Journal of Elementology ISSN 1644-2296

Szczepanek M., Wilczewski E., Pobereżny J., Wszelaczyńska E., Keutgen A., Ochmian I. 2015. *Effect of biostimulants and storage on macroelement content in storage roots of carrot*. J. Elem., 20(4): 1021-1031. DOI: 10.5601/jelem.2015.20.1.768

EFFECT OF BIOSTIMULANTS AND STORAGE ON THE CONTENT OF MACROELEMENTS IN STORAGE ROOTS OF CARROT

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Abstract

The processes of growth and development as well as the yield quality of crops depend on the abundance of soil nutrients and the ability of the plants to uptake nutrients. Nutrients can be taken up more efficiently after application of a biostimulant. The effect of biostimulants depends on the content of their active substance as well as the dose, timing and frequency of their application. In 2009-2011, a controlled field experiment was conducted in the Kuyavian-Pomeranian Province (53°13′N; 17°51′E). The objective was to analyse the effect of the timing and doses of foliar application of the biostimulants: Kelpak SL (seaweed extract containing phytohormones) and Asahi SL (a mixture of phenolic compounds) on the content of macroelements: Mg, P, Ca, N, Na and K in the storage roots of carrot directly after harvest and after storage (for 6 months in chambers with controlled conditions: temp. +1°C, Rh 95%). Kelpak SL was applied once in a dose of 3 or 2 dm^3 ha^{-1}, twice in doses of 3+2 dm^3 ha^{-1} or 2+2 dm^3 ha^{-1} at intervals of two or four weeks, as well as three times in doses 3+2+2 dm^3 ha^{-1} or 2+2+2 dm^3 ha^{-1}, every two weeks. Asahi SL was applied twice in doses 0.5+0.5 dm^3 ha^{-1},at a two-week interval. The first application of biostimulants was always performed at the 4-leaf stage. The study showed that the biostimulants Kelpak SL and Asahi SL, irrespective of the dose and frequency of application, increased the N concentration in the carrot roots. An increase in the Mg, P, Na and K concentrations was observed after a single application of Kelpak SL in a dose of 2 dm^3 ha^{-1}, and in the Ca concentration after a dose of 3 dm^3 ha^{-1}. Asahi SL did not affect the Mg, P, Ca and Na concentrations but increased the K content in the roots. After storage, the content of Mg, Na and K decreased, whereas the concentration of P, Ca and N did not change. Directly after harvest and after storage, positive correlation between N and K and between N and Na, as well as between Na and K was indicated.

Keywords: biostimulant, macroelement, storage, seaweed, Kelpak SL, Asahi SL.

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INTRODUCTION

The growth and development as well as the yield quantity and quality of field crops are determined by the natural properties of species and varieties as well as external factors related to the site and cultivation technology. The quality of vegetable crops, including carrot, is often more important than yield, in which they differ from field crops (DIAS 2013). One of the indicators of carrot quality is the content of mineral elements in roots. Nutritionally, carrot roots are an abundant source of mineral salts, in particular potassium, phosphorus and calcium (MAJKOWSKA-GADOMSKA, WIERZBICKA 2010). Previous research proved that changes in quality traits, including the mineral composition of roots, depended mostly on a cultivar (NICOLLE et al. 2004,), but also on fertilization (INAL et al. 1998, BOSKOVIC et al. 2012, SMOLEŃ et al. 2012) and interaction of both factors (MAJKOWSKA-GADOMSKA, WIERZBICKA 2010, DAVINDER et al. 2012). Significant influence of other cultivation factors: sowing method (DYŚKO, KANISZEWSKI 2007) and cultivation methods (organic or conventional) (DOMAGAŁA-ŚWIĄTKIEWICZ, GĄSTOŁ 2012) has also been indicated.

