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ORIGINAL PAPER

YIELD AND MINERAL COMPOSITION OF STORAGE ROOTS OF CARROTS (*DAUCUS CAROTA* L.) PROTECTED WITH BIOLOGICAL METHODS*

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Abstract

The aim of this study was to evaluate the yield and mineral composition of storage roots of carrots protected with biological methods, without the use of chemical control agents. The first experimental factor consisted of two carrot cultivars with different maturity periods. The second experimental factor comprised three methods of carrot fly biocontrol, compared in the following treatments: control – unprotected plants, carrots intercropped with dill (cultivar Szmaragd), carrots intercropped with Welsh onions (cv. Parade) and the application of Himal cubes containing paraffin-coated garlic pulp. The storage roots of carrots cv. Nantejska Polana and cv. Flakkese 2 were harvested in the first week of September and in the middle of October, respectively. After harvest, 100 carrot roots were collected from each replication to determine the percentage of roots infested by the carrot fly. In order to evaluate carrot yields in experimental treatments, the total and marketable yield of carrot storage roots were determined. Fifteen storage roots sampled from the marketable yield in each treatment were subjected to chemical analyses. The prepared material was analyzed to determine the content of: total- N, P, K, Mg, Ca and Cu. The organic crop protection methods based on the biological phenomenon of allelopathy as well as the biocontrol agent Himal significantly reduced the carrot fly population relative to the control treatment. An increase was noted in the total and marketable yield of carrots intercropped with Welsh onions, although the species competed for nutrients. Comparable yield was achieved when carrots were protected with Himal. The storage roots of carrots cv. Flakkese 2 intercropped with dill had the highest content of total N, K, Mg and Ca.

Keywords: intercropping, biological control, carrot fly, yield, mineral composition.

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INTRODUCTION

According to Szafirowska, Kłosowski (2008), biodiversity – the key assumption underlying organic farming – may contribute to maintaining soil fertility and protecting crops against pests and diseases. Biodiversity relies on the biological phenomenon of allelopathy. Within the same agrobiocenosis, the main crop can be grown with pest-repelling plants or plants that disorientate the pests invading a plantation, which are then unable to find the host plant (Szwejda, Wrzodak 2007, Szafirowska, Kłosowski 2008, Wierzbicka, Majkowska-Gadomska 2012, Jemiołkowska et al. 2016).

Interactions between different plant species were first observed in ancient times. Recent years have witnessed a growing interest in biological crop protection methods due to increasing consumer awareness of the adverse effects of chemicalization on human health (Makles, Domański 2008, Wrzodak, Rogowska 2013).

The carrot fly (*Chamaepsila rosae* (Fabr.) is one of the most dangerous pests attacking carrots. Larvae of the carrot fly burrow into storage roots, which facilitates pathogenic infections and leads to the decay of the root system. Female carrot flies are attracted to host plants by odour, including the volatile compounds produced by carrot leaves. Therefore, odoriferous companion crops can be grown in or near organic carrot plantations to mask the smell of host plants and deter the pest's attack (Dufault, Coacer 1987, Wierzbicka, Majkowska-Gadomska 2012, Rybczyński, Rogowska 2015).

Allelopathic interactions between plants have been investigated worldwide because they could provide a viable alternative to chemical protection against pathogens (Sas-Piotrowska, Piotrowski 2003, Sekutowski 2010, Marczewska-Kolasa, Kieloch 2012).

The objective of this study was to evaluate the yield and mineral composition of the storage roots of carrots protected with biological methods, without the use of chemical control agents.

MATERIALS AND METHODS

A two-factor field experiment was conducted in the Agricultural Experimentation Station of the University of Warmia and Mazury in Olsztyn, in 2013-2014, on brown soil of quality class IVa and good rye complex (according to the Polish soil classification system), with the humus content of 2.8%, pH in H_2O of 7.1, salt concentration of 0.36 g dm^{-3} and the following nutrient content: N-NO_3 – 34, P – 90, K – 154, Ca – 2880, Mg – 146, Cl – 16 mg dm^{-3}. Soil mineral deficiencies were supplemented so as to meet the requirements of each crop species. Carrots were grown after cruciferous vegetables. A plot size for harvest was 7.5 m^2. Soil was prepared for planting with a cultivator.

Carrots were grown on ridges. .The width of the ridges was 20 cm, the distance between ridges was approximately 68 cm. The experiment was performed in a randomized block design with three replications.

