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Accumulation of Sodium and Iron in *Solanum tuberosum* under Care and Foliar Feeding

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ABSTRACT

Minerals present in potato tubers are of particular interest due to the value of this crop as a food crop. The purpose of the three-year study was to evaluate the effects of herbicide treatment and foliar feeding with organic biostimulants on the content and uptake of sodium and iron in tubers of two varieties of edible potato (Oberon and Malaga). The Malaga variety accumulated significantly more sodium and iron than the Oberon variety. On the other hand, higher tuber yield uptake of these components was recorded in the Oberon variety. Treatment with a weedkiller and a stimulant fertilizer increased the content and uptake of sodium and iron compared to tubers harvested from the control object, and the most favorable effect was shown by the mixture of the weedkiller with the biostimulant Agro-Sorb Folium. It is also worth noting that weather conditions had a significant effect on mineral content and uptake.

Keywords: sodium, iron, mineral fertiliser.

INTRODUCTION

Potato (*Solanum tuberosum* L.) one of the most important plants, serving as a major dietary staple in many countries due to its mineral content (Singh et al., 2021, Karan 2023). Potato tubers are an important item in the diet of the average Pole, due to their high bioavailability of minerals (Burligame et al., 2009, White et al., 2009, Alamar et al., 2017). Minerals are elements remaining after mineralization of tissues, i.e., getting rid of water and organic matter, whose daily recommended intake exceeds 100 mg per person, and whose content depends on the concentration of these substances in the soil, groundwater and fertilizers used. They mainly play a building role or are components of body fluids. Prominent among them are: sodium which is the most important and dominant cation in the body's extracellular fluid. It regulates the volume and systemic distribution of water in the body, and ensures the maintenance of adequate osmotic pressure of body fluids, which protects the body from excessive water loss (Jarosz et al., 2020). Processed potato products are typically categorized as high fat and sodium foods (Furrer et al., 2018). Micronutrients in the body are found in trace amounts. They have regulatory functions, are included in enzymes, hormones or vitamins. These include iron, copper, manganese, iodine, cobalt, zinc and fluoride, as well as selenium. Today, the most widespread nutritional problem in the world, especially in women and children, is micronutrient malnutrition, known as hidden hunger (Kromann et al., 2017). Despite their low content, they are essential for the proper functioning of the body (Orlicz-Szczęsna et al., 2011). It is estimated that more than 60% of the world's population is deficient in dietary iron (Fe) (Freire et al., 2013, Kromann et al., 2017). Iron is part of enzymes and metalloproteinic compounds involved in oxidation-reduction processes. It influences many aspects of the human immune system and is crucial to the function of more than 300 biological enzymes. Fe occurs in the body in two compartments, storage and

functional. The vast majority of iron is found in the blood mainly with hemoglobin, whose function is to transport oxygen from the lungs to the tissues (Sheftel et al., 2012, Sherry et al., 2001). Iron stores, necessary for tissue and organ function, are in constant internal circulation (Rocha et al., 2019). The micronutrient (Fe) is mostly recovered from destroyed red blood cells, while 20% of the resource is supplied by food (Gallego-Narbon et al., 2019). An innovation for the environment is becoming the use of foliar feeding with natural plant biostimulants, which improve plant growth, crop yield and quality, nutrient use efficiency, and relieve stress (Rouphael and Colla 2020). Increasingly, these products are a complement to, as well as a sustainable alternative to, synthetic chemicals (fertilizers and pesticides). In addition, their use benefits human health, the environment, biodiversity and the economy (Malik et al., 2021).

Du Jardin (2015) research confirms the beneficial effects of biostimulants that were applied independently of other crop protection products on mineral content. There are few scientific reports on foliar application of biostimulants with herbicide on mineral content in potato tubers. Therefore, it is extremely important to study the effect of different treatments applied to the plantation and the impact of climatic conditions on tuber quality parameters.

Research hypothesis: assume that the content and uptake of sodium and iron depend on the cultivated varieties, foliar feeding with biostimulants and climatic conditions.

The aim of the study was to evaluate herbicide treatment and foliar feeding with biostimulants: PlonoStart, Aminoplant, Agro-Sorb Folium on the content and uptake of sodium and iron in edible potato tubers comparing to the control variant under different climatic conditions.