The application of biostimulants has become an important cultivation technology component in the intensive production of plant food produce. By supporting metabolic processes and plant resistance, biostimulants contribute to the optimization of the use of environmental resources by plants and help to improve the quantity and quality of yield. Biostimulants may have a special role in obtaining high yields when the use of synthetic crop protection products is limited. Seaweed (macroalgal) concentrates constitute an important group of biostimulants. The application of macroalgal biostimulants on crop plants yields multiple benefits, including better rooting, higher crop yields, stronger drought tolerance, enhanced photosynthesic activity, better resistance to fungi (KHAN et al. 2009, SHEKHAR SHARMA et al. 2014). Macroalgal biostimulants can also increase the nutrient concentration (SOSNOWSKI et al. 2014) and the nutrient uptake, especially under stress conditions (BECKETT, VAN STADEN 1990). The application of seaweed onto vegetable plants was found to induce an increased content of N, P, K and Ca (BECKETT et al. 1994). The study by GAJEWSKI et al. (2009) showed a favourable effect of seaweed extracts, as well as of the biostimulant Asahi, on the quantitative and qualitative parameters of carrot. The effect of biostimulants on carrot depends, among other things, on the dose and application frequency (ALAM et al. 2014).

The study by SMOLEŃ et al. (2014) shows that changes in the quality in roots during storage may necessitate different types of cultivation practice for carrots used directly after harvest and stored ones. According to WSZELACZYŃSKA and POBEREŻNY (2011), the quality of carrot roots deteriorates during storage (e.g. a decreased carotenoid and vitamin C content). These changes depend on carrot cultivars (GAJEWSKI et al. 2010) and on the duration of storage (SUOJALAA, TUPASELAB 1999). The aim of this study was to analyse the effect of the timing and doses of foliar application of the biostimulants: Kelpak SL (seaweed extract containing phytohormones) and Asahi SL (a composition of phenolic compounds) on the content of macroelements: Mg, P, Ca, N, Na and K in the storage roots of carrot directly after harvesting and after storage.

MATERIAL AND METHODS

Field experiments on carrot were carried out in 2009-2011. They were established in The Kuyavian-Pomeranian Province (53°13'N; 17°51'E), on Alfisols originating from sandy loam. The granulometric composition of the topsoil is typical for fine sandy loam, whereas the deeper layers are classified as sandy clay loam. The topsoil is characterized by a medium content of available phosphorus 190-210 mg kg^{-1} and potassium 95-150 mg kg^{-1} (both determined with the Egner-Riehm method), a very low content of magnesium <20.0 mg · kg^{-1} (Schetschabel method) and slightly acid reaction (pH in 1M KCL 5.7-6.1) (measured by potentiometry). The content of organic carbon (7.55-7.80 g kg^{-1} of soil) and total nitrogen (0.69-0.75 g kg^{-1} of soil) was relatively low. The field study was conducted in a randomized block design with four replications. The area of plots for harvest was13 m^2. The biostimulants tested in the experiment were Kelpak SL (*Ecklonia maxima*), which contains natural plant phytohormones: auxins and cytokinins (11 and 0.031 mg l^{-1}, respectively) as well as the preparation Asahi SL (sodium para-nitrophenol – PNP) 0.3%, sodium ortho-nitrophenol (ONP) 0.2% and sodium 5-nitroguaiacol (5NG) 0.1%. The results were compared with the control treatment (without biostimulators). The following combinations of the foliar application of the biostimulants were compared (factor 1): Kelpak SL as a single application in a dose of 3 or 2 dm^3 ha^{-1}; Kelpak SL applied twice in doses 3+2 dm^3 ha^{-1} and 2+2 dm^3 ha^{-1}, at intervals of two and four weeks; Kelpak SL applied three times in doses 3+2+2 dm^3 ha^{-1} or 2+2+2 dm^3 ha^{-1}, every two weeks; Asahi SL applied twice in doses 0.5+0.5 dm^3 ha^{-1}, at a two-week interval. Kelpak SL was applied in total doses of 0, 2, 3, 4, 5, 6 and 7 dm^3 ha^{-1}, whereas Asahi SL was sprayed in a dose of 1 dm^3 ha^{-1}. The first application of Kelpak SL or Asahi SL was always performed at the 4-leaf stage. The biostimulant Kelpak SL was applied after dissolving the preparation in 300 dm^3 ha^{-1} of water, whereas Asahi SL was mixed with 500 dm^3 ha^{-1} water, in a concentration of 0.1%.