The first experimental factor consisted of two carrot cultivars with different maturity periods, Nantejska Polana (KHNO Polan) and Flakkese 2 (Royal Sluis). The second experimental factor comprised three methods of carrot fly biocontrol, compared in the following treatments:

- control – unprotected plants;
- the application of Himal cubes containing paraffin-coated garlic pulp, at a dose of 50 g dm^{-3} per 10 m^2, during the invasion of first- and second-generation carrot flies, at intervals determined according to the number of carrot flies caught on yellow sticky traps;
- carrots intercropped with dill (*Antheum graveolens* L.) cv. Szmaragd (one row of carrots and one row of dill, 8 cm apart);
- carrots intercropped with Welsh onions (*Allium fistulosum* L.) cv. Parade (one row of carrots and one row of Welsh onion sets, 8 cm apart; six-week-old Welsh onion seedlings were produced in a greenhouse).

Carrot and dill seeds were sown on ridges, 2 cm deep, in the first week of May. Carrots were grown at the density of 25 plants per running meter. When carrots were intercropped with dill cv. Szmaragd, 25 carrot plants were grown per running meter of each ridge, in one row, and 20 dill plants were grown per running meter in the other row. When carrots were intercropped with Welsh onions cv. Parade, 25 carrot plants were grown per running meter of each ridge, in one row, and 10 onion sets were planted per running meter in the other row.

The plants were cultivated in line with the generally observed standard for each species. During the growing season, hand weeding was performed three times at two-week intervals. During seedling emergence, yellow sticky carrot fly traps measuring 24 cm x 17 cm were placed in each plot. The traps were collected and replaced every 7 days.

The storage roots of carrots cv. Nantejska Polana and cv. Flakkese 2 were harvested in the first week of September and in the middle of October, respectively. After harvest, 100 carrot roots were collected from each replication to determine the percentage of roots infested by the carrot fly (*Chamaepsila rosae* (Fabr.).

In order to evaluate carrot yields in experimental treatments, the total and marketable yield of carrot storage roots was determined according to the Commission Regulation (EC) No. 907/2004. The marketable yield consisted of healthy (not forked) carrot roots with a diameter of 2.5 to 6 cm.

Fifteen storage roots sampled from the marketable yield in each treatment were subjected to chemical analyses. The plant material was dried at 65°C, and samples were delivered to the Chemical and Agricultural Research Laboratory in Olsztyn. The study was carried out under Accreditation Certifi-

cate no. AB 277 issued by the Polish Center for Accreditation in Warsaw. The prepared material was mineralized in concentrated sulfuric acid, and it was analyzed to determine the content of: total nitrogen – by the potentiometric method, phosphorus – by the vanadium-molybdenum colorimetric method, potassium – by flame photometry, magnesium – by atomic absorption spectrometry (AAS), calcium – by flame photometry (No. AB 277), and copper – by AAS. Mean values obtained in 2013-2014 were presented in the paper.

The data were analyzed statistically. The significance of differences was determined by creating confidence intervals in the Tukey's test. The probability of error was 5%. Statistical analyses were performed in the Statistica 12 program.

RESULTS AND DISCUSSION

It was found that carrot fly infestation can be effectively reduced by carrot--Welsh onion and carrot-dill intercropping (Table 1). The highest percentage

Table 1

The effect of cultivar and crop protection method on root infestation (means of 2013-2014)

Crop protection method / Cultivar	% of infested roots				Mean for cultivar
	control	Himal	dill	Welsh onion	
Flakkese 2	34.0	12.0	5.0	6.0	14.3
Nantejska Polana	20.0	8.0	4.0	6.0	9.5
Mean for crop protection method	27.0	10.0	4.5	6.0	-
$LSD_{\alpha=0.05}$ Cultivar (a) Crop protection method (b) Interaction (a×b)	n.s. 4.9 1.7				

of infested roots, 27% on average, was noted in the control treatment. Himal cubes reduced root infestation to 10%, and carrot-onion and carrot-dill intercropping – to 6.0% and 4.5%, respectively. Our results corroborate the findings of other authors (Wierzbicka, Majkowska-Gadomska 2012), who demonstrated that intermixing carrots and tall herbaceous plants contributes to reducing the carrot fly population. Such plants also provide shelter from wind, rain and high temperatures as well as food sources to insects. Dill can also serve as a host plant for the juvenile forms of beneficial insects – antagonists of carrot pests. Onions secrete volatile allelopathic compounds that disorientate the pests (Kaczmarek 2009). The percentage of roots infested by the carrot fly was not influenced by a cultivar, but a significant effect was exerted by the

cultivar x biocontrol method interaction. The significantly highest infestation rates were noted on the storage roots of carrots cv. Flakkese 2 in the control treatment. Carrots cv. Nantejska Polana were characterized by considerably lower infestation levels in the control treatment. The roots of both carrot cultivars were least infested when carrots were grown with companion crops.

