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ORIGINAL PAPER

Chemical composition, nitrate content, and yield of lettuce (*Lactuca sativa* L.) grown under different concentrations of NaCl*

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Abstract

Global climate change observed in recent decades and the impact of anthropopressions have led to a gradual deterioration of the physical properties of and chemical properties of soil and water. One of the most important factors determining the quality of water used in a hydroponic system is salinity. The aim of this study was to determine the induced effect of sodium chloride on yield, content of selected nutrients and sodium and nitrates in aerial parts of butterhead lettuce (*Lactuca sativa* L.) cultivar 'Zeralda F1' grown hydroponically. The trials were conducted at the following concentrations of NaCl: 0 (control treatment), 10, 20, 40, 60, 80 and 100 mmol dm^{-3}. In the range of NaCl concentrations from 10 to 80 mmol dm^{-3}, no significant differences in fresh weight yield of lettuce were found. Significantly the lowest weight of aerial parts of lettuce was obtained at a sodium chloride concentration in the nutrient solution of 100 mmol dm^{-3} compared to the control combination. An increase in the concentration of NaCl in the nutrient solution resulted in an increase in the sodium content and a decrease in the content of phosphorus, potassium, and magnesium in the aerial parts of the lettuce. The iron and manganese content with the induced effect of sodium chloride in all combinations was significantly lower than in the control combination. There was a significant reduction in the nitrate content of the aerial parts of the lettuce caused by increasing concentrations of sodium chloride in the nutrient solution. The sodium chloride content in the concentration range 40-100 mmol dm^{-3} had a significant effect on increasing the dry matter content and decreasing the relative water potential (RWC) in the range of 60-100 mmol dm^{-3}.

Keywords: salinity, sodium, nitrate, RWC, macronutrients, micronutrients,

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INTRODUCTION

Butterhead lettuce is classified as a salinity-sensitive vegetable (Qin et al. 2013). The nutrient content of the aerial parts of butterhead lettuce and the yield are closely related to the climatic and soil conditions in which the plants are grown. This is due to the plant's response to environmental stress, also known as an abiotic stress. The negative effect of salinity on plants can be the result of two mechanisms. One is the individual toxic effect of an 'ion' on the plant, (e.g. Na, B), and the other one is exceeding the plant's tolerance limit to the total salt concentration, leading to a reduction in water uptake by the plant. This mechanism is less damaging, as a higher ion concentration in the root environment is accompanied by a more intensive uptake of ions by the plant, resulting in a decrease in the water potential in the roots and, consequently, the stimulation of water uptake (Breś et al. 2009). The salinity effect can be caused by irrigating plants with high salinity EC (electrical conductivity) water due to the concentration of sodium chloride. Salinization of groundwater used in horticulture occurs during uncontrolled drainage water run-off from growing mats. As a result of the nutrient concentration in the root environment, the content of nutrients in the drainage water (except phosphorus) is higher than in the nutrient solution supplied to the plants (Dyśko, Kowalczyk 2005, Kleiber 2012). Malorgio et al. (2001) reported that 2,123 m^3 ha^{-1} of fertilizer solution, containing 1,477 kg of nitrogen, was discharged in an uncontrolled manner into the ground of a greenhouse with an open soilless culture system. The presence of NaCl in the soil can lead to the excessive accumulation of sodium and chloride ions in plant tissues (Ghoulam et al. 2002, Sacała et al. 2002). The effect of salinity in lettuce cultivation has been the subject of scientific research for many years, e.g. De Pascale and Barbieri (1995), Beltrão et al. (1997), Pérez-Alfocea et al. (2002), Tesi et al. (2003), Andriolo et al. (2005), Scuderi et al. (2009), Kleiber, Markiewicz (2010), Markiewicz and Kleiber (2010), Kleiber (2014), Breś et al. (2022). According to Julkowska and Testerink (2015), as well as Munns and Gilliham (2015), plants exposed to sodium (Na^+) and chloride (Cl^-) ions under conditions of excessive salinity are capable of developing defense mechanisms. These are: osmotic stress tolerance; Na^+ and Cl^- exclusion from leaves, and tissue tolerance to Na^+ and Cl^- accumulation (Munns and Tester 2008).

