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ACCUMULATION OF POTASSIUM, MAGNESIUM, CALCIUM IN FRESH AND COLD STORED LEAVES OF LETTUCE (*LACTUCA SATIVA* L.) AFTER $CaCl_2$ FOLIAR TREATMENT BEFORE HARVEST

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Abstract

The aim of this study has been to determine the effect of foliar application of $CaCl_2$ before harvest on the accumulation of K, Mg and Ca in fresh and stored lettuce heads. The experimental material comprised cv. Omega lettuce, which was grown in a greenhouse at the Department of Cultivation and Fertilization of Horticultural Plants of the University of Life Sciences in Lublin. $CaCl_2$ solutions of the concentrations of 0.1 M and 0.2 M were sprayed over plants 20 and 10 days before harvest. After harvest, some plants were analysed immediately (fresh plants), while the remaining lettuce heads were cold-stored at 4°C for 7 and 14 days in dark polyethylene bags. The levels of dry matter, K, Mg and Ca were determined in whole leaves and leaf blades (without the midrib) of fresh and stored plants. The accumulation of dry matter, K, Mg and Ca varied depending on the leaf part, $CaCl_2$ treatment and time of storage. The Ca content was lower leaf blades than in whole leaves of fresh plants not treated with $CaCl_2$, but the K and Mg concentrations were on a similar level in both parts of leaves. The results of this study indicated that $CaCl_2$ foliar spray of plants caused higher K and Mg concentrations in whole leaves compared to the control plants (no $CaCl_2$ treatment) but decreasing Ca and K levels were observed in leaf blades without the midrib from fresh plants treated with 0.2 M $CaCl_2$. During the 14-day cold storage of lettuce, the Ca and Mg levels in decreased whole leaves but increased in leaf blades of the control plants and after the 0.2 M $CaCl_2$ treatment. Changes in the K, Mg and Ca accumulation affected the K:Mg and K:(Ca+Mg) ratios, which rose in whole leaves of stored plants compared to fresh ones.

Key words: lettuce, $CaCl_2$ treatment, potassium, magnesium, calcium, cold storage.

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AKUMULACJA POTASU, MAGNEZU I WAPNIA W ŒWIE¯YCH I PRZECHOWYWANYCH W WARUNKACH CH£ODNICZYCH LIŒCIACH SA£ATY (*LACTUCA SATIVA* L.) PO DOLISTNYM TRAKTOWANIU $CaCl_2$ PRZED ZBIOREM

Abstrakt

Celem pracy by³o okreœlenie wp³ywu dolistnego traktowania $CaCl_2$ sa³aty przed zbiorem na akumulacjê K, Mg i Ca w œwie¿ych i przechowywanych g³ówkach. Materia³ badawczy stanowi³a sa³ata odmiany Omega, uprawiana w szklarni Katedry Uprawy i Nawo¿enia Roœlin Ogrodniczych Uniwersytetu Przyrodniczego w Lublinie. Na roœliny 20 i 10 dni przed zbiorem zastosowano roztwory $CaCl_2$ o stê¿eniu 0,1 M i 0,2 M. Czêœæ roœlin analizowano bezpoœrednio po zbiorze (roœliny œwie¿e), natomiast pozosta³e przechowywano w temp. 4^{o}C przez 7 i 14 dni w ciemnych foliach polietylenowych. Zawartoœæ suchej masy, K, Mg, i Ca oznaczono w ca³ych liœciach i blaszkach liœciowych (bez g³ównego nerwu liœciowego) roœlin œwie¿ych i przechowywanych. Stwierdzono, ¿e akumulacja suchej masy, K, Mg i Ca by³a zró¿nicowana w zale¿noœci od czêœci liœcia, stosowania $CaCl_2$ i okresu przechowywania. Zawartoœæ Ca w blaszkach liœciowych by³a mniejsza w œwie¿ych roœlinach nie traktowanych $CaCl_2$ ni¿ w ca³ych liœciach, natomiast zawartoœæ K i Mg by³a podobna w obu czêœciach liœci. Wykazano, ¿e dolistne traktowanie roœlin $CaCl_2$ spowodowa³o zwiêkszenie koncentracji K i Mg w ca³ych liœciach w porównaniu z roœlinami kontrolnymi (bez traktowania $CaCl_2$) natomiast w blaszkach liœciowych bez g³ównego nerwu liœciowego zaobserwowano zmniejszenie zawartoœci Ca i K w œwie¿ych roœlinach traktowanych $CaCl_2$ w stê¿eniu 0,2 M. Podczas 14 dni przechowywania sa³aty w warunkach ch³odniczych zawartoœæ Ca i Mg w ca³ych liœciach zmala³a, natomiast wzros³a w blaszkach liœciowych roœlin kontrolnych i po zastosowaniu $CaCl_2$ w stê¿eniu 0,2 M. Zmiany w akumulacji K, Mg i Ca mia³y wp³yw na stosunki K:Mg i K:(Ca+Mg). Zanotowano ich zwiêkszenie w ca³ych liœciach roœlin przechowywanych w porównaniu ze œwie¿ymi.

