Impact of structured water on yielding and quality of lettuce (*Lactuca sativa* L.) growth using hydroponic system

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Abstract: In this vegetative experiment a butter head lettuce was grown in plastic tunnel using hydroponic system. Nutrient solution was prepared with the use of two types of water for fertigation - tap water (control) and structured water. The use of structured water contributed to a significant increase in the marketable yield of lettuce compared to tap water This yield was higher average by 6.7%. Moreover, lettuce watered with structured water contained more photosynthetic pigments and two times more carotenoids compared to the control one. The vitamin C contained within lettuce leaves was higher when nutrient solution consisted of tap water – 28.45 mg·100 g^{-1} f.m., while nitrates contents were lower using structured water – 895.5 mg NO_3^-·kg^{-1} f.m. The lettuce leaves grown on the nutrient solution from the tap water contained significantly more calcium, iron and boron while on the structured water it contained more potassium, manganese and copper. The differences in the content of other mineral nutrients were statistically insignificant. The research confirmed the beneficial effect of structured water on the yield and the quality of butter head lettuce and revealed the possibility of using it for growing plants.

Key-Words: structured water; *Lactuca sativa* L.; butter head lettuce; yield, quality

1. Introduction

Plants are traditionally part of the human diet containing components which may exert various bioactive properties, therefore can improve human health [1]. It has been proven that proper amount of fruits and vegetables in diet can diminish the possibility of occurrence of cancer, cardiovascular and central nervous system diseases [2][3][4][5].

Lettuce is one of the most popular leaf vegetables worldwide, often applicable in sandwiches and various mix salads [6][7]. What is important, this vegetable has low amount of sodium and fat but is rich in beneficial fiber, iron, folate and vitamin C. It also poses a good source of various bioactive compounds, for instance anti-inflammatory, cholesterol-lowering and anti-diabetic [6].

Lettuce is widely grown on all continents, especially in temperate and subtropical regions. According to the FAO data, lettuce production was around 25 million tons in 2014 worldwide. The largest producers of lettuce in the world are China, USA, Italy and Spain. In Poland lettuce and parsley were grown on area of around 70 thousand hectares in 2016 and what is more, prospects for the development of production of leaf vegetables in the country are referred as very good [8]. Along with the increase in the income of Polish population, it is likely that the demand for already-made mixtures of leaf vegetables will increase, as in the countries in Western Europe and North America [8]. Lettuce can be grown in a variety of ways. The most advanced is hydropinic cultiwation technology, which ensure rapid plant growth and high yields. The root system is immesed in the nutrient medium from which it

takes water and nutrients. This ensures optimal hydration and nutrition of the plants. However, considering the costs of producing lettuce in soil and cultivation under cover [8], it is extremely important to seek the productive innovations in order to promote profitability of production and thus gain a competitive advantage. One of them is structured water, which increases crop yield and its quality [9] [10]. Such water is characterized by, inter alia, low viscosity. Thanks to this, it is easily intake by roots and transported through the plants tissue. Also, fertilizers dissolve more easily in it. These properties can be beneficial to plant growth and quality.

With regard to these reports, we have decided to take up the research on the assessment of the effect of structured water produced by Hydreset AG on yielding and crop quality of lettuce.