Greenhouse and associated soilless culture account for a small share of the total area used for agriculture, but are mostly concentrated near large cities or in specific areas of the country, where they can contribute significantly to environmental deterioration (Kowalczyk et al. 2013). According to Iammarino et al. (2014), lettuce is among the leafy vegetables with the highest nitrate content. Nitrates are naturally occurring components of plants. Under conditions of insufficient light intensity and deficiencies of molybdenum, manganese, calcium or magnesium, they can cause nitrate accumulation in plants in the presence of a high nitrate nitrogen content in the soil (Mengel, Kirkby 1983). According to Wasilewska (1996), the level of nitrate in lettuce depends on factors such as the form of nitrate fertilizers used, their amount and the timing of application. Nitrogen metabolism thus plays an important role not only in plant growth and productivity, but also in processes that improve plant tolerance to environmental stresses. The primary source of nitrogen for plants is nitrate (V), which must be reduced to ammonium ions before being incorporated into organic compounds (Sacała 2008). The nitrate content permitted by the European Commission, set by the Regulation of 2 December 2011, varies with the date and type of crop. For crops harvested between 1 October and 31 March, it is 4,000 mg NO_3 kg^{-1} in open field cultivation and 5,000 mg NO_3 kg^{-1} fresh weight. In spring and summer, for crops harvested from 1 April to 30 September, the thresholds are 4000 mg NO_3 kg^{-1} for cover crops and 3000 mg NO_3 kg^{-1} for field crops. An exception is iceberg lettuce, for which the permissible nitrate level depends only on the crop type (2,000 mg NO_3 kg^{-1} for open field, 2,500 mg NO_3 kg^{-1} under cover). The accumulation of excessive amounts of sodium and nitrates in vegetables is a particularly important problem for humans. The application of sodium chloride reduces the nitrate content of lettuce.

The aim of the model study was to determine the effect of increasing concentrations of sodium chloride on the yield and chemical composition of hydroponically grown lettuce (*Lactuca sativa* L.).

MATERIALS AND METHODS

Experimental site and materials

The experiment was conducted in a specialist culture greenhouse equipped with a modern climate control system. It took place in the spring of 2021. The cultivar 'Zeralda F1' butterhead lettuce (*Lactuca sativa* L.) seeds were sown individually into rockwool cubes (25 May). Seedlings were transplanted into rockwool blocks (Grodan) (10 × 10 × 10 cm). At the stage 3-4-leaf (24 June), the plants in blocs were transferred to the cultivation system. The plants were grown hydroponically in a Willma system with recirculation of the nutrient solution.

For the fertigation of lettuce plants, the standard nutrient solution with the following chemical composition was prepared (mg dm^{-3}): N-NH_4 – 2,1, N-NO_3 – 173, P – 42, K – 317, Ca – 135, Mg – 60, S-SO_4 – 120, Na – 35, Fe – 0.32, Mn – 0.52, Zn – 0.51, Cu – 0.03. Fertilizers available for hydroponic cultivation were used: HNO_3 (38%), potassium nitrate (13% N-NO_3, 38.2% K), calcium nitrate (14.5% N-NO_3, 19.6% Ca), magnesium nitrate (11.0% N-NO_3, 9.5% Mg), KH_2PO_4 (22.3% P, 28.2% K), K_2SO_4 (44.8% K, 17.0% $S\text{-}SO_4$), $MgSO_4$ (9.5% Mg, 12.7% S), Librel FeDP7 (7% Fe), $MnSO_4$ H_2O (32.3% Mn), ($CuSO_4$ $5H_2O$ (25.6% Cu), Borax (11.0% B), Na_2MoO_4 $2H_2O$ (39.6% Mo).

Increasing sodium chloride doses were added to the basic nutrient solution.

The experiment consisted of 7 combinations with the following concentration of NaCl (Table 1).

