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EFFECT OF A MYCORRHIZAL INOCULUM ON THE YIELDING AND CHEMICAL COMPOSITION OF FRUIT FOUR CULTIVARS OF TOMATO

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Abstract. The objective of the study was to determine the yield and chemical composition of the fruits of four tomato cultivars‘Growdena F_1’, ‘Torero F_1’, ‘Listell F_1’ and ‘Mamirio F_1’ grown in coir fibre inoculated with mycorrhizal fungi of the genus *Glomus*. The mycorrhizal inoculum was applied directly to the coir fibre, at 20 g per m^2. The content of dry matter, total sugars, reducing sugars, L-ascorbic acid and organic acids (expressed as malic acid) in tomato fruit was determined. The total and marketable yields of tomato fruits were influenced by the cultivar the highest yields were abtained from plants of ‘Torrero F_1’ cv. and lowest yields produceal plants of‘Mamirio F_1’ cv. Tomato plants that received the mycorrhizal inoculum, except cv. ‘Torero F_1’, produced higher yields than control plants. The fruit of cv. ‘Mamirio F_1’ had the highest content of dry matter, total sugars, reducing sugars and L-ascorbic acid, nitrates and the lewest weight of fruit.

Key words: dry matter, sugars, organic acids, fertigation, coir fibre, inoculum.

INTRODUCTION

Tomatoes (*Lycopersicon esculentum* Mill.)are widely grown and eaten around the world. The increasing economic significance of tomato fruit is a consequence of their high biological value, specific taste and flavor as well as a wide range of culinary uses and applications [Winiarska and Kołota 2007]. In Poland, the introduction of high-yielding tomato varieties that can be grown in small amounts of substrate and improved cultivation technologies contributed to a 35% increase in tomato production since 2004,

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and the total yield of tomatoes grown under covers reached 498.000 tons [Martyniak--Przybyszewska 2000, Winiarska and Kołota 2007]. Tomato yields achieved under the climatic conditions of Poland range from 51 $kg \cdot m^{-2}$ in inert substrates to 17 $kg \cdot m^{-2}$ in organic substrates [Chudzik 2014]

In Poland, tomatoes grown in a controlled environment in rockwool mats with fertigation and circulating nutrient solution produce the highest yields. However, the disposal of used rockwool is a major problem for growers [Kobryń et al. 2007]. Coir fibre, which has a high water-holding capacity and porosity of 30%, provides a viable alternative to rockwool [Jarosz and Dzida 2011].

Symbiotic mycorrhizal fungi are introduced to crops in the form of vaccines. Their application allows to achieve much better results in the vegetative growth of plants, their target yield, and also positively affects the quality of the obtained crop [Kubiak 2007]. Particular importance of preparations containing strains of mycorrhizal fungi is manifested in crops under conditions in which plants can be exposed to different kind of stress factors such as water or temperature stress, soil with a low abundance of nutrients or under conditions which hinder the uptake of those components [Nowak and Nowak 2013].Mycorrhizas are of particular importance when tomatoes and cucumbers are grown under covers. A mycorrhizal inoculum introduced into the substrate leads to a symbiotic relationship between the fungus and the host plant's roots that involves nutrient exchange. Mycorrhizal fungi protect plants against pathogens such as *Verticillium*, *Fusarium*, *Phytium* and *Rhizoctonia* [Sumorok et al. 2011]. They also promote plant health and growth [Kubiak 2007].

The aim of this study was to determine the effect of a mycorrhizal inoculum on the yield and chemical composition of the fruits of four tomato cultivars grown in coir fibre.

MATERIALS AND METHODS

The experiment was conducted in 2012–2013 in the Experimental Garden of the University of Warmia and Mazury in Olsztyn (NE Poland). Tomatoes were grown in a heated plastic tunnel in coir fibre. The experimental materials comprised seedlings of four tomato cultivars, 'Growdena F_1', 'Torero F_1', 'Listell F_1' and 'Mamirio F_1'. Tomato seeds were sown in rockwool cubes in a horticultural farm. The second experimental factor was inoculation of the substrate with endomycorrhizal fungi of the genus *Glomus*.