The carrot variety grown in the experiment was the late cultivar Karotan, characterized by a long storage life and a very high dry matter concentration. The cultivar is particularly suitable for production of dried and frozen vegetables. Pre-sowing fertilization was applied at doses of 60 kg ha^{-1} N, 30.6 kg ha^{-1} P and 66.4 kg ha^{-1} K. Plant protection measures against weed infestation, diseases and pests were performed according to recommendations. Carrot storage roots were harvested at the full maturity stage (the end of September). Storage roots were submitted to chemical analysis at two dates (factor 2): directly after harvest and after long storage. The roots were stored in chambers with controlled conditions. During the six-month storage, constant temperature +1°C and relative air humidity (Rh) 95% were maintained, adjusted to the way the carrot roots were to be used. Chemical analyses involved determinations of the dry matter concentrations of nitrogen (total) by the Kjeldahl method, magnesium by atomic absorption spectrometry (AAS), phosphorus spectrophotometrically by the vanadium-molybdenum method, potassium, calcium and sodium by flame photometry. Analyses of the roots were made after the plant material had been mineralized in a Digest Automet K-438, auto-sampler K371.

The results underwent statistical analysis, composed of the analysis of variance for single experiments in each year (2009, 2010 and 2011) and synthesis for all the years in a mixed model. The significance of differences was verified with the multiple comparison Tukey's test at $P = 0.05$. No significant interactions between the biostimulant application and the date of analyses versus the macroelement content in storage roots were indicated. Therefore, only the mean concentrations of macroelements for each factor are presented separately. The correlation coefficients between the nutrient content at different dates of analysis were calculated using Statistica for Windows.

RESULTS AND DISCUSSION

The Mg content in cv. Karotan carrot roots was high, reaching the average value of 1.740 g kg^{-1} DM (Table 1). Nicolle et al. (2004) give the content range of this element from 0.8 to 1.6 g kg^{-1}. The use of the the biostimulants Kelpak SL and Asahi SL, on average for all the combinations, caused a 7.5% increase in the Mg content as compared with the control. A favourable effect of the biostimulants Asahi SL and Bio-algeen (extract from macroalgae *Ascophyllum nodosum*) was also indicated in respect of other quality traits of carrots, such as: L-ascorbic acid and total sugars in carrot roots (Kwiatkowski et al. 2013). The effect of the preparation Kelpak SL depended on the method of its application. A double use of the preparation in a dose of 2 dm^3 ha^{-1} at the 4-leaf stage + 2 dm^3 ha^{-1} after 4 weeks caused a significant increase in the Mg concentration compared with the control and also to a single application in a dose of 3 dm^3 ha^{-1}, double application 3+2 dm^3 ha^{-1} after two weeks as well as triple application 3+2+2 every two weeks. The difference in the Mg concentration after the application of Asahi SL and in the control was not statistically significant.

The macroalgal biostimulants improve the growth and development of roots (Khan et al. 2009, Craigie 2011). Also phosphorus promotes root development, and most crop plants, including carrot, absorb 60-75% of total phos-

Table 1

Macroelement content in carrot roots depending on the type, rate and frequency of biostimulant application (on average for analyses directly after harvest and after long-term storage), mean for 2009-2011

Type, rate and frequency of biostimulant application	Macroelements (g kg^{-1}DM)					
	Mg	P	Ca	N	Na	K
Control	1.630	2.864	4.014	10.68	1.189	26.52
Kelpak SL (3 dm^3 ha^{-1})*	1.712	3.022	4.344	11.38	1.233	27.16
Kelpak SL (2 dm^3 ha^{-1})*	1.747	3.029	4.121	11.40	1.239	27.24
Kelpak SL (3+2 dm^3 ha^{-1})**	1.713	2.930	4.125	11.25	1.235	27.14
Kelpak SL (2+2 dm^3 ha^{-1})**	1.795	2.914	4.083	11.10	1.228	27.31
Kelpak SL (3+2+2 dm^3 ha^{-1})**	1.713	28.99	4.076	11.42	1.235	27.34
Kelpak SL(2+2+2 dm^3 ha^{-1})**	1.774	2.935	4.096	11.19	1.242	27.05
Kelpak SL (3+2 dm^3 ha^{-1})***	1.747	2.905	4.112	11.43	1.215	26.98
Kelpak SL (2+2 dm^3 ha^{-1})***	1.840	2.946	4.048	11.41	1.220	27.43
Asahi SL (0.5+0.5 dm^3 ha^{-1})**	1.732	2.882	4.020	11.06	1.233	27.16
Mean	1.752	2.947	4.104	11.23	1.231	27.21
$LSD_{(P = 0.05)}$	0.117	0.072	0.246	0.339	0.045	0.560