Table 1

Hydroponic NaCl concentrations, pH and EC

Treatment	Hydroponic concentration (mmol dm^{-3})	pH	EC ($dS\ m^{-1}$)
NaCl-0	0 (control treatment)	5.66	2.90
NaCl-II	10	5.98	3.98
NaCl-III	20	6.56	5.16
NaCl-IV	40	7.13	7.22
NaCl-V	60	7.88	9.08
NaCl-VI	80	8.21	9.94
NaCl-VII	100	8.90	10.51

Analysis of DM and RWC

On the last day of cycle (July 11), the following were determined: the fresh weight of a lettuce head (g), and the Relative Water Content (%), (Gonzáles and Gonzáles-Vilar 2001). The dry matter ratio (%) was calculated using the following formula:

$$DM = \frac{W_{dry}}{W_{fr}} \times 100$$

where: DM – dry matter ratio (%), W_{fr} and W_{dry} – fresh and dry weight of samples respectively.

Nitrates analysis

The content of nitrates was measured with the colorimetric method, using direct cadmium reduction. In this method, the sample was extracted with hot water and deproteinized with potassium ferrocyanide and zinc acetate. Nitrates were reduced with powdered cadmium to nitrites, and then the concentration of the colored compound was measured colorimetrically after reacting with the Griess reagent. The absorbance was read with a photocolorimeter at 538 nm (PN-92/A-75112).

Chemical analyses of leaves

Collected plant material (head of lettuce) was dried at a temp. of 45-50°C and then ground. The total forms of nitrogen, potassium, magnesium and sodium, were determined after dissolution in concentrated sulphuric acid with the addition of hydrogen peroxidethe. In order to determine total contents of iron, manganese, zinc and copper, the plant material was mineralized in a mixture of acetic and perchloric acids (3:1 v/v). Digestion of the sample was carried out in a classic apparatus for manual digestion in Kjeldahl flasks (250 ml) with 10 heating blocks (IUNG 1972).

After mineralization of the plant material, the following measurements were made: N-total – using the distillation method according to Kjeldahl in a Parnas Wagner apparatus, P – by colorimetric analysis with ammonium molybdate, and K, Mg, Na, Fe, Mn and Zn – using flame atomic absorption (on an FAAS, Carl Zeiss Jena apparatus). The accuracy of the methods used for the chemical analyses and the precision of analytical measurements of nutrient levels were verified with the LGC7162 reference material, with an average nutrient's recovery of 96% (N, P, K, Ca, Mg).

Statistical analysis

The experiments were set up in a systematic design with 4 replications (4 lettuces were 1 replicate). The data were analysed with the Statistica 13.3 software (StatSoft Inc., Tulsa, OK, USA). The results of chemical analyses and plant yield measurements were subjected to ANOVA. The results were analyzed statistically with the Duncan's test, at a significance level = 0.05.

RESULTS AND DISCUSSION

The effect of increasing concentrations of sodium chloride on lettuce yield, DM and RWC

The effect of increasing concentrations of sodium chloride in the nutrient solution on the weight of aerial parts of butterhead lettuce, dry matter and RWC was demonstrated (Table 2). In the experiments conducted, an average plant yield ranging from 52.5 to 84.4 g plant^{-1} was obtained. The average yield of lettuce leaves was lower than that obtained in the author's own earlier studies (Breś et al. 2022), but the relationships concerning yield, dry matter content and RWC in the range of sodium chloride concentrations in the nutrient solution 0 - 60 mmol dm^{-3} were similar. The fresh weight yield of the aboveground parts of lettuce at NaCl concentrations of 80 and 100 mmol dm^{-3} was 28.8 and 60.8% lower compared to the with the control combination. The significantly lowest weight of the aerial parts of lettuce (52.5 g plant^{-1}) compared to the yield in the control combination (84.4 g plant^{-1}) was obtained at the sodium chloride concentration in the nutrient solution of 100 mmol L^{-1}. There were no significant differences in the yield of lettuce heads at sodium chloride concentrations in the nutrient solution of 80 and 100 mmol dm^{-3}. The yield of aerial parts of lettuce obtained in own

Table 2

The effect of increasing concentrations of sodium chloride on lettuce yield, dry matter and RWC