Each year, towards the end of February, treatment temperature was adjustment to the requirements of tomato plants and coir fibre mats were saturated with a nutrient solution whose chemical composition was determined based on the chemical composition of water (pH w H_2O – 6.99, EC mS – 0.57, N-NO_3 – 0.76 mg dm^3, P-H_2PO_4 – 0.02 mg dm^3, K – 5.50 mg dm^3, Ca – 88.74 mg dm^3, Mg – 16.26 mg dm^3) and the nutrient requirements of tomato plants. The nutrient solution contained (per dm^3): N – 170 mg, P – 70 mg, K – 360 mg, Mg – 60 mg, Ca – 200 mg, Fe – 1.8 mg, Mn – 0.55 mg, B – 0.33 mg, Cu – 0.05 mg, Zn – 0.38 mg, Mo – 0.05 mg. During the experiment, the composition of the nutrient solution was modified to account for changing weather conditions, the growth stages and nutrient requirements of tomato plants.

The experiment was carried out in triplicate. Each replicate consisted of three coir fibre mats (100 × 20 × 7.5 cm) with two tomato plants grown in each mat, pruned to produce 23 clusters. Tomato seedlings were placed next to the holes made in the mats. The mycorrhizal inoculum was applied directly to the coir fibre, at 20 g per m^2, immediately before transplanting the seedlings. Mycorrhizal fungi were not used in the control treatment. the seedlings were placed in holes when the first inflorescence was visible on 50% of the plants. For three to four days, nutrient solution was applied at a single dose of 130 ml six to seven times a day, which promoted superior root development. During the four to six weeks, a starter nutrient solution with EC of 3.2–3.5 mS cm^{-1} was used, and EC in coir fibre reached 5.0 mS·cm^{-1}. In subsequent weeks, a standard nutrient solution was used, with EC ranging from 2.5–2.7 mS cm^{-1} on sunny days to 3.1–3.3 mS cm^{-1} on cloudy days. The flow rate was set at 10–30% depending on weather conditions. After six weeks, they were tested quality mycelium substrate plate method.

Tomatoes were harvested twice a week. The fruits were weighed and sorted to determine total and marketable yields according to the European Standards – Commission Regulation (EU) No 1258/2011 of 2 December 2011. In both years of the study, harvest ended between 20 and 31 October. When the fruits had reached full size and form (beginning of August), tomatoes were collected from the marketable yield in each replication to obtain an average sample per treatment. Data are presented as mean values for two years. At the laboratory of the Department of Horticulture, University of Warmia and Mazury in Olsztyn, tomato fruit were assayed for the content of:

– dry matter – by drying to constant weight at 105°C,

– total sugars and reducing sugars –determination based on the reaction outcome of Cu^{2+} ions contained in the liquid by the Luff-reducing saccharides present in the solution [PN-90/A-75101/07],

– organic acids expressed as malic acid – by measuring the electromotive force cell

– L-ascorbic acid – by color reaction of ascorbic acid with a solution of 2,6-dichloroindophenol (Tillman's reagent) [PN-90A-75101/11],

– nitrates (V) – by the colorimetric method with the use of salicylic acid [Krauze and Domska 1991].

Due to the small differences of the results in both years, the tables show the average of the years 2012–2013. The results were processed statistically. The significance of differences between means was estimated using Tukeys confidence intervals at a 1% significance level. All calculations were performed in the STATISTICA 10 application.

RESULTS AND DISCUSSION

Tomato plants can be grown in soilless media in a greenhouse or a heated plastic tunnel until the 25th cluster reaches typical form and size. The tomato growing season, which lasts from the beginning of March to the end of October, is characterized by different sunlight conditions. Tomato plants often suffer from insufficient light exposure until mid-April, the highest photosynthetic efficiency is observed until the end of August, and in September and October days become shorter and plants receive less sunlight [Nurzyński et al. 2004]. Mycorrhizal fungi are applied to improve and stimulate plant growth. Mycorrhizas also contribute to root system development. This mutualistic symbiosis between a fungus and the host plant's roots provides benefits to both partners which exchange nutrients and other beneficial substances. Mycorrhizas can be divided into ectomycorrhizas and endomycorrhizas. The hyphae of endomycorrhizal fungi penetrate the root tissue of herbaceous plants without suppressing root hair development.

