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MORPHOLOGICAL CHARACTERISTICS AND NUTRITIONAL VALUE OF PURPLE-COLOURED STORAGE ROOTS OF CARROTS PROTECTED WITH A BIOFUNGICIDE

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A b s t r a c t. A field experiment was conducted in 2013-2014. The experiment had a randomised block design with three replicates. The first experimental factor was two carrot (*Daucus carota* L.) cultivars, 'Purple Haze F_1' and 'Deep Purple F_1', and the second experimental factor was the application of the biocontrol agent Bioczos BR. In the control treatment, plots were sprayed with water. The aim of the study was to determine the effect of Bioczos BR on selected morphological traits and the nutritional value of purple-coloured storage roots of carrots. The analysed carrot cultivars differed considerably in root weight and length. Carrots of cv. 'Deep Purple F_1' had higher average root weight. Consistent changes were observed in the nutrient content of carrot roots. Bioczos BR contributed to an increase in the content of dry matter (by 14%), total sugars (by 28%), reducing sugars (by 31%) and nitrates (V) (by 32%) in carrot roots, in comparison with the control treatment.

K e y w o r d s: carrots, morphology, nutritional value, storage roots

INTRODUCTION

Carrots (*Daucus carota* L.) are one of the most popular root vegetables grown worldwide. According to Arscott and Tanumihardja (2010), Wierzbicka and Majkowska-Gadomska (2012), the consumption of carrots has been increasing steadily in recent years because they are a rich source of nutrients, including antioxidants. Carrot cultivars with purple roots, which are relatively uncommon in Europe, provide considerable health benefits (Czapski *et al.* 2009).

There is a growing interest among consumers in organic crops (Jamiołkowska and Hetman 2016). Therefore, vegetable growers and producers have to optimise production technologies with the use of biocontrol agents that improve the quality and yield of vegetables, and increase the productivity of horticultural crops (Calvo *et al.* 2014, Pytlarz-Kozicka and Zagórski 2012). According to Jamiołkowska and Hetman (2016) biological preparations protect plants against pathogens and induce various resistance mechanisms in the plants. A good biopreparation in plant protection is Bioczos BR. The preparation Bioczos BR is based on natural garlic pulp. Garlic extract has antifungal and antibacterial properties. The antimicrobial activity of garlic juice is due to allicin. Allicin is a natural biological substance, a phytoanticipin produced in garlic upon wounding (Jamiołkowska and Wagner 2011).

The objective of this study was to determine the effect of the biofungicide Bioczos BR on selected morphological traits and the nutritional value of purple-coloured storage roots of carrots.

MATERIAL AND METHODS

Two carrot cultivars with purple-coloured storage roots were grown in a two-factorial experiment conducted in 2013-2014 in the Experimental Garden owned by the University of Warmia and Mazury in Olsztyn. The experiment had a randomised block design with three replicates. The first experimental factor was two carrot cultivars, 'Purple Haze F_1' and 'Deep Purple F_1' from Johnny's Selected Seeds. The second experimental factor was the application of the biocontrol agent Bioczos BR at 2.5%. In the control treatment, plots were sprayed with water. The effect of Bioczos BR on the morphological traits and nutrient content of carrot roots was determined. Carrots were grown on ridges, in the second year after manure application, on brown soil of quality class IVb, with pH 7.3, salt concentration of 0.8 g dm^{-3} and the following mineral composition: N-NO_3 – 38, P – 90, K – 157, Ca – 1840, Mg – 194 mg dm^{-3}. Soil mineral deficiencies were corrected based on chemical analysis. Carrots were grown after cruciferous vegetables. Each year, carrot seeds were sown in the middle of May, at ridge spacing of 65 cm. Plot size was 7.5 m^2. Bioczos BR was applied three times, at 10-day intervals, beginning at 2 weeks after seedling emergence. The Bioczos preparation was applied in the form of spraying at a concentration of 3%. Carrot plants were cultivated in line with the generally observed standard for this vegetable species. Each year, once-over harvest of carrot roots was carried out in the middle of October. The roots were divided into fractions of total yield, representing marketable and non-marketable yields, according to the relevant commercial quality standards (Commission Regulation (EC) No. 46/2003). Ten carrot roots were sampled from the marketable yield to prepare average samples in each treatment. The weight, length and width of root and the horizontal diameter of the core were determined at the height of 2 cm from the root head. The chemical composition of carrot roots was analysed in the laboratory by determining the content of dry matter – by drying the samples at 105°C to constant weight (PN90/A-75101/03), total sugars and reducing sugars – by the method proposed by Luff-Schoorl (PN-90/A-75101/07), L-ascorbic acid – by the method proposed by Tillmans and modified by Pijanowski (Determination of vitamin C content... PN-90/A-75101/11), nitrates (V) – colorimetrically, with the use of salicylic acid (Krauze and Domska 1991).