NaCl (mmol dm^{-3})	Fresh mass (g $plant^{-1}$)	Dry matter ratio (%)	RWC (%)
0 (control)	84.40 *c**	5.97 *a*	90.22 *d*
10	73.00 *bc*	6.07 *a*	90.06 *d*
20	80.10 *b*	6.11 *a*	89.97 *d*
40	77.10 *bc*	6.94 *b*	89,32 *d*
60	78.00 *bc*	7.02 *b*	86.44 *c*
80	65.50 *ab*	7.13 *b*	84.67 *b*
100	52.50 *a*	7.10 *b*	82.13 *a*

* Means followed by the same letters do not differ significantly at p=0.05.

research was lower than the yield obtained in experiments on the effect of sodium chloride conducted in closed systems without recirculation (Breś et al. 2022). According to Parente et al. (2004), lettuce achieved the best quality with a dry matter content above 7%. It has been shown that a sodium chloride concentration in the nutrient solution of 60 - 100 mmol dm^{-3} can be a determining factor for yield quality. Plants growing at this NaCl concentration were characterized by a dry matter content above 7%, the effect of increasing salinity was a reduced water content of the plants. One method of plant adaptation to stress caused by excessive salinity is the reduction in osmotic potential. This process is a direct result of the decrease in plant-available water due to increased salinity (Acosta-Motos et al. 2017). The increase in the plant's dry matter content induced by sodium chloride is a well-known phenomenon described by many authors (Tas et al. 2005, Bartha et al. 2015, Shin et al. 2020, Conversa et al. 2021, Breś et al. 2022). The dry matter content of plants such as butterhead lettuce determines their post-harvest shelf life, and is also an important parameter of the commercial value of vegetables for direct consumption. The use of a plant tolerance mechanism to salinity has been described by many authors (Maas, Hoffman 1977, Clarkson et al. 2003, Andriolo et al. 2005). Salinity is one of the factors also determining the development of the root system of lettuce grown in hydroponic systems. According to Ahmed et al. (2019), a concentration of 100 mmol dm^{-3} results in a 21% reduction in the root system of lettuce, and doubling this concentration to 200 mmol dm^{-3} will result in reductions of up to 41%.

The effect of increasing concentrations of sodium chloride on the chemical composition of lettuce

According to many authors, the content of nutrients and sodium in the aerial parts of lettuce is highly varied (Kleiber 2014) – Tables 3, 4.

Table 3

The content of macronutrient and sodium (%) in lettuce leaves according to other authors (Kleiber 2014)

Source	N	P	K	Ca	Mg	Na
Abou-Hadid et al. (1996)	3.54-4.21	0.97-0.98	7.24-8.20	-	-	-
Markiewicz and Kleiber (2010)	-	-	-	-	-	0.24-0.57
Kleiber and Markiewicz (2010)	3.18-3.54	0.37-0.63	4.4-9.04	1.39-1.52	0.62-0.69	-
Gül et al. (2007)	3.72-4.16	0.29-0.38	4.58-7.10	1.73-2.07	0.27-0.40	-
Karimaei et al. (2004)	1.57-4.23	0.18-0.39	4.6-8.9	-	-	
Kleiber et al. (2013)	4.04-5.21	0.74-1.07	8.15-9.16	1.37-1.39	0.75	0.24-0.59
Jarosz and Dzida (2006)	4.97-5.84	0.38-0.43	6.54-7.70	1.00-1.21	0.33-0.39	
Matraszek et al. (2002)	-	0.93-4.08	1.74-2.58	0.30-0.44	0.50-0.63	

Table 4

The content of micronutrient (mg kg^{-1}) in lettuce leaves according to other authors (Kleiber 2014)

Source	Fe	Mn	Zn
Abou-Hadid et al. (1996)	821.0-838.8	115.1-119.8	60.8-83.0
Gül et al. (2007)	91.2-126.5	42.92-66.22	60.86-75.57
Hakerlerler et al. (1992)	55.9	22.0	30
Markiewicz, Kleiber (2010)	133.8-244.8	34.9-100.2	146.7-218
Kozik et al. (2008*a*)	149.1-193.4	174.4-346.8	110.7-187.3
Kozik et al. (2008*b*)	185.7-193.3	233.3-342.2	148.5-162.7
Matraszek et al. (2002)	76.9-96.0	14.1-43.7	73.9-120.2
Winsor, Adams (1987)	50-200	-	-