* single application at 4-leaf stage
** first application at 4-leaf stage, next ones every 2 weeks
*** first application at 4-leaf stage, next one after 4 weeks

phorus in the first quarter of the plant-growing period (Negrea et al. 2012). The present study indicated that a single application of Kelpak SL at the early developmental 4- leaf stage in a dose of 2 or 3 dm^3 ha^{-1} as well as the double application of Kelpak SL in a dose of 2+2 dm^3 after 4 weeks resulted in an increase in the P content as compared with the control. However, no effect of the biostimulant Asahi SL on the phosphorus content in the roots of the analyzed carrot cultivar was observed.

The Ca content in the roots of the above carrot cultivar was high in comparison with the results presented by Nicolle et al. (2004). No effect of Asahi SL on the content of this element was observed. However, a significant increase in the Ca concentration relative to the control was detected only after a single application of the biostimulant Kelpak SL in a dose of 3 dm^3 ha^{-1} at the 4-leaf stage. Increased calcium concentrations after the application of algal extract were also found in cherry tomato (Dobromilska et al. 2008).

The N content in the roots was relatively small when confronted with the results presented by Dyśko, Kaniszewski (2007). The use of the biostimulants Kelpak SL and Asahi SL, irrespective of the dose and application time, resulted in an increase in the N content versus the control. Similarly, Beckett et al. (1994) demonstrated that Kelpak SL tended to increase the N concentration in beans. The study by Jannin et al. (2012) proved that application of extracts from algae caused the activation of genes associated with the metabolic pathway of nitrogen. Although the application of the biostimulant Asahi SL increased the N concentration in the carrot roots compared to the control, it gave worse results than achieved in some variants with the application of Kelpak SL (doses of 2 dm^3 ha^{-1} at the 4-leaf stage, doses of 3 or 2 dm^3 ha^{-1} + next 2 dm^3 ha after 4 weeks and sequential doses 3+2 +2 every 2 weeks).

Application of the biostimulant Kelpak SL resulted in a higher sodium concentration than in the control in the following variants: a single dose of 2 dm^3 ha^{-1}, a double dose 3+2 dm^3 ha^{-1} after 2 weeks and triple application 3+2+2 or 2+2+2 dm^3 ha^{-1} every 2 weeks. The biostimulant Asahi, in turn, had no significant effect on the sodium concentration in the roots.

Potassium is the most important mineral in carrot (Nicolle et al. 2004). Proper fertilization with this element enhances the root quality and improves storability after harvest (Negrea et al. 2012). The study by Beckett, Staden (1989) demonstrated that the application of Kelpak SL had a favourable effect on potassium management. In the present experiment, the application of this preparation caused an increase in the K concentration in the carrot roots as compared with the control in almost every variant of its application (except for the triple application in a dose of 2 dm^3 ha^{-1} every 2 weeks and double application of 3 dm^3 ha^{-1} at the 4-leaf stage + 2 dm^3 ha^{-1} after 4 weeks). An increased K content relative to the control was also noted after the application of Asahi.