2. Materials and Methods

Experiment regarding lettuce cultivation was performed in the spring season 2020 at Lower Silesia, Poland in unheated plastic tunnel. It was established as one - factorial experiment in four replications, one contained 10 pots with the capacity 3.5 dm^3. Lettuce was grown from transplant using classical hydroponics - culture medium based on structured water (research test and culture medium based on tap water - control). Structured water was produced by Hydreset AG The lettuce root system was immersed in nutrient solution. Plants were grown in 3.5 L pots filled with nutrient solution. Nutrient solution was prepared with special fertilizers (0.75 g Peters Orange [in %]: N 16, P 5, K 25, Mg 3.5 + micro Fe 0.1, Mn 0.04, B 0.01, Zn 0.01, Cu 0.01, Mo 0.001 plus 0.6 ml calcium nitrate 15.5 N and 18.5 Ca mg, per liter) in order to obtain the standard concentration on nutrients in the lettuce medium. The average temperature was 22˚C during day and 16.5˚C at night. Lettuce was harvested after reaching commercial size about 200g. Nutrient solution parameters (pH, EC and temperature) were measured using Hach's probes (Intellical PHC101 for pH, temperature and Sension+EC5 for EC) and HQ40D multimeter. Measurement accuracy for temperature was 0.1˚C and for pH 0.01. Dry matter content was determined after drying the material to constant weight at 105˚C, while the content of chlorophyll a, b and carotenoids - spectrophotometrically on the Spectroquant Pharo 300 Merck apparatus. The nitrogen content in the plant material was determined using the Kjeldahl method on the Gerhard Vapo Dest 20 apparatus, and the remaining elements after mineralization of the material in the Milestone Ethos UP mineralizer using the ICP method. The results were subjected to statistical analysis and the least significant differences were calculated by Tukey's test at = 0.05.

3. Results and discussion

The table 1 shows the results of lettuce yield. As can be seen, the average total yield of lettuce was over 3 kg per square meter and did not differ significantly between the tested combinations, while the commercial yield of lettuce grown on the nutrient from structured water was significantly higher compared to the control the difference was +6.7%. In the control combination, the non-commercial yield was significantly higher compared to the structured water. In the average weight of a head of lettuce fertilized with structured water nutrient was significantly higher than the control. A similar tendency was observed in the case of fresh mass of the root system. Consequently, the average weight of the whole plant was significantly higher when the lettuce was grown on structured water medium - 227 g as compared to the control - 211.4 g.

Table 1. Fresh mass yield of butter head lettuce Omega F_1 cv. irrigated by different types of water

Yield and fresh mas	Lettuce grown on nutrient solution based on	
	structured water	tap water
Total yield [g·m^{-2}]	3345.5a	3251.3a
Marketable yield [g·m^{-2}]	3136.5a	2939.2b
Unmarketable yield [g·m^{-2}]	209.0b	312.1a
Head mass [g·plant^{-1}]	196.0a	184.3b
Roots mass [g·plant^{-1}]	30.9a	27.7b
Total fresh plant mass [g]	227.0a	211.4b

*means marked with the same letters do not differ significantly at α=0.05.

Nitrates are undesirable compounds accumulated in lettuce leaves. On the basis of the analyzes, presented in the Table 2, it was shown that the lettuce grown on the structured water nutrient solution contained 895.5 mg NO_3^- · kg^{-1} f.m. A similar situation occurred with vitamin C, but the differences were not statistically confirmed. Considering the photosynthesis dyes, significantly higher content of chlorophyll a and b was found in the lettuce grown on the nutrient solution with structured water. Even greater differences occurred in the case of carotenoids - the lettuce grown on a medium with structured water contained twice as much dyes as in the control.

Table 2. Quality of butter head lettuce Omega F_1 cv. watered by tap water and structured water

*means marked with the same letters do not differ significantly at α=0.05.

The dry matter content is very stable in plants, which was confirmed in the authors' own research, was presented in the table 3. The dry matter content in the roots and leaves of lettuce was not significantly differentiated by the type of water used to prepare the nutrients. However, the dry matter yield of roots and leaves per plant was significantly higher when the lettuce was grown on a structured water based nutrient solution. As a consequence, the dry mass yield per plant was significantly lower in the control with the use of tap water.

Table 3. Dry matter content and dry matter yield in butter head lettuce Omega F_1 cv.

Dry matter content or yield	Lettuce grown on nutrient solution based on	
	structured water	tap water
DM content in leaves [%]	5.00a	5.03a
DM content in roots [%]	10.34a	9.73a
Head dry mass [g·plant^{-1}]	9.80a	9.22b
Roots dry mass [g·plant^{-1}]	3.19a	2.69b
Yield DM per plant [g·plant^{-1}]	12.99a	11.91b

*means marked with the same letters do not differ significantly at α=0.05.

