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CONTENT OF SOME CHEMICAL COMPONENTS IN CARROT (*DAUCUS CAROTA* L.) ROOTS DEPENDING ON GROWTH STIMULATORS AND STUBBLE CROPS

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Abstract

Agronomic factors, and mineral fertilization in particular, have a strong impact on the quality of carrot roots. In recent years, researchers have begun to design eco-friendly agricultural practices that would stimulate the quality and yield of carrot roots. Our aim has been to analyse selected quality parameters pertaining to the chemical composition of carrot roots, and relate them to the application of different growth stimulators and cover crops. For this purpose, a field experiment was conducted in 2009-2011 investigating the effect of growth stimulators and stubble crops on the accumulation of chemical components in storage roots of carrot (cv. Laguna F1). The study included three growth stimulators: Asahi SL, Bio-algeen S 90 and Tytanit. Plots without any foliar application of these growth stimulators served as control treatment. Another factor consisted of the previous crop (spring barley) and stubble crops: tansy phacelia and a mixture of spring vetch and field pea, grown after the harvest of barley and then ploughed in. All the growth stimulators significantly reduced the NO_3 content in carrot roots. Asahi SL significantly increased the phenolic content. The effects of the growth stimulators on the macronutrient content in carrot roots were statistically significant in the case of Mg and Na. Stubble cropping contributed to the reduction of nitrates and stimulated an increase in the content of phenolics as well as of P, K, Ca and Mg in carrot roots.

Keywords: *Daucus carota* L., growth stimulators, stubble crops, macronutrients, nitrates, phenolics.

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INTRODUCTION

Carrot (*Daucus carota* L.) is an important root vegetable. Rich in bioactive compounds like carotenoids and dietary fibres, it also contains appreciable levels of several other functional components. Hence, it can produce a significantly beneficial influence on the human health. The consumption of carrots and carrot products grows steadily because the vegetable is thought to be an important source of natural antioxidants with anticancer activity (Sharma et al. 2012). Carrots are also a good source of carbohydrates and minerals like Ca, Fe, Na, K, Mg, Cu, Zn, carotenes, thiamine, riboflavin, niacin, vitamin C (Arscot, Tanumihardio 2010, Sharma et al. 2012). Phenolics or polyphenols have received considerable attention because of their physiological functions, including antioxidant, antimutagenic and antitumor activities. They have been reported to be a potential scavenger of free radicals, which are harmful to our body and food systems (Nagai et al. 2003). Although phenolic compounds do not have any known nutritional function, they may be important to human health because of their antioxidant potency (Hollman et al. 1996).

While the chemical composition of carrot roots is a cultivar-specific character, it is also affected by agronomic factors, of which fertilization exerts the strongest impact on the content of nutrients (Kaack et al. 2001, Singh et al. 2012, Smoleń et al. 2012). Expectations have been aroused by environmentally friendly methods of plant growth stimulation through the use of biostimulators or cover cropping, which have a beneficial effect on the nutritional composition of roots (Dobrzański et al. 2008, Kwiatkowski et al. 2013). In addition to improving the growth and health of plants, biostimulators contribute to a better use of environmental conditions, including soil nutrient availability (Dobromilska et al. 2008). In turn, cover crops contribute to the reduced leaching of minerals from the soil to groundwater by taking up nutrients and making them available to succeeding crops (Marshall et al. 2003, Kwiatkowski 2012).

The aim of this study was to analyse selected quality parameters of the chemical composition of roots of carrot plants treated with different growth stimulators and grown with or without cover crops.

MATERIAL AND METHODS

A field experiment in which carrot (*Daucus carota* L.) was grown for the summer harvest of roots was carried out in Fajsławice (51°05′48″N 22°57′38″E), in 2009-2011 The experiment was set up in a split-plot design with 3 replicates, on 10 m^2 plots. The total area covered by the experiment was 360 m^2. Carrot (cv. Laguna F1) was grown on incomplete podzolic soil (pH in 1 mol KCl = 6.4), classified as good wheat soil complex. Throughout the study, the soil was distinguished by high availability of essential macronutrients (P = 86.3-88.7; K = 98.5-101.9; Mg = 34.7-35.5 mg kg^{-1}). The soil humus content was 1.45-1.51%.

The experimental design included two factors:

I. Growth stimulators:

A – no application of biostimulators (control treatment);

B – foliar spraying with Asahi SL – Atonik (0.1%);

C – foliar spraying with Bio-algeen S 90 (1.0%);

D – foliar spraying with Tytanit (0.05%).