S³owa kluczowe: sa³ata, traktowanie $CaCl_2$, potas, magnez, wapñ, przechowywanie ch³odnicze.

INTRODUCTION

Leaf vegetables are an important component of a balanced diet, which promotes consumption of more fruit and vegetables. Lettuce leaves, which contain vitamins C and E, carotenoids, phenolic acids with anti-free radical activity, and minerals, are an important part of the human diet. There is evidence which supports the role of mineral elements in cardiovascular diseases. Magnesium is important for the metabolic activity because it is related to many enzymes controlling the metabolism of carbohydrates, fats, proteins and electrolytes (CHAKRABORTI et al. 2002, HAARENEN 2003). Magnesium deficit and anomalies in metabolism are an important aspect when considering the aetiology of diabetes and the pathophysiology of many cardiovascular diseases in humans, such as cardiac arrhythmia, congestive heart failure, dyslipidemia, hypertension, myocardial ischaemia, atheromatosis and myocardial infraction. Its deficit gradually contracts coronary vessels, significantly blocking the flow of oxygen and nutrients to muscle fibres of the heart (SINGH et al. 1997, GAZMURI et al. 2001, CHAKRABORTI et al. 2002, HAARENEN

2003). It is known that magnesium deficit distorts the balance of other important macrominerals such as calcium, potassium and sodium. This suggests some dependence between cellular ion transport mechanisms and magnesium levels (BIJVELDS et al. 1997). Magnesium deficit may increase the level of intracellular Ca^{2+}, support the formation of oxygen radicals, proinflammatory factors, and induce changes in the membrane permeability and transport processes in the heart muscles (SINGH et al. 1997). A high Ca:Mg ratio favours blood coagulation (SEELIG 1994, HAARENEN 2003).

The main macroelements, i.e. potassium, magnesium and calcium, are vital nutrients for metabolism and transport across cell membranes. They support different cellular functions, such as controlling ion charge and concentration gradients in membranes which are used in transport processes, osmosis, cytoplasmic pH regulation, stabilisation of ribosome and nucleic acid structure, activation of DNA, RNA and protein synthesis enzymes (CAMPO et al. 2000, GHARIEB 2001).

Calcium increases the membrane permeability (BHARTI et al. 1996) and may influence the growth and ageing of plants (MAKSYMIEC, BASZYÑSKI 1998). It is one of the key initiators of signal processing in cells of higher plants, including processes such as bud formation, polar growth, control of gas exchange, light- and hormone-controlled growth and development (BHARTI et al. 1996, HUBER et al. 1996, SAURE 1998, RUIZ et al. 1999, BURTON et al. 2000).

Certain disorders in plants, for example tipburn, are related to Ca^{2+} deficiency (SAURE 1998, BARTA, TIBBITTS 2000). It was found that calcium salts can be used for shelf stability as a firming agent in different fruit (LUNA-GUZMAN, BARRETT 2000). Lettuce is one of the vegetables whose quality is limited by a short shelf life.

The objective of this study was to determine the effect of pre-harvest foliar application of different concentrations of $CaCl_2$ on the accumulation of K^+, Mg^{2+} and Ca^{2+} in whole leaves and leaf blades (without the midrib) of fresh and cold-stored lettuce heads.