There were no significant differences in the nitrogen content of the aerial parts of the lettuce (Figure 1). The effect of increasing concentrations of sodium chloride in the nutrient solution on the mean percentage of phosphorus in the aerial parts of the lettuce plant was found. The highest phosphorus content was obtained in the NaCl-VII combination (0.19% P) with the NaCl concentration in the nutrient solution of 100 mmol dm^{-3} (Figure 1). The lowest phosphorus content (0.11% P) was obtained in the NaCl-II combination. The effect of increasing concentrations of NaCl in the nutrient solution on the phosphorus content was demonstrated, with the exception of the NaCl-II combination, in which the phosphorus content was lower than in the control combination. The nitrogen and phosphorus contents of lettuce leaves obtained in our study were lower than those obtained by other authors (Abou-Hadid et al. 1996, Matraszek et al. 2002, Gül et al. 2007, Markiewicz, Kleiber 2010, Kleiber et al. 2013, Breś et al. 2022). The nitrogen content

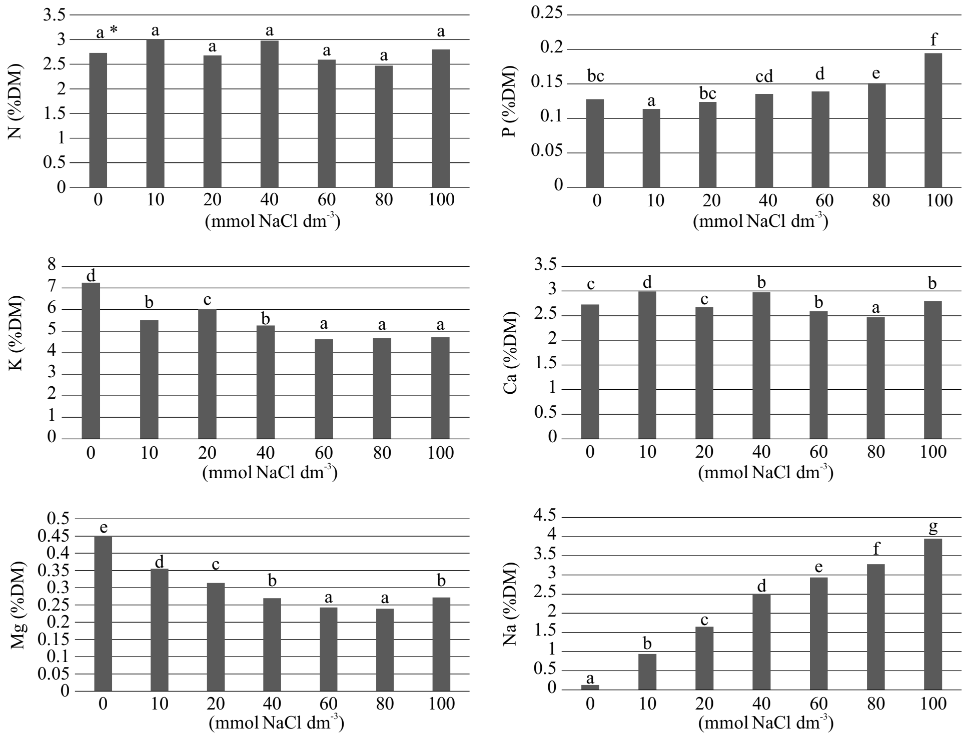

Fig. 1. The effect of increasing sodium chloride concentrations in the nutrient medium on the nitrogen, phosphorus, potassium, calcium, magnesium and sodium content of lettuce leaves; * means followed by the same letters do not differ significantly at p=0.05

levels were within the range reported by Karimaei et al. (2004), while those of phosphorus – only at the NaCl concentration of 100 mmol dm^{-3}.