II. Stubble crop to be ploughed into soil:

1) without stubble crop (control);

2) stubble crop – tansy phacelia (*Phacelia tanacetifolia* B.) cv. Natra;

3) stubble crop – spring vetch (*Vicia sativa* L.) cv. Jaga + field pea (*Pisum arvense* L.) cv. Roch.

The choice of plant species grown as stubble crops was dictated by the agricultural practices used in the area of Fajsławice (the study site). Spring barley (*Hordeum sativum* ssp. *vulgare*) cv. Justina was the preceding crop for the stubble crops in the whole experimental area. Since stubble crops were grown for green manure, no farmyard manure was applied. The following fertilization and cultivation practice was implemented: in stubble cropping, a seedbed cultivator was used after harvest of barley and mineral N fertilization (20 kg ha^{-1}) but before sowing tansy phacelia. Stubble crops were sown in the second 10-day period of August at the following doses: 14 kg ha^{-1} (tansy phacelia) and 40 + 60 kg ha^{-1} (field pea + spring vetch). Stubble biomass was determined in the third 10-day period of October (before the stubble crops were ploughed in). Whole plants were pulled out from an area of 1 m^2 in each plot. After the stubble crops were first cut, the stubble biomass left in the plots was ploughed into the soil in the autumn. The fertilizer value of the stubble crops is shown in Table 1. The total stubble biomass yield (fresh weight and dry weight) and the amount of nutrients incorporated into the soil with the stubble biomass (N, P, K, Ca, Mg) were similar for tansy phacelia and for the legume mixture. It can be therefore concluded that both stubble crops had a similar fertilizer effect on carrot.

Table 1

The quality of the ploughed stubble crops biomass and mineral nutrients introduced with it (mean for 2009-2011)

Stubble crops	Fresh matter (t ha^{-1})	Dry matter (t ha^{-1})	N (t ha^{-1})	P (t ha^{-1})	K (t ha^{-1})	Ca (t ha^{-1})	Mg (t ha^{-1})
Tansy phacelia	8.76	1.42	50.4	5.06	24,7	12.1	3.44
Spring vetch + field pea	9.51	1.62	58.6	5.12	22.5	11.3	3.27

Each year, carrot was sown into the soil in the third 10-day period of April. Seeding was done using a pneumatic precision seed drill at a density of 4.5 kg ha^{-1} (1.2 million seeds). Mineral fertilization was the same for all the treatments. Considering the initial soil nutrient availability (calculated on a per hectare basis), which was similar in all the years, fertilization was applied before sowing at the following doses: N – 70 kg, P – 40 kg, K – 150 kg. Mineral N fertilization was applied in the form of 34% ammonium nitrate, P was given in the form of 46% granulated triple superphosphate, whereas K was supplied as 50% potassium salt. Conventional tillage was used for carrot cultivation, adjusted to the specific characteristics of this plant.

Before sowing, carrot seeds were dressed with the seed dressing Marshal 250 DS to protect them from diseases (at 70 g kg^{-1} of seeds). The herbicide Stomp 330 EC (3 l ha^{-1}) was sprayed 5 days after seeding for chemical weed control. Mechanical weed control was performed twice: 1) inter-row hoeing at the 3-5 true leaf stage of carrot; 2) hand weeding before row closure.

The growth stimulators (treatments B-D) were applied with a field sprayer under a pressure of 0.25 MPa. They were used at the 6-7 true leaf stage of carrot (according to the manufacturer's recommendations).

Carrot roots were harvested in the first 10-day period of September.

The content of selected macronutrients in carrot roots was determined with the following methods: nitrogen (total) by potentiometry, phosphorus – by the vanadium-molybdate method, potassium – by flame photometry, magnesium – by atomic absorption spectrometry (AAS), calcium and sodium – by flame photometry.

The content of nitrates (NO_3) was determined spectrophotometrically. Finely grated roots were extracted with acetic acid (10 g of grated roots + 100 ml of 2% acetic acid + active carbon to eliminate colour). The nitrate content was determined at a wavelength of 440 nm.

The phenolic content was determined by the colourimetric method using the Folin Ciocalteu's reagent (Swain, Hills 1959). In this method, the reagent is a mixture of sodium tungstate (Na_2WO_4), sodium molybdate (Na_2MoO_4), lithium sulphate (Li_2SO_4), bromine water as well as of concentrated hydrochloric and phosphoric acids.