A small but significant decrease in the concentrations of Mg, Na and K in the carrot roots was noted after storage as compared with their content after harvesting (Table 2). No significant interaction of the analyzed factors was observed (biostimulant applications and the date of analysis), implicating that the use of biostimulants in carrot cultivation does not prevent the loss of macroelement concentrations in carrot roots during storage. There-

Table 2

Macroelement content in carrot roots directly after harvest and after long-term storage (on average for type, rate and frequency of biostimulant application), mean for 2009-2011

Time of analysis	Macroelements (g kg^{-1}DM)					
	Mg	P	Ca	N	Na	K
Directly after harvest	1.777	2.979	4.175	11.32	1.238	27.33
After long-term storage	1.728	2.916	4.032	11.14	1.224	27.09
Mean	1.752	2.948	4.104	11.23	1.231	27.21
$LSD_{(P = 0.05)}$	0.037	NS	NS	NS	0.008	0.173

fore, the quality of stored carrot cannot be improved by this element of a cultivation technology. Reversely, fertilization with N and J has been demonstrated to create such a possibility. In order to maintain high quality, carrot intended for consumption or processing directly after harvesting should be fertilized with iodine and with smaller doses of nitrogen, whereas carrot intended to be stored should be supplied with higher N amounts (Smoleń et al. 2014).

Alam et al. (2014) indicated that application of excessive doses of seaweed extract should be avoided in carrot fields, as they are not effective and may even inhibit the plant growth. In the present study, using the maximal dose of Kelpak SL was not justified also because of the carrot's ability to absorb and accumulate macroelements in the roots. The highest increase in the Mg concentration after the application of Kelpak SL in relation to the control was observed in response to the treatment 4 dm^3 ha^{-1} (11.5%); with respect to the Ca increase, it was the highest after the application of 3 dm^3 ha^{-1} (8.33%) – Figure 1*a*. In the case of P, a decrease in its concentration in the roots was shown along with an increase in the dose of this biostimulant ($y = -0.9163x + 6.3951$; $R^2 = 0.7827$). No direct reactions of the concentrations of N, Na and K to the growing doses of the biostimulant Kelpak SL were observed (Figure 1*b*). The N content in the roots increased by 6.8% in response to just 2 dm^3 ha^{-1} of the biostimulant, and at the maximal dose of

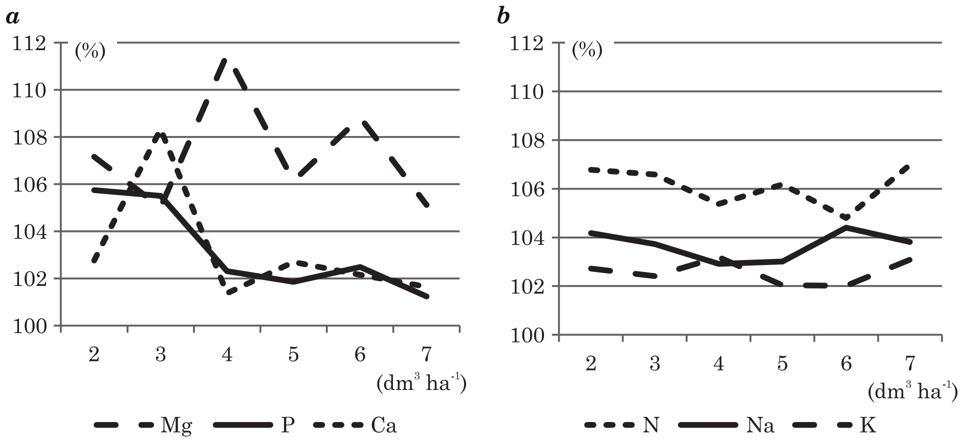

Fig. 1. Percentage relations of Mg, P and Ca (*a*) and N, Na and K (*b*) in carrot roots after Kelpak SL applications in total doses from 2 to 7 kg ha^{-1} (on average for analyses after harvest and after storage), mean for 2009-2011, control = 100%

7 dm^3 ha^{-1} raised the nitrogen content by 7.0%. The Na concentration increased from 2.9% after the application of 4 dm^3 ha^{-1} to 4.4% after the dose of 6 dm^3 ha^{-1}. The K content, in turn, was higher than in the control by 2.0% after the application of 6 dm^3 ha^{-1} up to 3.2% at the dose of 4 dm^3 ha^{-1}.

The highest increase in the Mg content compared to the control (8.8%) was noted after the double application of the preparation Kelpak SL (Figure 2). In turn, the increase in the P and Ca content was the highest (5.6%) after a single application. The rise in the N, Na and K content in the carrot roots was independent of the number of applications in the growing period.