The highest significant potassium content was determined in the control combination NaCl-I (7.24% K) – Figure 1. The lowest potassium content was found in the combination NaCl-V (4.62% K) - NaCl-VII. The study showed a decreasing trend in the potassium content of lettuce leaves with an increasing sodium chloride concentration in the nutrient solution, with the exception of the NaCl-III combination. The potassium content of the aerial parts of lettuce was within the range of the content determined by other authors (Abou-Hadid et al. 1996, Jarosz, Dzida 2006, Gül et al. 2007, Markiewicz, Kleiber 2010, Kleiber et al. 2013), significantly lower levels of the potassium content were determined by Matraszek et al. (2002).

The effect of an increasing sodium chloride concentration in the nutrient solution on decreasing the mean percentage of magnesium in the aerial parts of lettuce was demonstrated (Figure 1). The highest significant magnesium content was determined in the control combination NaCl-I (0.45% Mg), while the lowest one was in the combinations NaCl-V and NaCl-VI (0.24% Mg). No significant differences in the magnesium content were found between the

NaCl-VII and NaCl-IV combinations. The magnesium content of the aerial parts of lettuce in the control combination was higher than the results obtained by some other authors, e.g. Jarosz and Dzida (2006), Gül et al. (2007), and but lower than those obtained by Matraszek et al. (2002), Markiewicz and Kleiber (2010), Kleiber et al. (2013), Breś et al. (2022).

The effect of increasing sodium chloride concentrations in the nutrient solution on decreasing the average percentage of calcium in lettuce heads was demonstrated (Figure 1). The changes in the content of this macronutrient were multidirectional. The highest significant calcium content was determined in the NaCl-II combination (0.85% Ca). The lowest mean calcium percentage was determined in the NaCl-VI combination (0.62% Ca). The calcium content in our research did not exceed 0.9% d.m. Comparing our results with the literature data, it can be concluded that the plants were in a state of insufficient nutrition with this macronutrient, but despite such low content, no tipburn symptoms were observed on the plants.

The effect of increasing concentrations of sodium chloride in the nutrient solution on the increase of the sodium content in the aerial parts of lettuce was demonstrated (Figure 1). The lowest sodium content was determined in the control combination NaCl-I (0.12% Na). The highest significant sodium content was determined in the NaCl-VII combination (3.95% Na) at the highest NaCl concentration in the nutrient solution of 100 mmol dm^{-3}. Changes in the sodium content of lettuce leaves with increasing concentrations of sodium chloride in the nutrient solution were linear and resulted directly from the use of increasing concentrations of sodium chloride in the fertigation nutrient solution. The sodium content of lettuce leaves grown at the concentration of sodium within the range of 0 - 60 mmol dm^{-3} was lower than that obtained by Breś et al. (2022).

According to Shabala and Pottosin (2014), the regulation of Na+ uptake and transport in plants under salt stress has been widely interpreted in the context of maintaining high tissue K+/Na+ ratios, and hence high cytosolic K+/Na+ ratios, which has become a key salt tolerance trait. Because Na+ interferes with K+ homeostasis, and especially given its involvement in numerous metabolic processes, maintaining a balanced cytosolic Na+/K+ ratio has become a key salinity tolerance mechanism (Assaha et al. 2017). The minimum value of the K/Na ratio is about 1 (Maathuis, Amtmann 1999). In our study, the K/Na ratio was higher and amounted to about 1.2 even at the highest NaCl concentration in the medium. (Figure 2).

The highest significant iron content was found in the control combination NaCl-I (150.5 mg kg^{-1}). The lowest significant iron content was found in the NaCl-VII combination (131.5 mg kg^{-1}), where the NaCl content in the nutrient solution was 100 mmol NaCl dm^{-3}. In all combinations with the sodium chloride concentrations in the range of 10-100 mmol dm^{-3}, the iron content was lower than in the control combination. According to the data contained in the world literature, the iron content of the aerial parts