MATERIAL AND METHODS

The study involved a pot experiment conducted in a greenhouse of the Department of Cultivation and Fertilization of Horticultural Plants of the University of Life Sciences in Lublin. The experimental material comprised cultivar Omega lettuce. Two-litre pots were filled with transitional peat with the pH of 5.4 and limed to 6.4 with calcium carbonate. The peat was enriched with 4 g of superphosphate, equivalent to 0.8 g of phosphorus, per pot. The micronutrient concentrations in 2 L of the substrate were: Cu – 26.6 mg, Mn – 10.2 mg, B – 3.2 mg, Mo – 7.4 mg, Zn – 1.48 mg. The culture medium was added to the pots three times: before planting the lettuce on 17th March and twice afterwards, on 31th March and 7th April. The total content of mineral components in the medium was after planting in experiment: N – 0.7 g, K – 1.5 g and Mg – 0.45 g. The temperature in the greenhouse was maintained at 18^{o}C at night and 23^{o}C during the day. Two weeks after planting, the vegetables were sprayed with $CaCl_2$ solutions of two different concentrations. For this purpose, plants were divided into three groups. The first group was treated with a $CaCl_2$ solution of the concentration 0.1 M, the second one – 0.2 M, while the third group, which served as the control, was sprayed with water. The plants were sprayed twice until the first drop, 20 and 10 days before harvest. The applied $CaCl_2$ concentrations were determined during the preliminary study (PERUCKA et al. 2007). The experiments were carried out in a randomized block design with five replications. After harvest, some plants were analysed immediately (fresh plants), while the remaining lettuce heads were cold-stored at 4^{o}C for 7 and 14 days in dark polyethylene bags. Five plants were sampled from each plot for chemical analysis. The plants were washed with distilled water before analysis. Leaf blades (without the midrib) and whole leaves were dissected. The prepared material was dried at room temperature, ground and mineralized in a muffle furnace at 300-500^{o}C. The levels of K, Mg and Ca were determined in an atomic absorption spectrometer (Unicam 939/395). The content of macronutrients was determined according to the analytical curve with the method described by PERUCKA et al (2007). The weight ratios of Ca:Mg, K:Ca, K:Mg, K:(Ca+Mg) were also calculated.

Statistical analysis consisted of an analysis of variance (Anova), using Statgraphics v 3.1 for Windows. Tukey's test (P<0.05) was used to detect significant differences among the means from three replicates.

RESULTS AND DISCUSSION

The results of the study on the effect of pre-harvest $CaCl_2$ foliar application on the accumulation of potassium, magnesium, calcium and dry matter in fresh and cold-stored lettuce are presented in Tables 1 and 2. The data indicate that the dry matter ranged from 3.17% to 4.19% and depended on the concentration of $CaCl_2$ and time of storage (Table 1). Foliar $CaCl_2$ application had a statistically significant influence on modifications in the content of dry matter. It was found that more dry matter was accumulated in the whole leaves of plants treated with the $CaCl_2$ solution of the concentration of 0.2 M and in leaf blades after using the $CaCl_2$ solution of either concentration. During the storage, the level of dry matter increased in whole leaves and leaf blades compared to the control plants due to water loss.

Potassium in lettuce leaves was within the range of 43.75-63.76 g kg^{-1} of dry matter (Table 1). It generally depended on a $CaCl_2$ solution concentra-

Table 1

Concentration of dry matter and potassium in fresh and stored leaves of lettuce after foliar $CaCl_2$ treatment

Analyzed part of plant	$CaCl_2$ (M)	Dry matter (%)				K (g kg^{-1} d.m.)			
		storage time – days			$\bar{x}$	storage time – days			$\bar{x}$
		0	7	14		0	7	14	
Whole leaves	0	3.226	3.505	3.924	3.552	55.63	52.39	60.64	56.22
	0.1	3.166	3.309	3.251	3.242	63.76	55.74	63.76	61.09
	0.2	3.548	3.788	3.875	3.737	61.46	51.74	62.76	58.65
	$\bar{x}$	3.313	3.534	3.683	3.510	60.283	53.29	62.39	58.65
	$LSD_{0.05}$ for: $CaCl_2$ – I storage time – II interaction – I x II	 0.215 0.173 0.273				 3.202 4.227 5.845			
Leaf blades	0	3.265	3.737	3.428	3.477	56.91	48.32	60.49	55.24
	0.1	3.627	4.188	3.668	3.828	55.72	45.77	50.89	50.79
	0.2	3.648	3.914	3.631	3.731	43.75	54.94	60.61	53.10
	$\bar{x}$	3.513	3.946	3.576	3.379	52.127	49.677	57.33	53.04
	$LSD_{0.05}$ for: $CaCl_2$ – I storage time – II interaction – I x II	 0.144 0.175 0.257				 4.816 5.279 6.840			

tion applied during the pre-harvest foliar treatment. More potassium was noticed in the whole leaves of fresh plants after the $CaCl_2$ treatment with a solution of either 0.1 M or 0.2 M concentration; the lowest potassium content appeared in the leaf blades of plants treated with $CaCl_2$ of the concentration of 0.2 M, compared to the control. During the 14-day storage under cold conditions, the potassium level was observed to be higher in whole leaves of the control plants and after the $CaCl_2$ treatment with a solution of the higher concentration than in fresh plants.