The results were validated statistically by analysis of variance. LSD values were determined by the Tukey's test at $\alpha = 0.05$. The data presented in the tables are means for the three seasons of the study.

The results did not differ significantly between the years, which is why the tables contain only means for the three-year period (2009-2011).

RESULTS AND DISCUSSION

The content of minerals (N, P, K, Ca, Mg, Na) in carrot roots found in the present experiment was close to the standard values and similar to the results obtained by other authors (Kaack et al. 2001, Dyśko, Kaniszewski 2007, Majkowska-Gadomska, Wierzbicka 2010, Smoleń et al. 2012). The growth stimulators used in the experiment did not have a major effect on the content of total nitrogen, phosphorus and potassium in carrot roots. The concentrations of these nutrients were similar to those found under the control conditions. The application of the growth stimulators resulted in a statistically significant decrease in the Ca content (on average by 12-25%) relative to the control treatment. The use of growth stimulators had a beneficial effect on the magnesium content in carrot roots. Compared to the control treatment, Asahi SL promoted higher Mg accumulation (by 42%), while Bio-algeen and Tytanit caused an increase in the magnesium content by 36%. All the growth stimulators used had a significant effect on increasing the sodium content in relation to the control plots, on average by 55% (Asahi SL), 34% (Tytanit) and 24% (Bio-algeen). Moreover, Asahi SL caused significantly higher Na accumulation in carrot roots compared to the treatments where Tytanit and Bio-algeen were applied (Table 2). According to Djanaguiraman et al. (2005), growth

Table 2

Content of macronutrients, nitrate and total phenolic in carrot roots depending on foliar fertilization (mean for 2009-2011)

Specification	Growth stimulators				$LSD_{\alpha = 0.05}$
	control	Asahi SL	Bio-algeen	Tytanit	
Nitrogen (g kg^{-1} DW)	11.4	11.1	11.0	10.7	i.d.
Phosphorus (g kg^{-1} DW)	3.50	3.30	3.20	3.30	i.d.
Potassium (g kg^{-1} DW)	24.0	23.4	22.8	22.7	i.d.
Calcium (g kg^{-1} DW)	4.11	3.59	3.30	3.10	0.462
Magnesium (g kg^{-1} DW)	0.69	1.22	1.11	1.11	0.191
Sodium (g kg^{-1} DW)	0.52	1.14	0.68	0.79	0.160
Nitrate (mg NO_3 kg^{-1} FW)	198.0	162.0	168.0	175.0	19.83
Total phenolic (mg kg^{-1} FW)	268.0	307.8	277.0	281.0	26.12

i.d.– insignificant differences

stimulators have a positive effect on crop yields. However, their influence on the content of minerals in the plant organs proves to be debatable (Król 2009). Kwiatkowski and Juszczak (2011) found a negative influence of biostimulators (Asahi SL, Bio-algeen, Tytanit) on the content of N, P, K, Mg and Ca in common basil raw material. The absence of growth stimulators also proved to be more beneficial for the chemical composition (N, P, K, Ca) of garden thyme raw material (Kwiatkowski 2011). In studying the response of carrot to extracts of natural origin obtained from algae of the genus *Sargassum* and to extracts derived from leonardite, Dobrzański et al. (2008) found the growth stimulators used to have had a favourable effect on the yield and chemical composition of carrot roots. Kwiatkowski et al. (2013) demonstrated that growth stimulators used in a carrot plantation had no effect on reducing the specific quality parameters and even caused a significant increase in the content of some components (L-ascorbic acid, total sugars).

Another advantage of the foliar application of the growth stimulators was a statistically significant reduction in the content of nitrates (NO_3) compared to the control treatment. The highest reduction in the root nitrate content, by 18% (36 mg NO_3 kg^{-1} FW), was observed under the influence of Asahi SL. Bio-algeen S 90 and Tytanit had an effect on decreasing the nitrate content, on average by 23-30 mg NO_3 kg^{-1} FW (12-15%). However, the growth stimulators had an ambiguous effect on the content of phenolics in carrot roots. A significantly higher content of these compounds (on average by 26.8-39.8 mg kg^{-1} FW) was found in the treatments with Asahi SL compared to the control and the treatments with Bio-algeen and Tytanit (Table 2). The above values are similar to the results obtained in the present experiment as well as to those reported by Soltoft et al. (2010). Gajewski et al. (2009*a*,*b*) claimed that the nitrate content in carrot roots was primarily a varietal character but also depended on the time when this parameter was determined during the growing season. The highest nitrate content is found in the 7^{th}-10^{th} week of carrot growth, decreasing in the 13^{th} week and then rising again in the 16^{th} week, ranging from 135 to 349 mg NO_3 kg^{-1} FW.