The concentrations of individual macroelements in the carrot roots determined immediately after harvest were correlated with one another more often than after storage (Table 3). After harvesting, a negative correlation was shown between the content of P and N, as well as between P and K. Also, a positive correlation was indicated between the content of Na and K, between Na and Ca, as well as between N and the other macroelements: K, Ca, Mg

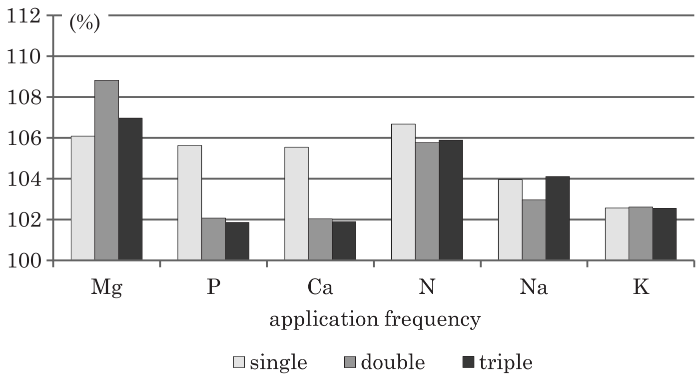

Fig. 2. Percentage relations of Mg, P, Ca, N, Na and K in carrot roots depending on the Kelpak SL application frequency (on average for analyses after harvest and after storage), mean for 2009-2011, control = 100%

Table 3

Correlation coefficient of macroelement content in carrot roots directly after harvest and after long-term storage

Macroelement	N	P	K	Ca	Mg	Na
N	–	-0.063	0.691**	0.015	0.274	0.397*
P	-0.509**	–	-0.295	0.506**	-0.021	-0.132
K	0.512**	-0.388*	–	-0.214	0.228	0.353*
Ca	0.352*	0.061	-0.287	–	-0.124	-0.170
Mg	0.354*	0.074	0.170	0.143	–	0.082
Na	0.648**	-0.293	0.366*	0.470**	0.015	–

(shaded) directly after harvest
(unshaded) after long-term storage

* indicates that the correlation is significant at the 0.05 probability level
** indicates that the correlation is significant at the 0.01 probability level

and Na. Negrea et al. (2012) reported a positive correlation between the uptake of N and K. The same authors claim that an increased N uptake may cause a reduction in the Mg concentration, since there is a negative correlation between these elements. This was not confirmed by the present study, probably because the nitrogen fertilization level and the concentration of this element in roots were relatively small. The positive correlations between the content of N and K and between N and Na, as well as between Na and K remained after storage. Additionally, a positive correlation was observed between the content of Ca and P.

CONCLUSIONS

1. The biostimulants Kelpak SL and Asahi SL, irrespective of the dose and frequency of application, increased the N concentration in the carrot roots. The effect of the seaweed preparation Kelpak SL on the content of the other macroelements (Mg, P, Ca, Na and K) varied in the tested variants of its application. The Mg, P, Na and K concentrations increased in response to just a single application of this preparation in a dose of 2 dm^3 ha^{-1}, while the Ca content rose after the application of 3 dm^3 of the biostimulant per ha. The application of Asahi SL did not affect the Mg, P, Ca and Na concentrations but increased the K content in the roots.

2. Changes in the macroelement concentrations in the carrot storage roots after storage in relations to the levels found after harvesting were similar in each variant of the biostimulant application. After storage, the content of Mg, Na and K decreased, whereas the concentrations of P, Ca and N did not change.

3. Increasing the dose of the biostimulant Kelpak SL resulted in a decrease in the P concentration in the roots, but there were no directional responses of the other macroelements (Mg, Ca, N, Na and K) to the growing doses of this preparation. Increasing the frequency of use of the biostimulant Kelpak SL to 2 or 3 times did not differentiate the concentrations of P, Ca, N, Na and K, but in the case of Mg, the highest increase in relation to the control was noted after the double application.

4. Correlations of the content of individual macroelements after carrot harvest were more frequent than after storage. On both dates, a positive correlation between the content of N and K and between N and Na, as well as between Na and K was indicated.

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