At the end of the cultivation, media analyzes were performed, on the basis of which it was found that the pH value based on structured water nutrient solution was lower and the EC higher than the control. The results are shown in the table 4. A similar situation occurred in the case of nitrates, sulphates and micronutrients. On the other hand, in the medium based on tap water, the concentration of calcium, potassium and magnesium was higher. In general, the differences in the chemical composition of the media were not statistically significant.

Table 4. Analysis of nutrient solutions in lettuce Omega F_1 cv.

Element, pH and EC	Nutrient solution based on	
	structured water	tap water
pH	6.87a	7.12b
EC [mS·cm^{-1}]	3.76a	3.56a
N-NO_3^-	415b	375a
N-NH_4^+	1.2a	0.9a
P	15.9a	12.3a
K	329.0a	340.2a
Ca	280.3a	290.1a
Mg	78.8a	83.1a
SO_4^-	189a	172a
Fe	1.89b	1.45a
Mn	0.87a	0.67a
Zn	0.56a	0.48a
Cu	0.35a	0.32a
B	1.34a	1.12a

Content in leaves	Lettuce grown on nutrient solution based on	
	structured water	tap water
Nitrates content [mg NO_3^-·kg^{-1} f.m.]	895.5a	956.6a
Vitamin C [mg·100 g^{-1} f.m.]	28.45a	25.21a
Chlorophyll a [mg·g^{-1} f.m.]	40.95a	31.46b
Chlorophyll b [mg·100 g^{-1} f.m.]	5.69a	5.70a
Chlorophyll a+b [mg·100 g^{-1} f.m.]	46.65a	37.16b
Carotenoids content [µg· 100 g^{-1} f.m.]	95.17a	47.13b

*means marked with the same letters do not differ significantly at α=0.05.

The type of water used to prepare the nutrients had a significant impact on the nutritional status of lettuce with some minerals, which is presented in the table 5. In the case of nitrogen, phosphorus and magnesium, the differences in their content were insignificant. Lettuce grown on the medium with structured water contained significantly more potassium while in the control contained more magnesium. The variation in the content of micronutrients was even greater. The lettuce grown on the nutrient solution of structured water contained significantly more manganese and copper. In the case of plants grown on the nutrient solution from tap water, they were characterized by a significantly higher content of iron and boron. The nutritional status of zinc did not depend on the type of water used to prepare the nutrient solution.

Table 5. Mineral content in lettuce Omega F_1 cv. watered by tap water and structured water

Element	Nutrient solution based on		Mean
	structured water	tap water	
[in % d.m.]			
N	4.85a	4.67a	4.76
P	0.47a	0.45a	0.46
K	8.51b	7.63a	8.07
Ca	1.39a	1.65b	1.52
Mg	0.51a	0.53a	0.52
[in mg· kg^{-1} d.m.]			
Fe	224a	234b	229
Mn	182b	176a	179
Zn	68.7a	66.5a	67.6
Cu	18.7b	15.5a	17.1
B	43.4a	48.2b	45.8

*means marked with the same letters do not differ significantly at α=0.05.

Application of structured water allowed to obtain significantly higher yielding in comparison to tap water. It confirms the information given by Ptok [11] who noticed and reported the positive effect of structured water on better growth lawn, radish sprout, Japanese mustard plant. As reported by Dubey et al. [9] structured water has been found to increase crop yield of e.g. winter wheat (28%), corn (17%), cucumber (32%) and tomato (32%). This positive results were confirmed in our research, where the increase in yield was 6.7%.