Stubble crops did not have a statistically significant influence on the N content in carrot roots compared to the control treatment (without cover crop). On the other hand, the ploughing-in of cover crop biomass significantly affected the root content of phosphorus and potassium . Growing the mixture of legumes caused an increase in the content of phosphorus and potassium by 24% and 10%, respectively, while the cultivation of phacelia contributed to a respective increase in the P and K content by 20% and 8% compared to the control. The stubble crops had a different effect on the Ca content in carrot roots. The spring vetch/pea mixture caused an increase in the calcium content, on average by 37% compared to the control treatment, whereas tansy phacelia contributed to a 32% increase in the root Ca content. Stubble cropping also positively affected the Mg content in carrot roots relative to the control (a 27% increase in the case of the legume mixture and a 20% increase in the treatment with tansy phacelia). The fact that the statistically proven lowest content of this nutrient was found in the control treatments is the evidence of the beneficial effect of stubble crops. Regardless of the use of growth stimulators, a field after stubble crops had an effect leading to a significantly higher content of sodium in carrot roots, on average by 20% (spring vetch + pea) and 9% (tansy phacelia) compared to the control without stubble crop (Table 3).

Table 3

Content of macronutrients, nitrate and total phenolic in carrot roots depending on the stubble crop (mean for 2009-2011)

Specification	Stubble crops			$LSD_{\alpha = 0.05}$
	without stubble crop (control)	tansy phacelia	spring vetch + field pea	
Nitrogen (g kg^{-1} DW)	10.9	11.1	11.2	i.d.
Phosphorus (g kg^{-1} DW)	2.80	3.50	3.70	0.62
Potassium (g kg^{-1} DW)	21.8	23.7	24.3	1.85
Calcium (g kg^{-1} DW)	2.59	3.81	4.12	0.97
Magnesium (g kg^{-1} DW)	0.81	1.01	1.10	0.016
Sodium (g kg^{-1} DW)	0.70	0.77	0.87	0.152
Nitrate (mg NO_3 kg^{-1} FW)	212.0	165.0	150.0	22.51
Total phenolic (mg kg^{-1} FW)	258.4	274.6	317.3	3.783

i.d.– insignificant differences

Stubble cropping also contributed to a statistically significant reduction in the NO_3 content in carrot roots – the legume mixture reduced nitrates by an average 29% (62 mg NO_3 kg^{-1} FW), whereas tansy phacelia caused an average reduction by 22% (47 mg NO_3 kg^{-1} FW). Regardless of the use of any growth stimulator, the mixture of legumes caused a significantly higher content of phenolic compounds (on average by 58.4 mg kg^{-1} FW) relative to the treatment without stubble crop and by 42.7 mg kg^{-1} FW compared to the plots sown with tansy phacelia (Table 3). In another study, Kwiatkowski (2012) observed that ploughed-in stubble crop biomass contributed to some reduction in harmful substances in the soil and in the plant (including nitrates). Nevertheless, statistically significant differences were found in the content of phosphorus, potassium, calcium and magnesium as influenced by stubble crops. The incorporation of additional minerals into the soil with stubble crop biomass is a form of additional fertilization (which replaces farmyard manure) and generally contributes to an improvement in the quality parameters of plant raw material (Jabłońska-Ceglarek, Rosa 2002, Marshal et al. 2003, Kwiatkowski 2011, Kwiatkowski, Juszczak 2011, Kwiatkowski et al. 2013).

Alongside beta-carotene and vitamin C, phenolics belong to a group of important plant origin antioxidants (Singh et al. 2012). Smoleń and Sady (2007) note that additional fertilization of carrot leads to a significantly lower content of phenolics. On the other hand, Rożek et al. (2000) observed an increase or decrease in the phenolic content in carrot depending on the type of extra-root fertilization. In the current experiment, the phenolic content was on average 242.2-351.7 mg kg^{-1} FW, and the upper limit of this content occurred when the biostimulator Asahi SL was used and the legume stubble crop was grown. The positive influence of Asahi SL on the quality of carrot roots has been confirmed by Kwiatkowski et al. (2013) and Przybysz et al. (2010) in other plants. Singh et al. (2012) found a higher phenolic content in carrot roots than in our experiment. There were significant differences among the five cultivars of carrot, and phenolics were significantly higher in Kuroda and Dragon Purple carrot cultivars than in Kuettinger White, Nutri Red and Yellow. Carrot is a lesser source of phenolics than fruits – berries and some other vegetables – spinach and broccoli (Kahkonen et al. 1999).