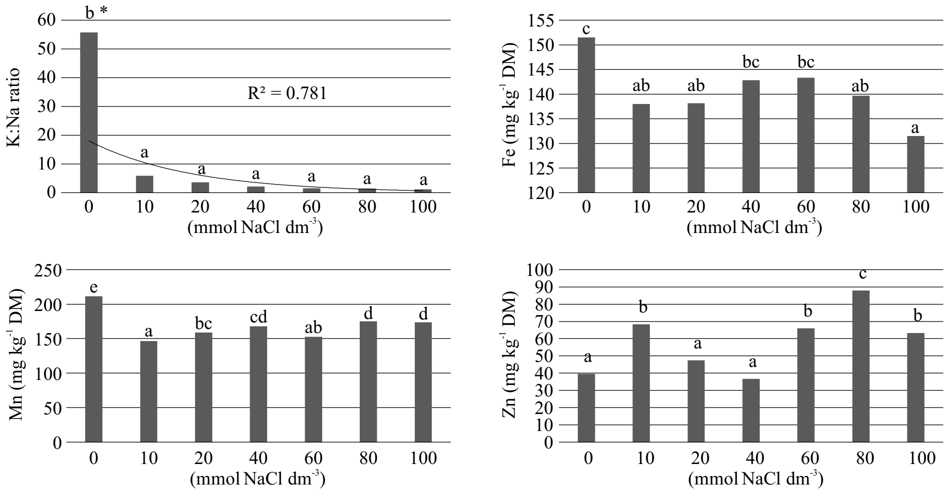

Fig. 2. The effect of increasing sodium chloride concentrations on the iron, manganese and zinc content of lettuce leaves and the K/Na ratio;
* means followed by the same letters do not differ significantly at p=0.05

of lettuce can range from 50.0 (Winsor, Adams 1987) to 838.8 mg kg^{-1} (Abou-Hadid et al. 1996). The results of the iron content of lettuce heads obtained in our study were higher than those obtained by Hakerlerler et al. (1992), Matraszek et al. (2002), or Gül et al. (2007).

The effect of sodium chloride on the manganese content in the aerial parts of lettuce was demonstrated (Figure 2). The highest significant manganese content was found in the control combination NaCl-I (211.3 mg kg^{-1}), while the lowest one was determined in the combinations NaCl-II and NaCl-V (146.5 and 152.8 mg kg^{-1}) with a sodium chloride content in the nutrient solution of 10 and 60 mmol L^{-1}, respectively. No significant differences in the manganese content were found in the combinations NaCl-VI and NaCl-VII (175.2 and 173.3 mg kg^{-1}). As in the case of iron, the range of the manganese content in studies by other authors is very wide, ranging from 22.0 (Hakerlerler et al. 1992) to 346.8 mg kg^{-1} (Kozik et al. 2008*a*).

The effect of sodium chloride on the zinc content of the aerial parts of lettuce was demonstrated (Fig. 2). The changes in the content of this micronutrient were multidirectional. The lowest zinc content was found in the combinations NaCl-I, NaCl-III and NaCl-IV (36.6 mg kg^{-1}), where the values obtained did not differ significantly, while the highest zinc content was determined in the combination NaCl-VI (87.8 mg kg^{-1}). No significant differences were found in the zinc content obtained in the NaCl-II and NaCl-V combinations (68.3 and 65.9 mg kg^{-1}, respectively). The zinc content determined in our study in the control combination and in the combinations with chloride content of 20 and 40 mmol dm^{-3} was lower than the results obtained by Abou-Hadid et al. (1996) and Gül et al. (2007).

From the data summarized in Table 5, it emerges that increasing concentrations of sodium chloride in the range 10 - 100 mmol dm^{-3} in the fertigation nutrient solution had an effect on decreasing the content of magnesium (20.97-46.82%), iron (5.39-13.20%) and manganese (17.11-30.67%) compared to the control combination, and calcium in the range 20-100 mmol dm^{-3} (2.72-23.62%) in lettuce leaves. At the same time, NaCl concentrations in the range 10-100 mmol dm^{-3} had the effect of increasing potassium (16.90-36.27%) and sodium content in the aerial parts of lettuce. The sodium content increased from 637.96 to 3,013.65% under the influence of the increasing NaCl content in the nutrient solution.