MATERIAL AND METHODS

The three-year field experiment was conducted as a two-factor experiment (I – varieties, II – treatments applied) in triplicate, using the split-plot method. Before the start of the experiment, soil samples were taken for analysis every year. Cultivation and agrotechnical treatments were also carried out in accordance with the principles of good agricultural practice. Potatoes were planted by hand in the third decade of April and harvested in the first decade of September. Sodium and iron content was determined by conducting chemical analyses in the dry weight of the tubers, in triplicate. Dry samples were subjected to acid digestion and heating in a microwave mineralization system. The mineralized samples were diluted, and the resulting solution was analyzed using an ICP-OES spectrometer.

The three-year meteorological conditions are shown in Figures 1 and 2, and the K-factor values were determined and shown in Figure 3. The content and absorption of selected minerals were statistically analyzed using analysis of variance. The significance of the sources of variation was evaluated using the Fisher-Snedecor "F" test, and the significance of differences between the compared means at the significance level of $p \leq 0.05$ was tested using Tukey's multiple ranges. All statistical calculations were carried out using a proprietary algorithm implemented in Excel. Significantly different values are marked with different letters above the bars at $p \leq 0.05$

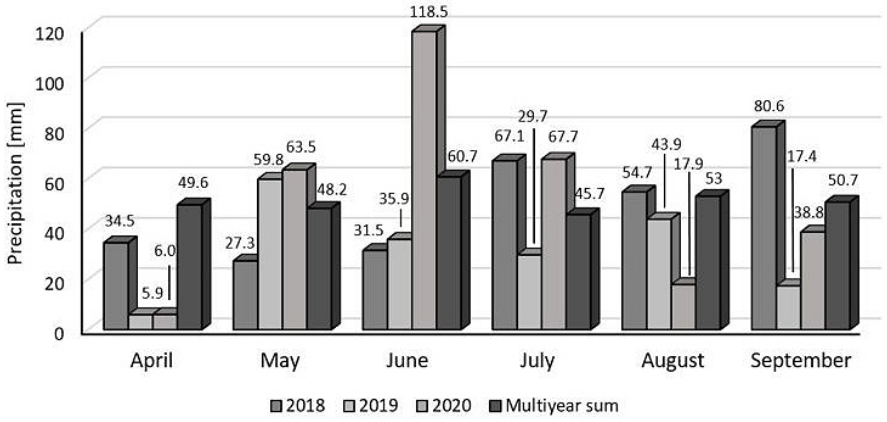

Figure 1. Mean precipitation comparison with the mean multiyear

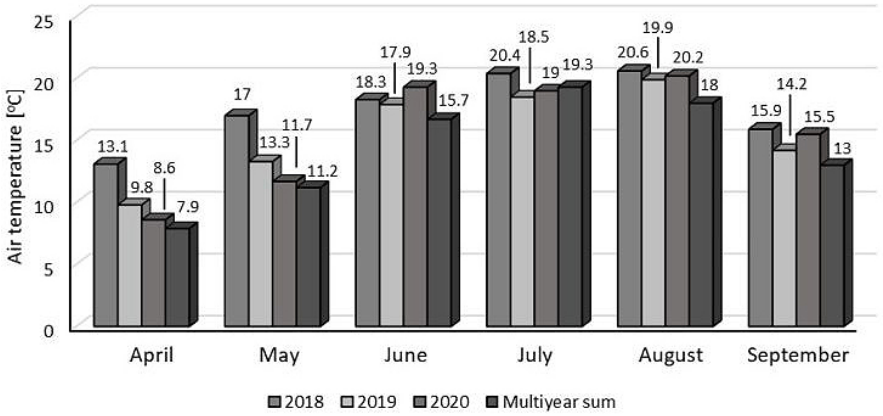

Figure 2. Mean air temperature comparison with the mean multiyear

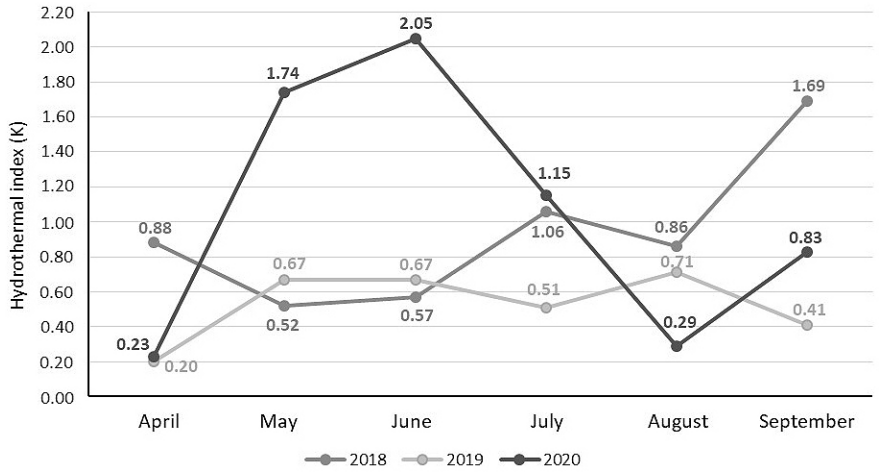

Figure 3. Index (K)

RESULTS AND DISCUSSION

Content and uptake with tuber yield of sodium

Potato is one of the most accessible crops in the world, for reasons of both price and its high nutrient content (Devaux et al., 2021). One of the most important nutrients is sodium (Na). It is the predominant cation in the body's extracellular fluid. Sodium also plays an important role in nerve conduction (Farag 2023), maintaining acid-base balance (Ali 2023) and supporting muscle function, including the heart. However, controlling sodium intake is key to maintaining a healthy body, and being aware of the amount of salt you consume can help you take better care of your own health (Bernal 2023). In our study, sodium concentration in tubers averaged 0.75 g·kg^{-1} D.M. but ranged from 0.61 to 0.88 g·kg^{-1} D.M. and depended significantly on the cultivar grown, application of herbicide and biostimulants, and moisture and thermal conditions prevailing during the potato growing season. Of the cultivated varieties, the Malaga variety had a higher concentration of this component than Oberon (Figure 4).

A significant effect of genetic traits of varieties on sodium content was shown by Gunko