Biological crop protection methods used together with or instead of conventional methods have gained increasing popularity in recent years. Consumers search for products characterized by high market and biological value and free of harmful chemicals such as pesticide residues. Intercropping, i.e. growing several crop species (e.g. carrots, onions, Lacy phacelia, mustard, dill) simultaneously in the same field, reduces pest infestations. The rationale behind intercropping is that different crops planted together in the same agrobiocenosis can disorientate the pests invading a plantation or provide habitat for natural enemies of pests, ladybirds, green lacewings, *Encarsia formosa* (Jankowska et al. 2009, Wiech et al. 2009).

The total and marketable yield is a key criterion used to evaluate the effectiveness of integrated and organic crop protection methods. Tables 2 and 3

Table 2

Total yield of carrot roots protected with biological methods (means of 2013-2014)

Crop protection method / Cultivar	Total yield (t ha^{-1})				Mean for cultivar
	control	Himal	dill	Welsh onions	
Flakkese 2	28.82	45.54	32.52	52.89	39.94
Nantejska Polana	18.80	27.58	29.45	30.77	26.65
Mean for crop protection method	23.81	36.56	30.99	41.83	-
$LSD_{\alpha=0.05}$ Cultivar (a) Crop protection method (b) Interaction (a×b)			6.72 9.98 10.07		

Table 3

Marketable yield of carrot roots protected with biological methods (means of 2013-2014)

Crop protection method / Cultivar	Marketable yield (t ha^{-1})				Mean for cultivar
	control	Himal	dill	Welsh onions	
Flakkese 2	13.93	15.79	15.40	23.58	17.18
Nantejska Polana	13.06	15.34	15.18	17.70	15.32
Mean for crop protection method	14.43	14.64	15.29	20.64	-
$LSD_{\alpha=0.05}$ Cultivar (a) Crop protection method (b) Interaction (a×b)			n.s. 1.96 9.00		

illustrate the effectiveness of different strategies of carrot fly control. The highest total and marketable yield was achieved when carrots cv. Flakkese 2 were intercropped with Welsh onions – 52.89 t ha^{-1} and 23.58 t ha^{-1}, respectively. A comparable total yield of carrots cv. Flakkese 2 was noted in the treatment with Himal cubes – 45.54 t ha^{-1}. The lowest yield marketable of both carrot cultivars (Flakkese 2 and Nantejska Polana) was determined in control treatments and treatment Flakkese 2 in the facility cultivation of dill. In an earlier experiment, Szafirowska, Kłosowski (2008) observed improved health and yield in beans intercropped with dill.

The mineral composition of carrot storage roots is a varietal trait, but it may vary in response to changing environmental conditions during the growing season. Cultivation methods and crop protection agents also affect the mineral composition of the edible parts of vegetables (Wolański et al. 2015).

The nutritional value of carrot roots is determined by their mineral composition. Carrots are a rich source of potassium, phosphorus and calcium, which play essential roles in numerous physiological processes. The content of total N, P, K, Mg, Ca and Cu in the storage of roots of carrots protected against the carrot fly with the use of biological methods was analyzed in the present study. Nutrient concentrations in carrot roots were influenced by the cultivars. The content of the macronutrients potassium, magnesium and calcium was higher in the roots of carrots cv. Flakkese 2, whereas the content of the micronutrient copper was higher in the roots of carrots cv. Nantejska Polana. The concentrations of minerals in carrot roots determined in our study were lower than those reported by Kunachowicz et al. (2006), and Dyśko and Kaniszewski (2007), but considerably higher than those obtained by Wierzbicka, Majkowska-Gadomska (2010). The roots of carrots intercropped with dill had the highest average content of total N, P, K, Mg and Ca, and the noted differences were statistically significant. Carrots cv. Flakkese 2 grown with dill as a companion crop were characterized by the most desirable chemical composition, including the highest content (per g kg fresh $weight^{-1}$) of total N – 0.664, P – 0.299, K – 3.106, Mg – 0.122 and Ca – 0.309 (Table 4). The copper content of carrot roots was also determined in our study. According to Bolesławska et al. (2009), copper is essential to human health because it plays an important role in many biochemical processes, is necessary for haemoglobin synthesis in humans, and inhibits the enzymes pepsin, amylase and lipase. The recommended daily dietary intake of copper is 1 - 5 mg. Copper deficiency symptoms include drowsiness, insufficient haemoglobin production, memory impairment and poor concentration. In the present experiment, the average copper content of carrot roots was 4.40 mg kg DM^{-1}. The highest average copper content was noted in carrots intercropped with Welsh onions (4.60 mg kg DM^{-1}), and the mean value for cultivar was higher in cv. Nantejska Polana (4.40 mg kg DM^{-1}) than in cv. Flakkese 2.