Table 5

Percentage increase or decrease in nutrient and sodium content relative to the content in the control combination (the content of an element in the control combination assumed to be 100%)

Nutrient	NaCl (mmol dm^{-3})						
	0	10	20	40	60	80	100
N	100	+9.52	-1.84	+9.15	-6.13	-9.53	+2.56
P	100	-11.33	-3.29	+5.85	+8.75	+17.96	+51.95
K	100	+23.82	+16.90	+27.46	+36.27	+35.42	+34.93
Ca	100	+4.88	-2.72	-16.52	-13.59	-23.62	-15.23
Mg	100	-20.97	-30.14	-39.93	-46.00	-46.82	-39.44
Na	100	+637.96	+1203.63	+1853.43	+2217.84	+2491.40	+3013.65
Fe	100	-8.91	-8.80	-5.72	-5.39	-7.81	-13.20
Mn	100	-30.67	-24.76	-20.58	-27.68	-17.11	-17.82
Zn	100	+72.83	+19.58	-7.52	+66.44	+121.70	+59.57

The effect of increasing concentrations of sodium chloride applied in the fertigation nutrient solution on the reduction of nitrate content in the aerial parts of the lettuce (Figure 3). In the combinations NaCl-I, NaCl-II, NaCl-III, where the concentration of sodium chloride did not exceed 20 mmol dm^{-3}, the highest nitrate contents were determined to be significant ± 3500 NO_3 kg^{-1} fresh weight. The highest determined nitrate content did not exceed the permissible nitrate levels in lettuce grown under covers in the period from 1 April to 30 September (4,000 NO_3 kg^{-1} fresh weight) – Maximum Levels for Nitrates in Foodstuffs (2011). A significant decrease in the nitrate content was determined at NaCl concentrations of 40 mmol dm^{-3} and 60 m mmol L^{-1}, where the results did not differ significantly from each other. The lowest nitrate content was found in NaCl-VI - and NaCl-VII combinations (1,626.3 and 1,616.0 NO_3 kg^{-1} fresh weight). According to Miceli et al. (2003) and Di Mola et al. (2017), high chloride content in water may reduce the absorption of nitrates and reduce their accumulation in leaves. The nitrate content of the aerial parts of lettuce can also be a varietal trait (Kappel et al. 2021).

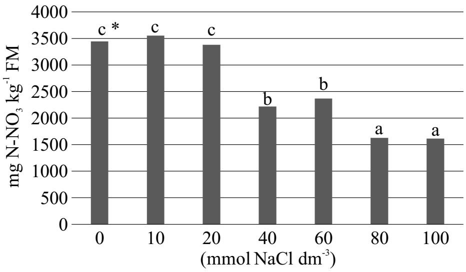

Fig. 3. The effect of increasing sodium chloride concentrations on the nitrate content of lettuce leaves;
* means followed by the same letters do not differ significantly at p=0.05

Butterhead lettuce is classified as a vegetable with high nitrate accumulation capacity, hence the use of chlorides is one way to reduce their content in lettuce heads (Liu, Shelp 1996).

CONCLUSIONS

The aim of this study was to determine the effect of salinity induced by increasing concentrations of sodium chloride in the fertigation nutrient solution on the yield, nutrient and nitrate content of the aerial parts of butterhead lettuce (*Lactuca sativa* L.). The induced salinity had a significant effect on increasing the dry matter content of the aerial parts of lettuce with a simultaneous decrease in the relative water potential (RWC), which is one of the methods to increase the post-harvest stability of plants. Salinity significantly modified the nutrient and sodium content of lettuce leaves, except nitrogen. A negative effect was the narrowing of the K: Na ratio. Increasing concentrations of sodium chloride in the fertigation nutrient solution had a significant effect on the reduction of the nitrate content in lettuce leaves in the concentration range exceeding 20 mmol dm^{-3}. The study confirms the possibility of using sodium chloride to reduce the nitrate content and to improve the post-harvest stability of plants by increasing the dry matter content in lettuce.

Author contributions

Conceptualization – B.M., M.B., J.R., K.M., methodology – B.M., M.B. statistical analysis – M.M., chemical analyses – E.M., J.R., investigation – M.B., B.M., J.R., K.M. data curation – B.M., M.B. writing – original draft preparation – M.B., B.M.; writing – review and editing – M.B., B.M. visualization – J.R., K.M. project administration – M.M. funding acquisition – M.B., B.M., J.R., K.M. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

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