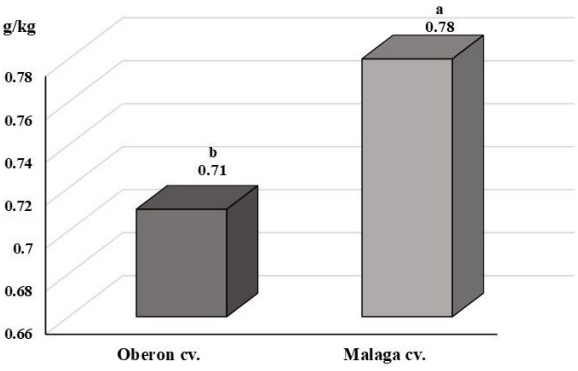

Figure 4. Concentration of Na in the varieties

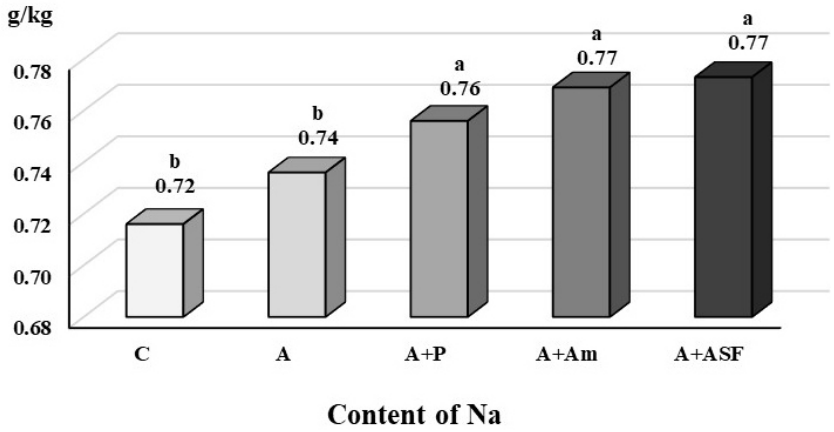

Figure 5. Effect of applied treatments on Na concentration

(2023). Subramanian et al. (2011) on the other hand, studied Na content in flesh/flesh ranging from 0.66 to 0.85, and in skin/skin from 1.18 to 1.61 g·kg^{-1} D.M. Showed concentrations that macronutrients were higher in skin than in flesh of potato tubers. All of the biostimulants used in the experiment, such as PlonoStart, Aminoplant and Agro-Sorb Folium, significantly increased the sodium content of the tubers compared to the control plot, which was mechanically weeded, and the plot where herbicide was applied (Figure 5).

Agro-Sorb Folium showed a particularly favorable effect on this trait. In contrast, research by Malik et al. (2021) suggests that the application of biostimulants led to changes in sodium concentration compared to the control object. Analysis in our experiment showed that tubers harvested in the dry year of 2018 had the highest sodium content, while significantly lower values were recorded in the other growing seasons (Figure 6). These results confirm the influence of weather conditions on sodium content, which is in line with the studies of Gunko (2023).

The uptake of mineral nutrients by potato tubers depends on their content and the dry weight of the crop. The process of sodium uptake from the potato tuber yield was significantly shaped by experimental factors and weather conditions during vegetation, as illustrated in Figures 7, 8 and 9.

The Oberon variety was characterized by higher sodium uptake per unit area compared to the Malaga variety, mainly due to different yields (the total yield of the Oberon variety was 39.0 t·ha^{-1}, while the Malaga variety reached 33.1 t·ha^{-1}) (Figure 7). The highest sodium uptake was recorded after application of the herbicide and biostimulant Agro-Sorb Folium, where it amounted to 6.36 kg/ha and was significantly higher compared to the control object (Figure 8). Sodium intake varied from one study year to the next, reaching the highest value in the dry year of 2018 (6.62 kg·ha^{-1}), while it was significantly lower in the other growing seasons (5.57 and 4.06, respectively) (Figure 9). Analysis of variance revealed an interaction between varieties and years of study, indicating a differential

