tomato fruit diameter and weight
Tabela 5. Wpływ inokulacji szczepionką mikoryzową oraz terminu zbioru na masę i średnicę owocu handlowego pomidora

Date of harvest Data zbioru	Fruit weight (g) Masa owocu			Fruit diameter (mm) Średnica owocu		
	inoculated rośliny inokulowane	non inoculated rośliny nieinokulowane	mean średnio	inoculated rośliny inokulowane	non inoculated rośliny nieinokulowane	mean średnio
July 29th 29 lipca	79.8	88.5	84.2	48.5	51.9	50.2
August 5th 5 sierpnia	134.6	133.3	134.0	59.3	58.3	58.8
August 13th 13 sierpnia	145.0	138.6	141.8	61.0	59.2	60.1
August 20th 20 sierpnia	136.9	144.2	140.1	58.8	60.7	59.8
Mean Średnio	124.1	126.2	125.0	56.9	57.5	57.2
$LSD_{0.05}$ (mean) $NIR_{0.05}$ (średnio)	n.s./n.i.			n.s./n.i.		

Table 6. Effect of mycorrhizal inoculation in content of several components and acidity of marketable tomato fruits
Tabela 6. Wpływ inokulacji szczepionką mikoryzową na zawartość wybranych składników i kwasowość handlowych owoców pomidora

Components Składniki	Inoculated Rośliny inokulowane	Non inoculated Rośliny nieinokulowane	Mean Średnio	$LSD_{0.05}$ $NIR_{0,05}$
Total sugars (% f.w.) Cukry ogółem (% św.m.)	2.02	1.75	1.89	0.119
Monosaccharides (% f.w.) Cukry proste (% św.m.)	1.55	1.36	1.46	0.187
L-ascorbic acid (mg · 100 g^{-1} f.w.) Kwas L-askorbinowy (mg · 100 g^{-1} św.m.)	19.98	18.00	18.99	1.853
Total chlorophyll (mg · 100 g^{-1} f.w.) Chlorofil całkowity (mg · 100 g^{-1} św.m.)	0.0792	0.0789	0.0791	n.s./n.i.
Carotenoids (mg · 100 g^{-1} f.w.) Karotenoidy (mg · 100 g^{-1} św.m.)	5.10	5.22	5.18	n.s./n.i.
Dry matter (%) Sucha masa (%)	4.96	5.03	5.00	n.s./n.i.
Acidity (%) Kwasowość (%)	0.224	0.170	0.197	0.0296

DISCUSSION

Many authors proved beneficial effects of mycorrhization on growth and yield of tomato [Conversa *et al*. 2007, Candido *et al*. 2013, 2015, Colella *et al*. 2013] but in this experiment inoculation of transplants with Mycoflor® preparation did not influence stem length and diameter or fruiting of 'Malinowy Ożarowski' tomato under field cultivation. These results confirm the data obtained by Mueller *et al*. [2009], Smith *et al*. [2003] and partially also by Makus [2004]. Mycorrhization did not affect fruit mean weight and diameter and this is in line with the results obtained by Candido *et al*. [2013, 2015], Colella *et al*. [2013], Dubova *et al*. [2014] and Makus [2004]. In the experiment, tomatoes were cultivated on a fertile soil and were supplied well with water and macronutrients. Moreover, air temperature was also suitable for their growth and according to Azcón-Aguilar and Barea [1997], Górka [2004], Głuszek *et al*. [2008] and Fiorilli *et al*. [2007] mycorrhization is more effective under stress conditions. Differentiated effects of mycorrhization on tomato plants can be explicated by differences in environmental factors occurring during cultivation period [Azcón-Aguilar and Barea 1997, Górka 2004, Głuszek *et al*. 2008] and also by different tomato cultivars used in the studies [Dubova *et al*. 2014]. In this experiment, main problem was an early appearance and rapid infestation of tomato plants with tomato blight what was favoured by rainy weather during first months of cultivation. There was no effect of mycorrhization on this process and this is in line with the results obtained by Colella *et al*. [2013]. However, in the literature there are data showing beneficial influence of mycorrhizal fungi on plant resistance against several fungal diseases [Fiorilli *et al*. 2011, Fritz *et al*. 2006]. According to Fiorilli *et al*. [2011] the effect depends on the life style of the pathogen and on its interaction with the host plant. Mycorrhization did not affect the content of macronutrients in tomato leaves. Similarly Mueller *et al*. [2009] stated no effect of this treatment on nitrogen and phosphorus uptake by tomato plants and Smith *et al*. [2003] stated no its effect on tomato phosphorus nutrition. Mycorrhization had a positive influence on the content of total sugars, monosaccharides, L-ascorbic acid and on acidity of marketable tomato fruits and had no effect on other studied components and this agrees partially with the results referring to basil obtained by Borowy and Matela [2012] in the same natural conditions. Mycorrhization did not affect the content of dry matter in tomato fruits and this confirm the results obtained by Candido *et al*. [2013 and 2015], Dubova *et al*. [2014] and Mueller *et al*. [2009].

Data presented in this paper were obtained in one-year field experiment and should be confirmed in further studies.

CONCLUSIONS

1. Mycorrhizal inoculation did not affect the growth, the yield and the course of fruiting of 'Malinowy Ożarowski' tomato.

2. Content of nitrogen, phosphorus, magnesium and calcium in tomato leaves did not depend on mycorrhizal inoculation.

3. Tomato fruits harvested from inoculated plants contained total sugars, monosaccharides and L-ascorbic acid more and their acidity was higher, however content of dry matter, total chlorophyll and carotenoids did not differ in comparison to control plants.

4. Mycorrhizal inoculation did not affect the infestation of tomato plants by tomato blight.

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Streszczenie. Siedmiotygodniową doniczkowaną i szczepioną grzybami mikoryzowymi rozsadę pomidora sadzono na glebie płowej w połowie maja i prowadzono na jeden pęd przy palikach do 28 sierpnia. Mikoryzacja nie miała wpływu na długość i średnicę pędu ani na zawartość azotu, fosforu, potasu, wapnia i magnezu w suchej masie liści pomidora. Nie miała również wpływu na przebieg owocowania pomidora, porażenie roślin przez zarazę ziemniaka, wielkość i strukturę plonu owoców ani na świeżą masę i średnicę owocu handlowego. Owoce zebrane z roślin inokulowanych zawierały więcej cukrów ogółem, cukrów prostych i kwasu L-askorbinowego, a ponadto ich kwasowość była większa niż owoców wytworzonych przez rośliny nieinokulowane. Zawartość suchej masy, chlorofilu całkowitego oraz karetonoidów nie różniła się istotnie.

Słowa kluczowe: długość i średnica łodygi, makroelementy, sucha masa, zaraza ziemniaka