Magnesium ranged from 3.88-6.67 g kg^{-1} of dry matter. It depended on the level of $CaCl_2$ treatment and time of storage (Table 2). In fresh plants, it increased in the whole leaves of plants after the application of $CaCl_2$ in either concentration whereas while in leaf blades it rose only when the 0.1 M solution was applied. During the 14 days of storage in cold, the magnesium concentration increased in leaf blades of the control plants and treated with the $CaCl_2$ solution of the concentration of 0.2 M, but Mg decreased in whole leaves compared to fresh plants treated with calcium chloride in the same dose.

Table 2

Concentration of magnesium and calcium in fresh and stored leaves of lettuce after foliar $CaCl_2$ treatment

Analyzed part of plant	$CaCl_2$ (M)	Mg (g kg^{-1} d.m.)				Ca (g kg^{-1} d.m.)			
		storage time – days			$\bar{x}$	storage time – days			$\bar{x}$
		0	7	14		0	7	14	
Whole leaves	0	4.074	5.285	3.929	4.429	13.42	9.321	8.190	10.31
	0.1	5.088	4.181	4.663	4.644	13.42	10.070	8.431	10.6
	0.2	5.641	4.008	4.379	4.676	12.98	10.550	9.071	10.87
	$\bar{x}$	4.934	4.491	4.324	4.583	13.27	9.982	8.564	10.60
	$LSD_{0.05}$ for: $CaCl_2$ – I storage time – II interaction – I x II	0.614 0.643 0.811				0.797 1.803 1.137			
Leaf blades	0	4.596	4.948	6.671	5.405	10.98	9.669	12.720	11.12
	0.1	5.235	3.884	4.097	4.405	11.07	9.148	9.782	10.00
	0.2	4.399	4.962	5.827	5.063	8.95	10.620	10.060	9.877
	$\bar{x}$	4.743	4.598	5.532	4.958	10.33	9.812	10.85	10.33
	$LSD_{0.05}$ for: $CaCl_2$ – I storage time – II interaction – I x II	0.527 0.643 0.888				1.497 1.467 1.951			

Calcium in cv. Omega lettuce ranged from 8.19 to 13.42 g kg^{-1} d.m. (Table 2). The accumulation of this element was distinctly affected by both $CaCl_2$ solution concentrations, part of leaves and storage time. A statistically significant higher calcium content was noted in whole leaves of fresh control plants than in leaf blades. During the 14-day storage, the calcium concentration decreased in whole leaves, in contrast to leaf blades, in which the accumulation of this element increased in the control plants and after the application of $CaCl_2$ of the concentration of 0.2 M.

These results correspond to the ones obtained by MICHA£OJÆ and HORODKO (2006), who found that foliar treatment of sweet pepper plants with calcium ions had a weak effect on the potassium and magnesium content but the level of dry matter was higher in fruit of plants treated with Ca^{2+} ions. Foliar spray with calcium ions, both as $CaCl_2$ and $Ca(NO_3)_2$, increased the content of this ion in leaves and fruit of pepper compared to the control. Lettuce belongs to vegetables that have a low demand for nutrients but are sensitive to the ion concentration in soil, both during germination and in the vegetative period (CHIBA, SHIMIZU 2008, NURZYÑSKI at al. 2009).

The results obtained in our preliminary experiments on lettuce plants indicated that the application of $CaCl_2$ in the concentration 0.1 M decreased

Table 3

The Ca:Mg, K:Ca, K:Mg, K:(Ca+Mg) ratios in fresh and stored leaves of lettuce after $CaCl_2$ foliar treatment

Analyzed part of plant	$CaCl_2$ (M)	Ca:Mg				K:Ca				K:Mg				K:(Ca+Mg)			
		storage time – days			$\overline{x}$	storage time – days			$\overline{x}$	storage time – days			$\overline{x}$	storage time – days			$\overline{x}$
		0	7	14		0	7	14		0	7	14		0	7	14	
Whole leaves	0	3.294	1.764	2.084	2.381	4.145	5.621	7.404	5.723	13.65	9.913	15.43	12.99	3.179	3.587	5.004	3.923
	0.1	2.594	2.408	1.808	2.270	4.751	5.535	7.562	5.949	12.53	13.33	13.67	13.18	3.445	3.911	4.869	4.075
	0.2	2.303	2.633	2.071	2.336	4.735	4.904	6.919	5.519	10.89	12.91	14.33	12.71	3.298	3.553	4.666	3.839
	$\overline{x}$	2.730	2.268	1.988	2.239	4.544	5.353	7.295	5.730	12.36	12.05	14.48	12.96	3.307	3.684	4.846	3.946
Leaf blades	0	2.389	1.954	1.907	2.083	5.183	4.997	4.755	4.978	12.38	9.765	9.068	10.40	3.654	3.306	3.119	3.359
	0.1	2.115	2.355	2.388	2.286	5.033	5.003	5.202	5.079	10.64	11.78	12.42	11.61	3.417	3.512	3.667	3.532
	0.2	2.035	2.140	1.726	1.967	4.888	5.173	6.025	5.362	9.945	11.07	10.40	10.47	3.277	3.526	3.815	3.539
	$\overline{x}$	2.180	2.150	2.007	1.939	5.035	5.058	5.327	5.139	10.98	10.87	10.63	10.83	3.449	3.448	3.534	3.477