The nitrate content in our research did not exceed a thousand milligrams, which was very beneficial. Similar contents of nitrates were reported by Muramoto [12]. In turn, the results recorded for our own investigation did not fully confirm information reported by Favollo et al. [13], who noted much higher levels of this compound. On the other hand, our own research showed similar data for photosynthesis dyes content to reports by Favollo et al. [13]. The application of structured water was beneficial in increasing the content of carotenoids, which are antioxidant compounds. Similar results have been reported in studies of Stefanelli et al. [14] and Mahlangu [15]. The average nitrogen content was 4.76%. Similar nitrogen content in lettuce cultivated with the soilless method, amounting to 4.62% in spring and 4.80% in autumn was reported by Favollo et al. [13]. On the other hand, Wojciechowska et al. [16] reported lower nitrogen values in lettuce leaves in the range from 2.65% to 4.15%. Winsor and Adams [17] recorded that the optimal nitrogen content in lettuce ranges from 3.9% to 5.0% while Mills et al. [18] recommend 4.2-5.6%. A similar situation occurred for the other macronutrients and micronutrients - Kozik et al. [19] and Mills et al. [18]. This means that the value obtained in this study is within the optimal range recommended in the scientific literature by Wojciechowska et al. [16], White and Brown [20] and Delaide et al. [21]. The content of vitamin C in lettuce did not significantly depend on the type of water used to prepare the nutrients, but was higher than the content reported by Kowalczyk et al. [22]. Some relevant studies can be found in [23] and [24].

4. Conclusion

1. The use of structured water for preparing nutrient solution for hydroponically grown butter head lettuce resulted in a significant increase in the marketable yield as compared to tap water.
2. Lettuce watered with structured water contained more photosynthetic pigments and carotenoids compared to the control as well as less nitrates.
3. The use of two types of water for the preparation of the medium resulted in a significant changes in the concentration of minerals in the leaves of lettuce, but the content of elements remained at the levels typical for this species.
4. The research confirmed the beneficial effect of structured water on the yield, the quality of lettuce and the fact that it can be used for watering plants.

Summary

A significant increase in the commercial yield by 6.7% will allow an increase in profits from the cultivation of lettuce. Increasing the content of chlorophyll and reducing the concentration of nitrates in lettuce leaves is very beneficial for the quality of the crop and meets the criteria of the EU's Farm to Fork Strategy – for a fair, healthy and environmentally-friendly food system, which is at the heart of the European Green Deal.

References:

[1] Stintzing F.C., Carle R., Functional properties of anthocyanins and betalains in plants food, and in human nutrition, *Trends in Food Science & Technology*, Vol. 15, pp. 19-38, 2004.

[2] Baslam M., Fungi M., Goicoeche N., Arbuscular Mycorrhizal Fungi (AMF) Improved Growth and Nutritional Quality of Greenhouse-Grown Lettuce, *Journal of Agricultural and Food Chemistry*, Vol. 59, pp. 5504-5515, 2011.

[3] Block G., Patterson B., Subar A., Fruit, Vegetables and Cancer Prevention: A Review of the Epidemiological Evidence, *Nutrition and Cancer*, Vol. 18, pp. 1-29, 1992.

[4] Streinmetz K.A., Potter J.D., Vegetables, fruits and cancer prevention: A review, *Journal of the American Dietetic Association*, Vol. 96, pp. 1027-1039, 1996.

[5] La Vecchia C., Altieri A., Tavani A., Vegetables, fruit, antioxidants and cancer: a review of Italian studies, *European Journal of Nutrition*, Vol. 40, pp. 261-267, 2001.

[6] Kim M.J., Moon J., Tou J.C., Mou B., Waterland N.C., Nutritional value, bioactive compounds and health benefits of lettuce (*Lactuca sativa* L.), *Journal of Food Composition and Analysis*, Vol. 49, pp. 19-34, 2016.

[7] Mou B., Nutrient Content of Lettuce and its Improvement, *Current Nutrition & Food Science*, Vol. 5, pp. 1242-248, 2009.

[8] Zmarlicki K., Brzozowski P., Rynek sałaty masłowej i lodowej oraz pakowanych gotowych do spożycia mieszanek sałat, *Instytut ogrodnictwa*, pp. 1-13, 2017.