The influence of the experimental factors in both years of research was similar, therefore the results were averaged. The analyses were performed in 3 replicates, and the results were processed statistically by analysis of variance (ANOVA) in the STATISTICA 12 program. The significance of differences between means was estimated by Tukey's range test at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Research has shown that biopreparations can contribute to improving the health status and quality of horticultural crops (Sapieha-Waszkiewicz *et al.* 2010). According to Regulation (EC) No 1107/2009 of the European Parliament and of the Council (Regulation (EC)... 2009), integrated crop protection strategies should involve non-chemical control methods and natural alternative plant protection products. The biocontrol agent Bioczos BR containing paraffin-coated garlic pulp has been found to be highly effective in protecting plants and improving the chemical composition of the edible parts of vegetables (Wierzbicka and Majkowska-Gadomska 2012). The preparation is used to control bacterial and fungal diseases, and pest infestations in vegetable crops (Janas *et al.* 2002, Dłużniewska 2004). According to Sapiecha-Waszkiewicz *et al.* (2010), Bioczos BR can be applied at all growth stages of plants, starting from germination, through emergence to the end of vegetative growth and maturity. The high effectiveness of Bioczos BR has been demonstrated in many studies (Saniewska 2004, Sealy *et al.* 2007, Jemiołkowska and Wagner 2011, Hadian 2012, Jamiołkowska and Hetman 2016). Sapiecha-Waszkiewicz *et al.* (2010) found that the product had a toxic effect on the spore germination of pathogenic fungi. Horoszkiewicz-Janka *et al.* (2012) reported low infection rates in legume seeds treated with garlic pulp whose effect was comparable with that of chemical dressing. In a study by Sapiecha-Waszkiewicz *et al.* (2010), the biofungicide Bioczos Standard protected strawberries against gray mould, and its effectiveness was largely affected by weather conditions. Heavy rainfall during the growing season reduced the effectiveness of Bioczos BR.

The present study revealed significant differences in the biometric parameters and chemical composition of purple-coloured storage roots of two carrot cultivars. Bioczos BR had a significant effect on root morphology (Table 1). According to Wierzbicka *et al.* (2010) and Majkowska-Gadomska *et al.* (2007), the yield and quality of carrot roots are determined by weather conditions, the selection of appropriate varieties and adequate agronomic conditions.

Table 1. The effect of cultivar and of the biocontrol agent Bioczos BR on the biometric characteristics of carrot storage roots (means of 2013-2014)

Cultivar	Method of protection	Mass	Root length	Root width	Horizontal diameter of the core
		g	cm		
Purple Haze F_1	Control	60.43	19.10	2.18	1.98
	Bioczos BR	65.84	18.28	3.10	2.82
Mean		63.14	18.69	2.64	2.40
Deep Purple F_1	Control	156.77	26.27	2.60	2.53
	Bioczos BR	172.53	22.70	3.25	3.02
Mean		164.65	24.48	2.92	2.77
Mean	Control	108.60	22.68	2.39	2.25
	Bioczos BR	119.19	20.49	3.17	2.92
LSD $\alpha = 0.05$					
Cultivar		10.86	2.33	n.s.	n.s.
Method of protection		n.s.	n.s.	0.73	0.64
Interaction		11.60	2.38	n.s.	n.s.

Statistical analysis of the mean values of the analysed parameters, determined over the two-year study, revealed that the weight and length of carrot roots were significantly affected by cultivar and the interaction between the experimental factors. Carrot roots of cv. 'Deep Purple F_1' treated with Bioczos BR had the highest weight, and carrot roots of cv. 'Purple Haze F_1' grown in the control treatment had the lowest weight. The weight of carrot roots noted in this study is similar to the values reported by Majkowska-Gadomska *et al.* (2007) (117.2 to 272.1 g for various cultivars) and by Kozik *et al.* (2011) (60.0-140.0 g).

Significant differences in root length were also observed in our study. Carrot roots of cv. 'Deep Purple F_1' were longer than carrot roots of cv. Purple Haze F_1'. Carrots of cv. 'Deep Purple F_1' grown in the control treatment had the longest roots, and carrots of cv. 'Purple Haze F_1' treated with Bioczos BR and grown in the control treatment had the shortest roots. Similar results were reported by Gruszecki and Łopucka (2014) (16.1-17.8 cm), and Majkowska-Gadomska *et al.* (2007) (18.2-24.4 cm). In a study by Kozik *et al.* (2011), the length of carrot roots ranged from 14.8 to 22.8 cm.