The parameter which determines the size of tomato yield is the weight offruits. It was differentiated by all of the discussed factors (tab. 1). The biggest fruits were observed in case of cultivation of the 'Growdena F_1' variety, while the smallest ones were characteristic for the 'Marmirio F_1' variety. The use of mycorrhizal vaccine caused a reduction in the weight of a single fruit by 5.08%.A statistical analysis revealed significant differences in yield between the four analyzed tomato cultivars (tab. 1). On average, tomato plants of cv. 'Torero F_1' produced the highest total and marketable yields, at 17.41 kg m^{-2} and16.75 kg m^{-2}, respectively. Similar values were reported by Borowski and Nurzyński [2012]. Plants of cv. 'Mamirio F_1' produced the lowest total and marketable yields (13.73 kg m^{-2} and 10.90 kg m^{-2}, respectively). According to many authors, growing in coir fibre positively affects the size and quality of tomato fruit [Chohura and Komosa 1999, Piróg 1999]. However, Kobryń et al. [2007] obtained higher yields of tomato cv. 'Favorita', 'Organza', 'Flavorino' and 'Goldita' grown in rockwool, as compared with coir fibre. In our study, the mycorrhizal inoculum had a significant effect on the yields of the analyzed tomato cultivars, relative to control. The total and marketable yields of tomato fruit were also significantly influenced by the interaction between the experimental factors. Tomato plants that received the mycorrhizal inoculum produced significantly higher yields than control plants, ranging from 11.53 kg m^{-2} (cv. 'Mamirio F_1') to 15.61 kg m^{-2} (cv. 'Listell F_1').

Table 1. The effects of cultivar and mycorrhizal inoculum on the total on well as marketable fruit yields and fruit mean weight of tomato plants grown in coir fibre (means of 2012–2013)

Cultivar (a)	Mycorrhiza (b)	Mean fruit weight	Total yield	Marketable yield
		(g)	(kg m^{-2})	
'Listell F_1'	control	215.70	11.55	10.77
	mycorrhiza	203.07	15.90	15.61
	mean	209.39	13.73	13.19
'Growdena F_1'	control	301.40	14.28	11.76
	mycorrhiza	287.03	13.71	12.22
	mean	294.22	14.00	11.99
'Torero F_1'	control	283.30	17.85	17.32
	mycorrhiza	266.00	16.96	16.17
	mean	274.70	17.41	16.75
'Mamirio F_1'	control	197.04	12.99	10.26
	mycorrhiza	190.60	13.63	11.53
	mean	193.82	13.31	10.90
Mean	control	249.36	14.17	12.53
	mycorrhiza	236.70	15.05	13.88
$LSD_{\alpha=0.01}$				
Cultivar (a)		11.83	2.02	2.30
Mycorrhiza (b)		50.61	0.20	0.50
Interaction (a × b)		17.00	1.20	1.00

Table 2. The effects of cultivar and mycorrhizal inoculum on the dry matter and nutrient content of tomatoes grown in coir fibre (means of 2012–2013)