[9] Dubey P.K., Neethu T.M., Kaswala A.R., Structured water: an exciting new field in water science, *International Journal of Agriculture Sciences*, Vol. 10, pp. 6346-6347, 2018.

[10] Manoj K.G., Kailash C.J., Hemraj J., Pramod K., A review: structured water technology: its effect on productivity of agricultural crops, *International Journal of Chemical Studies*, Vol. 6, pp. 3248-3253, 2018.

[11] Ptok F.L., *Alternative Irrigation Methods; Structured Water in the context of a Growing Global Food Crisis due to Water Shortages*, University of Colorado at Boulder, pp. 1-49, 2014.

[12] Muramoto J., *Comparison of Nitrate Content in Leafy Vegetables from Organic and Conventional Farms in California. Revised Version*, University of California, Santa Cruz, pp. 1-69, 1999.

[13] Fallovo C., Rouphael Y., Rea E., Battistelli A., Colla G., Nutrient solution concentration and growing season affect yield and quality of *Lactuca sativa* L. var. *acephala* in floating raft culture, *Journal of the Science of Food and Agriculture*, Vol. 89, pp. 1682-1689, 2009.

[14] Stefanelli D., Winkler S., Jones R., Reduced nitrogen availability during growth improves quality in red oak lettuce leaves by minimizing nitrate content, and increasing antioxidant capacity and leaf mineral content, *Agricultural Sciences*, Vol. 2, pp. 477-486, 2011.

[15] Mahlangu R.I.S,. Maboko M.M., Sivakumar D., Soundy P., Jifon J., Lettuce (*Lactuca sativa* L.) Growth, yield and quality response to nitrogen fertilization in a non-circulating hydroponic system, *Journal of Plant Nutrition*, Vol. 39, pp. 1766-1775, 2016.

[16] Wojciechowska E., Gołcz A., Kozik E., Mieloszyk E., Effect of differentiated iron nutrition on the content of macronutrients in leaves of lettuce (*Lactuca sativa* L. var. *capitata* L.) cultivated in peat substrate, *Journal of Elementology*, Vol. 24, pp. 293-304, 2019.

[17] Winsor G., Adams, P., *Glasshouse crops. Volume 3. Diagnosis of mineral disorders in plants*, Her Majesty's Stationery Office, 1987.

[18] Mills H.A., Jones J.B., Benton J., *Plant analysis handbook II*, 1996.

[19] Kozik E., Tyksiński W., Komosa A., Effect of chelated and mineral forms of micronutrients on their content in leaves and the yield of lettuce, *Acta Scientiarum Polonorum*, Vol. 8, pp. 37-43, 2009.

[20] White P.J., Brown P.H., Plant nutrition for sustainable development and global health, *Annals of Botany*, Vol. 105, 1073-1080, 2010.

[21] Delaide B., Goddek S., Gott J., Soyeurt H., Jijakli H.M., Lettuce (*Lactuca sativa* L. var. *Sucrine*). Growth performance in complemented aquaponic solution outperforms hydroponics, *Water*, Vol. 8, pp. 1-11, 2017.

[22] Kowalczyk K., Zielony T., Grajewski M., Effect of Aminoplant and Asashi on yield and quality off lettuce grown on rockwool, *Biostimulators in Modern Agriculture. Vegetable Crops*, Vol. 2, pp. 15-24, 2008.

[23] Triani I. G.A.L, Soemarno, B. T. Rahardjo, E. Zubaidah, The influence of treatment variation of plant promoting pacteria in cultivation on the quality of chinese cabbage (*Brassica rapa* L. Ssp. *pekinensis*), *International journal of biology and biomedical engineering*, Vol. 14, pp. 114-127, 2020.

[24] Hariyadi , The Response of Eggplant (*Solanum Melongena* L.) Growth planted on raised-bog peatland towards the provision of chicken dung and swallow guano, *International journal of biology and biomedical engineering*, Vol. 14, pp. 191-196, 2020.