Significant differences were noted in the width of carrot roots treated with Bioczos BR and carrot roots from the control treatment. According to Majkowska-Gadomska *et al.* (2007), the weight of carrot storage roots ranges from 3.0 to 5.2 cm. Similar values were reported by Kozik *et al.* (2011) (2.50-3.30 cm). Significant differences were also found in the horizontal diameter of the core, which varied from 2.25 cm in the control treatment to 2.92 cm after the application of Bioczos

BR. The interaction between the experimental factors had no significant effect on the horizontal diameter of the core. Similar values were reported by Majkowska-Gadomska *et al.* (2007) (1.3-2.8 cm).

Boskovic and Rakocevic *et al.* (2007) and Majkowska-Gadomska and Wierzbicka (2010) demonstrated that the chemical composition of carrot roots may vary widely depending on environmental conditions. The nutrient content of purple-coloured storage roots of two carrot cultivars is presented in Table 2.

Table 2. The effect of cultivar and of the biocontrol agent Bioczos BR on nutrient content of carrot storage roots (means of 2013-2014)

Cultivar	Method of protection	Dry matter	Total sugars	Reducing sugars	L-ascorbic acid	Nitrates (V)
		%	g 100 g $^{-1}$ f.m.		mg 100 g $^{-1}$ f.m.	mg NO_3 kg^{-1} f.m.
Purple Haze F_1	Control	10.25	5.85	2.75	2.00	204.80
	Bioczos BR	12.83	7.36	3.87	2.10	285.20
Mean		11.54	6.60	3.31	2.05	245.00
Deep Purple F_1	Control	13.08	5.48	2.81	2.00	187.20
	Bioczos BR	13.69	7.21	3.45	2.10	235.30
Mean		13.38	6.34	3.13	2.05	211.25
Mean	Control	11.66	5.66	2.78	2.00	196.00
	Bioczos BR	13.25	7.28	3.66	2.10	260.25
LSD α = 0.05						
Cultivar		1.51	n.s.	n.s.	n.s.	n.s.
Method of protection		1.61	1.41	0.59	n.s.	27.51
Interaction		1.05	n.s.	n.s.	n.s.	13.24

The dry matter content of carrot roots reached 11.54% in cv. ‘Purple Haze F_1’ and 13.38% in cv. ‘Deep Purple F_1’, and it was significantly affected by protection method . The roots of carrots treated with Bioczos BR had higher dry matter content. The dry matter content of carrot roots in the control treatment was approximately 12% lower. A similar value (12.54%) was reported by Gajewski *et al.* (2007), Dobrzański *et al.* (2008), Majkowska-Gadomska and Wierzbicka (2010) and Roszkowska *et al.* (2015) who also analysed carrots with purple roots.

Carrot roots differed in their content of total sugars which was higher in cv. ‘Deep Purple F_1’ than in cv. ‘Purple Haze F_1’. A significant correlation was found between the applied protection method and the total sugar content of carrot roots. The application of Bioczos BR increased the concentration of total sugars in carrot roots by 28% relative to the control treatment. Similar values were noted by Wrzodak and Elkner (2010) who compared the quality of carrot roots in organic (7.32 g 100 g^{-1} fresh weight) and conventional (6.76 g 100 g^{-1} fresh weight) production systems. In a study by Roszkowska *et al.* (2015), the average total sugar content of carrots with orange-coloured and purple-coloured roots was 5.22 and

5.71 g 100 g^{-1} fresh weight, respectively. Hallmann *et al.* (2011) reported total sugar content of 5.60 g 100 g^{-1} fresh weight. In an experiment performed by Zadernowski *et al.* (2010), the total sugar content of carrots with dark-coloured roots reached 7.00 g 100 g^{-1} fresh weight.

The application of Bioczos BR led to an increase in the content of reducing sugars in carrot roots, from 2.78 g 100 g^{-1} fresh weight in the control treatment to 3.66 g 100 g^{-1} fresh weight. According to Roszkowska *et al.* (2015), the content of reducing sugars in carrots ranges from 3.56 to 3.88 g 100 g^{-1} fresh weight subject to cultivar, and it is higher in carrots with purple-coloured roots. Similar observations were made by Kreutzmann *et al.* (2008).