According to Kotowska and Wybieralski (1999), the nutritive value of edible vegetable parts is largely determined by the following ratios: K to Mg, Ca to Mg, and K to (Mg + Ca). According to Radkowski et al. (2005) as well as Majkowska-Gadomska and Wierzbicka (2008), the optimal Ca : Mg ratio should approximate 3, while the Ca : P ratio should be within the range of 1.2-2.2. In the present study, the growth stimulators beneficially affected the ratios between nutrients contained in carrot roots (Table 4). This was espe-

Table 4

Selected nutrient ratios in carrot roots depending on foliar fertilization (mean for 2009-2011)

Growth stimulators	Nutrient ratios			
	Ca : Mg	Ca : P	K : Mg	K : (Mg + Ca)
Control	5.8	1.2	34.2	5.0
Asahi SL	3.0	1.1	19.5	4.9
Bio-algeen	3.0	1.0	20.7	5.2
Tytanit	2.8	0,9	20.6	5.4
$LSD_{\alpha = 0.05}$	0.69	i.d.	4.96	i.d.

i.d.– insignificant differences

cially true about the Ca : Mg and K : Mg ratios. The introduction of cover cropping into the agricultural practice of growing carrot also modified the ratios of nutrients determined in carrot roots (Table 5), but an adverse trend

Table 5

Selected nutrient ratios in carrot roots depending on the stubble crop (mean for 2009-2011)

Stubble crops	Nutrient ratios			
	Ca : Mg	Ca : P	K : Mg	K : (Mg + Ca)
Without stubble crop (control)	3.2	0.9	27.2	6.4
Tansy phacelia	3.8	1.1	23.7	4.9
Spring vetch + field pea	3.7	1.1	22.1	4.7
$LSD_{\alpha = 0.05}$	0.47	i.d.	3.28	0.76

i.d. – insignificant differences

was found in the case of the Ca : Mg ratio, although the above trend was favourable for the K : Mg and K : (Mg + Ca) ratios. The Ca : Mg ratio averaged 3.2-3.7, whereas the Ca : P ratio ranged 0.93-1.11; these ratios were better in the treatment without cover crop. In turn, the K : Mg and K : (Mg + Ca) ratios were 22.1-27.2 and 4.7-6.4, respectively, and they were close to the determinations made by Majkowska-Gadomska and Wierzbicka (2010), cf. K : Mg (16.5-31.7); K : Mg + Ca (3.9-5.8). When considering the ratios of nutrients depending on the biostimulators, we noticed that the Ca : Mg ratio in the treatments with Asahi SL and Bio-algeen reached the exemplary value of 3 (Radkowski et al. 2005). The K : Mg and K : (Mg + Ca) ratios were also better when the biostimulators had been used, compared to the control (Majkowska-Gadomska, Wierzbicka 2010).

CONSLUSIONS

1. Foliar application of growth stimulators (Asahi SL, Bio-algeen S 90, Tytanit) in a carrot plantation resulted in a significant increase in the root content of magnesium (Mg) and sodium (Na) as well as in a reduction in the content of nitrates (NO_3). At the same time, the growth stimulators slightly decreased the content of total nitrogen (N), phosphorus (P) and potassium (K) while causing a distinct reduction in the root content of calcium (Ca).

2. The growth stimulators contributed to favourable ratios of nutrients contained in carrot roots, in particular the Ca : Mg and Ca : P ratios.

3. Among the growth stimulators used in the experiment, Asahi SL should be considered as the most favourable one, since it resulted in a significant increase in the content of phenolic compounds (natural antioxidants) and, to a smaller extent, stimulated the content of other beneficial chemical compounds in carrot roots.

4. The positive effects of stubble crops on the chemical composition of carrot roots primarily manifested themselves by the elimination of nitrates and an increase in the content of P, K, Ca, and Mg.

5. The mixture of legumes (spring vetch + field pea) generally had a stronger impact than tansy phacelia on the beneficial changes in the chemical composition. This was particularly true about the phenolic content.

6. To sum up, the introduction of growth stimulators and stubble cropping into the agricultural practice of growing carrot produced positive effects. When both of these factors were absent, certain deterioration of the chemical composition of carrot roots was observed, especially an increased accumulation of NO_3 as well as a significant loss of magnesium and sodium.

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