Cultivar (a)	Mycorrhiza (b)	Dry matter	Total sugars	Reducing sugars	Organic acids	L-ascorbic acid	Nitrates (V)
		(%)	(g 100 g $^{-1}$ FW)			(mg 100 g $^{-1}$ FW)	mg (NO_3^- kg^{-1} FW)
‘Listel F_1’	control	5.49	1.79	1.44	0.40	9,51	506
	mycorrhiza	5.34	2.01	1.77	0.40	8,10	462
	mean	5,42	1.90	1.61	0.40	8.81	484
‘Growdena F_1’	control	5.40	1.87	1.79	0.45	10.92	220
	mycorrhiza	5.42	2.39	2.24	0.40	11.28	108
	mean	5.41	2.13	2.02	0.44	11.10	164
‘Torero F_1’	control	5.05	1.72	0.91	0.40	12.33	538
	mycorrhiza	5.02	2.15	2.13	0.54	13.39	254
	mean	5.04	1.94	1.52	0.47	12.86	396
‘Mamirio F_1’	control	6.43	2.91	1.94	0.47	14.09	751
	mycorrhiza	6.99	2.81	2.13	0.40	14.09	881
	mean	6.71	2.86	2.04	0.44	14.09	816
Mean	control	5.59	2.07	1.52	0.44	11.71	504
	mycorrhiza	5.69	2.34	2.07	0.44	11.71	426
LSD $_{\alpha=0.01}$							
Control (a)		0.24	0.32	n.s	n.s.	0.80	140
Mycorrhiza (b)		n.s	n.s	0.37	n.s.	n.s.	n.s
Interaction (a× b)		0.14	0.02	0.12	0.02	0.03	100

The biological value of fresh tomato fruit is determined by climate and weather conditions, cultivar, farming practices and technological factors. According to Halmann and Kobryń [2002] and Nurzyński [2002], efficient organic substrates for growing tomatoes under cover are low-moor peat mixed with pine bark, coir fibre and straw. Coir fibre undergoes slow microbial decomposition, has pH of 6.5 to 6.8 and EC of around 0.5 mS cm^{-1}, and a high content of sodium (up to 40 mg dm^{-3}), potassium (up to 80 mg dm^{-3}) and chlorine (up to 70 mg dm^{-3}).

The main components of the edible parts of vegetables are water and dry matter. The processing suitability of plant materials is largely determined by dry matter content [Majkowska-Gadomska and Wierzbicka 2013]. A laboratory analysis revealed that the analyzed tomato cultivars differed significantly in dry matter concentrations (tab. 2). The fruit of cv. ‘Mamirio F_1’ had the highest dry matter content (6.71%). In the remaining cultivars, regardless of mycorhiza dry matter concentrations ranged from 5.04 to 5.42%. Similar dry matter levels were determined in tomato fruit of cv. ‘Raissa F_1’ by Dzida and Jarosz [2005], in tomato fruit of cv. ‘Cunero F_1’ grown in rockwool, perlite and expanded clay aggregate by Jarosz et al. [2012], and in tomato fruit of cv. ‘Flavorino’ by Kobryń et al. [2007]. In a study by Kobryń et al. [2007], tomato fruit of cv. ‘Favorita’, ‘Organza’ and ‘Goldita’ had higher dry matter concentrations than the cultivars analyzed in the present experiment. Mycorrhizal fungi exerted varied effects on the dry matter content of tomato fruit. Dry matter levels in tomato fruit, which varied from 5.02 to 6.99%, were significantly affected by the interaction between the experimental factors.

The flavor of tomato fruit is determined by the concentrations of sugars and organic acids [Kulka and Rejowski 1998]. In our study, the total sugar content of tomato fruit ranged from 1.72 to 2.91 g 100 g^{-1}, and organic acid levels ranged from 0.4 to 0.54 g 100 g^{-1}. Total sugar concentrations varied between cultivars, from 2.86 g 100 g^{-1} FW in cv. 'Mamirio F_1' to 1.90 g^{-1} FW in cv. 'Listel F_1'. Mycorrhizal fungi contributed to an increase in total sugar content in all tomato cultivars except 'Mamirio F_1'. The mycorrhiza and the mycorrhiza × cultivar interaction had a positive effect on the concentrations of reducing sugars in tomato fruit. The total sugar content of tomatoes was comparable to that noted by Jarosz et al. [2012].

Organic acid concentrations in tomato fruit varied between cultivars and inoculated vs. non-inoculated treatments. The mycorrhiza x cultivar interaction had a significant effect on organic acid content, only in 'Torrero F_1'cv. which ranged from 0.40 to 0.54 g 100 g^{-1} FW.