the level of Mg^{2+} and increased Ca^{2+} in fresh whole leaves (PERUCKA et al. 2007). The increasing soil calcium content had an effect on potassium and calcium concentrations in lettuce. Calcium increased but potassium slightly decreased in plants when calcium in soil reached the highest level (NURZYŃSKI et al. 2009).

An increase in the calcium chloride level in soil caused a proportional rise in calcium concentrations in both roots and leaves of other plants. In tobacco plants, calcium ions were more likely to accumulate in leaves than in roots, indicating that the ion permeation system differs in roots and leaves (RUIZ et al. 1999). Identical results were obtained by other authors in experiments on *Sesamum indicum* (BHARTI et al. 1996). In a study on bean plants, higher calcium levels in the substrate resulted in greater accumulation of calcium in the plant (MAKSYMIEC, BASZYŃSKI 1998).

BRES and WESTON (1992) concluded that the accumulation of calcium and magnesium in lettuce leaves was cultivar-dependent and significantly higher in cv. Summer Bibb than in cv. Buttercrunch. Lower calcium levels in cv. Buttercrunch could be responsible for a higher incidence of disease observed in this cultivar, most likely due to its increased sensitivity to adverse environmental conditions, as manifested by lower calcium concentrations in young leaves. According to a study conducted by LAZOF and BERNSTEIN (1999) into the transport of micronutrients to the youngest leaves of lettuce, it was found that the transport of calcium ions was halved in comparison with potassium ions, but no changes in the transport of magnesium ions to the youngest lettuce leaves were noted.

The results obtained in our experiments indicated that the concentrations of Mg and Ca in leaf blades were higher than in whole leaves during the 14 days storage of lettuce under cold conditions (Table 2). It may be affected by the transport of these elements from the midrib of whole leaves to leaf blades.

The ratios of mineral nutrients are an important indicator of the nutritive value of a diet. According to the present results (Table 3), the Ca:Mg ratio in whole leaves of fresh plant of cv. Omega lettuce was optimum, but the K:Mg and K:Ca ratios were twice as high as the optimum ones in a diet: less than 6.0 for K:Mg, 2.0 for K:Ca and 3.0 for Ca:Mg (KOTOWSKA, WYBIERALSKI 1999, FRANCKE 2010).

It was noticed that the Ca:Mg and K:Mg ratios in the whole leaves of cv. Omega lettuce were higher than in the leaf blades, but K:(Ca+Mg) was on the same level in both parts of fresh plants (Table 3). The $CaCl_2$ treatment of lettuce before harvest caused a decrease in the Ca:Mg and K:Mg ratios compared to the control, which was a result of the increasing content of Mg in whole leaves in response to a higher $CaCl_2$ concentration. During the 14 days of storage under cold conditions, the K:Mg, K:(Ca+Mg) ratios increased in the whole leaves depending on the $CaCl_2$ doses versus the fresh plants.

CONCLUSIONS

The results show that foliar treatment of lettuce with $CaCl_2$ in rising concentration stimulated the K and Mg accumulation in whole leaves of fresh plants. No significant changes in the Ca content were observed. In leaf blades without the midrib, the application of the higher $CaCl_2$ dose caused a decline in the Ca^{2+} and K^+ concentrations in fresh plants. This depressed the Ca:Mg and K:Mg ratios. During 14-day storage of lettuce in the cold, a decrease in the Ca levels in whole leaves and an increase in leaf blades in the control plants and after the application of the $CaCl_2$ solution of the concentration of 0.2 M were observed. The same tendency was noticed for the Mg content. In general, the changes in the K levels under the same conditions were not statistically significant but the K:Mg and K:(Ca+Mg) ratios increased in whole leaves compared to fresh plants.

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