Jarnuszewski and Meller (2013) demonstrated that the quality of the edible parts of plants is affected not only by the concentrations of macronutrients and micronutrients, but also by their mutual proportions. According

Table 4

Mineral composition of carrot roots protected with biological methods (means of 2013-2014)

Cultivar	Crop protection method	Total N	P	K	Mg	Ca	Cu
		(g kg^{-1}FM)					(mg kg^{-1}DM)
Flakkese 2	control	0.436	0.218	2.414	0.093	0.249	3.20
	Welsh onions	0.387	0.242	2.437	0.105	0.291	4.60
	dill	0.664	0.299	3.106	0.122	0.309	3.40
	Himal	0.406	0.271	2.870	0.102	0.305	3.60
Mean for cultivar		0.473	0.258	2.707	0.106	0.289	3.70
Nantejska Polana	control	0.437	0.197	1.900	0.086	0.191	4.40
	Welsh onions	0.340	0.269	2.300	0.092	0.226	4.60
	dill	0.522	0.301	2.586	0.103	0.205	3.60
	Himal	0.549	0.258	2.319	0.084	0.213	5.00
Mean for cultivar		0.462	0.256	2.276	0.072	0.209	4.40
Mean for crop protection method	control	0.437	0.208	2.157	0.090	0.220	3.80
	Welsh onions	0.364	0.256	2.369	0.099	0.259	4.60
	dill	0.593	0.300	2.846	0.113	0.298	3.50
	Himal	0.478	0.265	2.595	0.093	0.259	4.30
$LSD_{\alpha=0.05}$							
Cultivar (a)		n.s.	n.s.	0.024	0.011	0.018	0.47
Crop protection method (b)		0.069	0.016	0.030	0.015	n.s.	0.62
Interaction (a×b)		0.063	0.017	0.040	0.017	0.017	0.17

to the cited authors, the following ratios are particularly important: K:Mg, Ca:Mg and K:(Mg+Ca). The ratios of the analyzed nutrients varied depending on a carrot cultivar and cultivation method (Table 5). According to Majkowska-Gadomska (2006), Majkowska-Gadomska, Wierzbicka (2008), and Szpunar-Krok et al. (2009), the optimal Ca:Mg and Ca:P ratios are 3 and 1.2 - 2.2, respectively. Higher values of those ratios point to an inadequate intake of dietary magnesium or phosphorus. The analyzed carrot roots were characterized by an unfavorable Ca:Mg ratio. The Ca:P ratio was also below the recommended level, except in the roots of carrots cv. Flakkese 2 intercropped with Welsh onions. The Ca:P ratio is more important for children than for adults. In both carrot cultivars, the K:Mg and K:(Mg+Ca) ratios were wider than the recommended values which, according to Szpunar-Krok et al. (2009), should be 6:1 for K:Mg and 1.6 - 2.2 for K:(Mg+Ca).

Table 5

Weight ratios of macronutrient ions in carrot roots protected with biological methods (means of 2013-2014)

Cultivar	Crop protection method	Ca:Mg	Ca:P	K:Mg	K:(Mg+Ca)
Flakkese 2	control	2.68	1.14	25.96	7.06
	Welsh onions	2.77	1.20	23.21	6.15
	dill	2.53	1.03	25.46	7.21
	Himal	2.99	1.13	28.14	7.05
Mean for cultivar		2,74	1.13	25.69	6.87
Nantejska Polana	control	2.22	0.97	22.09	6.86
	Welsh onions	2.46	0.84	25.00	7.23
	dill	1.99	0.68	25.11	8.40
	Himal	2.54	0.83	27.61	7.81
Mean for cultivar		2.30	0.83	24.95	7.56
Mean for crop protection method	control	2.45	1.06	24.03	6.96
	Welsh onions	2.62	1.02	24.11	6.69
	dill	2.26	0.86	25.29	7.81
	Himal	2.77	0.98	27.88	7.43

CONCLUSIONS

1. Organic crop protection methods based on the biological phenomenon of allelopathy and the biocontrol agent Himal significantly reduced the carrot fly population relative to the control treatment.

2. An increase was noted in the total and marketable yield of carrots intercropped with Welsh onions, although the species competed for nutrients. Comparable yield was achieved when carrots were protected with Himal.

3. The storage roots of carrots cv. Flakkese 2 intercropped with dill had the highest content of total N, K, Mg and Ca.

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