The biological value of the edible parts of vegetables is determined by L-ascorbic acid levels which, according to Kunachowicz et al. [2006], should oscillated around 23 mg 100 g^{-1} in tomato fruit. In our study, the L-ascorbic acid content of tomato fruit was significantly affected by the cultivar and the mycorrhiza × cultivar interaction. The fruit of cv. 'Listell F_1' had the lowest concentration of L-ascorbic acid (8.81 g 100 g^{-1} FW), and the highest L-ascorbic acid level was noted in the fruit of cv. 'Mamirio F_1' (14.09 g 100 g^{-1} FW). Inoculation of the growth medium with mycorrhizal fungi had significant, but varied effects on L-ascorbic acid concentrations in tomato fruit, which were higher in the fruit of cv. 'Growdena F_1' and 'Torero F_1' than in the fruit of the other two cultivars. Dzida and Jarosz [2005] reported higher L-ascorbic acid levels in tomato fruit of cv. 'Cunero F_1' grown in rockwool, perlite and expanded clay aggregate.

Average nitrate (V) concentrations in tomato fruit, except the fruit of cv. 'Growdena F_1', exceeded the maximum permissible level (250 NO^-_3 kg^{-1} fresh weight) [Dz.U. 2005 nr 2 poz. 9] (tab. 3). The mycorrhizal inoculum had no significant effect on nitrate accumulation in tomato fruit, which was affected by the interaction between the experimental factors. The lowest nitrate concentrations (108 mg NO^-_3 kg^{-1} FW) were noted in tomato fruit of cv. 'Growdena F_1' treated with mycorrhizal fungi.

CONCLUSIONS

1. The total and marketable yields of tomato fruit were influenced by cultivar. The highest yield abtained from plants of 'Torrero F_1' cv. and the lowest one from plants 'Mamirio F_1'cv.

2. Tomato plants that received the mycorrhizal inoculum, except cv. 'Torero F_1', produced a higher yield than control plants.

3. The fruit of cv. 'Mamirio F_1' had the highest content of dry matter, total sugars, reducing sugars, L-ascorbic acid, nitrates and the lowest weight of fruit.

4. The mycorrhizal inoculum had no significant effect on the dry matter, nutrient content and nitrates level in tomato fruit.

5. Average nitrate (V) concentrations in tomato fruit, except the fruit of cv. 'Growdena F_1', exceeded the maximum permissible level (250 mg NO^-_3 kg^{-1} fresh weight).

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WPŁYW SZCZEPIONKI MIKORYZOWEJ NA PLONOWANIE I SKŁAD CHEMICZNY OWOCÓW CZTERECH ODMIAN POMIDORA

Streszczenie. Celem badań było określenie plonowania i składu chemicznego owoców czterech odmian pomidora: 'Growdena F_1', 'Torero F_1', 'Listell F_1' i 'Mamirio F_1' uprawianego we włóknie kokosowym z zastosowaniem grzybów mikoryzowych z rodzaju *Glomus*. Inokulum mikoryzowe zastosowano bezpośrednio do podłoża kokosowego w dawce 20 g/m^2. W owocach pomidora określono zawartość suchej masy, cukrów ogółem, cukrów redukujących, kwasu L-askorbinowego i kwasów organicznych (wyrażone w przeliczeniu na kwas jabłkowy). Rośliny poszczególnych odmian różniły się wysokością plonów. Największy plon ogółem i handlowy otrzymano z roślin odmiany 'Torero F_1', a najmniejszy z 'Mamirio F_1'. Pomidory z zastosowaną szczepionką mikoryzową, z wyjątkiem odmiany Torero F_1', plonowały lepiej niż rośliny kontrolne. Owoce odmiany Mamirio F_1' miały największą zawartość suchej masy, cukrów ogółem, cukrów redukujących, kwasu L-askorbinowego, azotanów (V) i najmniejszą masę owoców.

Słowa kluczowe: sucha masa, cukry, kwasy organiczne, fertygacja, podłoże kokosowe, inokulum

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