Neither the experimental factors nor their interaction significantly influenced L-ascorbic acid content of carrot roots. In 2013-2014, the average concentration of L-ascorbic acid reached 2.05 mg 100 g^{-1} fresh weight in both analysed cultivars. The values noted in this study are lower than those reported by other authors. In carrots with orange-coloured roots, analysed by Sikora *et al.* (2009), L-ascorbic acid levels ranged from 3.98 to 4.91 mg 100 g^{-1} fresh weight. In an experiment conducted by Zadernowski *et al.* (2010), L-ascorbic acid content of black carrots was 14.80 mg 100 g^{-1} fresh weight. Similar values were reported by Domardzki *et al.* (2010) (1.00-34.00 mg 100 g^{-1} fresh weight). According to the cited authors, the concentration of L-ascorbic acids in carrot roots is mostly determined by cultivar, environmental conditions and agronomic factors. Nawirska and Król (2004) observed a nearly two-fold difference in L-ascorbic acid levels between the examined carrot cultivars, pointing to varietal variations in this parameter.

In the present study, the concentration of nitrates (V) in carrot roots did not exceed the maximum permissible levels (Commission Regulation (EU)… 2011). Nitrate (V) content of edible carrot parts was 211.25 mg NO^{-}_{3} kg^{-1} fresh weight in cv. 'Deep Purple F_1' and 245.00 mg NO^{-}_{3} kg^{-1} fresh weight in cv. 'Purple Haze F_1', and the noted difference was statistically significant. A significant correlation was found between the applied protection method and nitrate (V) concentrations in carrot roots. The roots of carrots grown in the control treatment had a significantly lower content of nitrates (V) (196.00 mg NO^{-}_{3} kg^{-1} fresh weight) than the roots of carrots treated with Bioczos BR (260.25 mg NO^{-}_{3} kg^{-1} fresh weight). The levels of nitrates (V) in carrot roots were also significantly affected by the interaction between the experimental factors, and ranged from 187.20 to 285.20 mg NO^{-}_{3} kg^{-1} fresh weight. According to Gajewska *et al.* (2009), the concentration of nitrates (V) in carrots varies from 42.8 to 455.0 mg NO^{-}_{3} kg^{-1} fresh weight. In a study by Czerwińska and Zagóra (2011) nitrate (V) content of carrot roots was 366.49 mg NO^{-}_{3} kg^{-1} fresh weight.

CONCLUSIONS

1. Carrots of cv. 'Deep Purple F_1' were characterised by higher average weight, length and width of storage roots, and a larger horizontal diameter of the core than carrots of cv. 'Purple Haze F_1'.

2. The biocontrol agent Bioczos BR contributed to an increase in the mass, width of the roots and horizontal diameter of the core in carrot roots.

3. The biocontrol agent Bioczos BR contributed to an increase in the content of dry matter, total sugars, reducing sugars, L-ascorbic acid and nitrates (V) and a decrease in the concentrations of organic acids in carrot roots, in comparison with the control treatment.

4. Bioczos BR significantly increased the content of nitrates (V) in the storage roots of the analysed carrot cultivars.

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MORFOLOGIA I WARTOŚĆ ODŻYWCZA KORZENI SPICHRZOWYCH MARCHWI O FIOLETOWYM ZABARWIENIU UPRAWIANEJ Z WYKORZYSTANIEM BIOFUNGICYDU

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Streszczenie. Doświadczenie polowe przeprowadzono w latach 2013-2014. Eksperymentu dokonano metodą losowych podbloków w trzech powtórzeniach. Pierwszy czynnik doświadczalny stanowiły rośliny dwóch odmian marchwi (*Daucus carota* L.), „Purple Haze F_1" i „Deep Purple F_1", a drugim eksperymentalnym czynnikiem było zastosowanie środka Bioczos BR do biologicznej ochrony. Obiekt kontrolny spryskiwano wodą. Celem badania było określenie wpływu preparatu Bioczos BR na wybrane cechy morfologiczne i wartość odżywczą purpurowych korzeni spichrzowych marchwi. Analizowane odmiany marchwi różniły się znacznie pod względem masy i długości korzeni. Rośliny marchwi odmiany „Deep Purple F_1" miały wyższą średnią masę korzeni. Zaobserwowano stałe zmiany w zawartości składników odżywczych korzeni marchwi. Bioczos BR przyczynił się do wzrostu suchej masy (o 14%), całkowitej zawartości cukrów (o 28%), cukrów redukujących (o 31%) i azotanów (V) (o 32%) w korzeniach marchwi, w porównaniu do obiektu kontrolnego.

Słowa kluczowe: marchew, morfologia, wartość odżywcza, korzenie spichrzowe