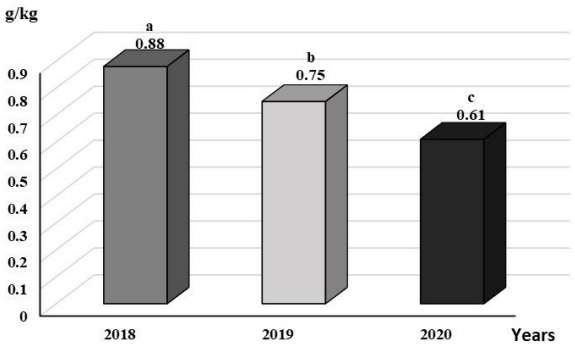

Figure 6. Effect of years of research on Na content in potato tubers

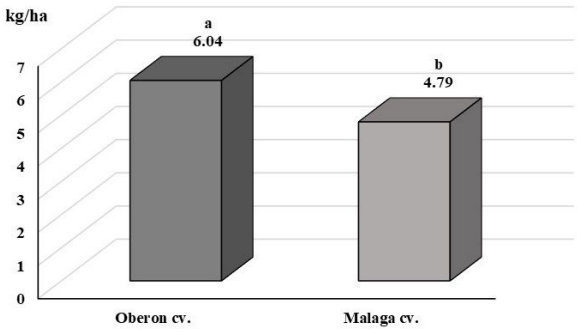

Figure 7. Effect of varieties on Na uptake by potato tubers

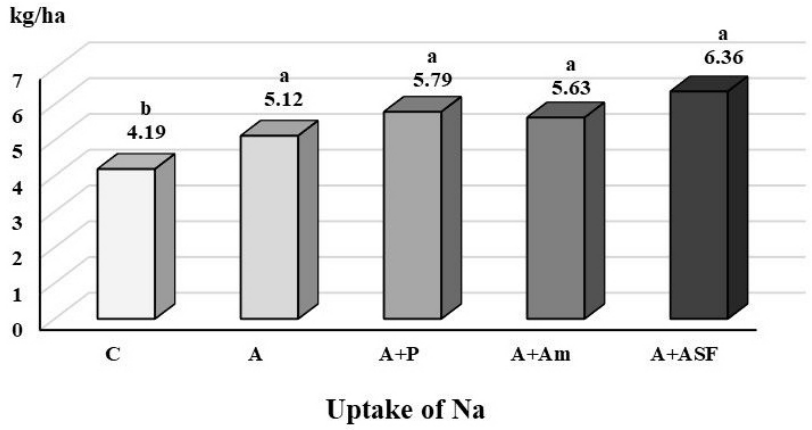

Figure 8. Uptake of Na by potato tubers

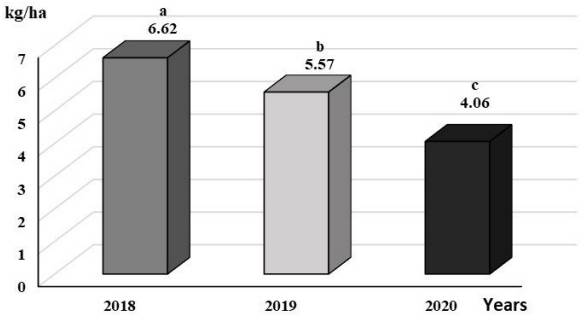

Figure 9. Effect of years on Na uptake of potato tubers

response of varieties to climatic conditions in terms of sodium uptake by tubers (Figure 10).

Content and uptake with tuber yield of iron

Iron (Fe) participates in the proper functioning of the circulatory, nervous and cardiovascular systems and is involved in metabolic processes due to its presence in the composition of enzymes, and is a component of myoglobin found in muscles, (Rocha et al., 2019). Maintaining adequate iron levels in organisms is essential for oxygen transport, energy transport and storage, protein synthesis, and other processes that include metabolic functions related to growth, immunity, muscle activity, bone strength and the nervous system (Blanco-Rojo and Vaquero 2019). Iron deficiency can lead to anemia, bone resorption, changes in the immune system and limitations in physical activity (Moretti 2017). Iron deficiency anemia affects about one-third of the world's population, and about half of cases are caused by dietary iron deficiency (Rocha et al., 2019).

In our study, tubers accumulated an average of 50.35 mg·kg^{-1} of iron, but the amount ranged from 47.83 to 51.84 mg·kg^{-1} D.M. Vaitkevičienė (2019) reported similar contents of this element in potatoes. In contrast, in the Burgos et al. (2007) study, Fe concentrations ranged from 17.13 to 164.83 mg·kg^{-1} D.M. In the study by Gunko et

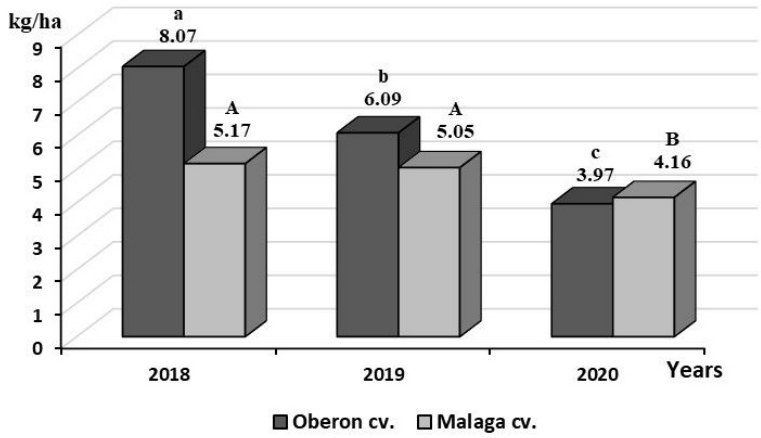

Figure 10. Sodium uptake by potato cultivars in the years of research

al. (2023) iron was also the main micronutrient. The content and uptake of iron with tuber yield depended significantly on the cultivated varieties, application of herbicide and biostimulants and moisture-thermal conditions in the years of the study. The Malaga variety accumulated higher amounts of iron in tubers compared to the Oberon variety (Figure 11); however, higher uptake of this micronutrient was observed in the Oberon variety, which produced a higher yield (Figure 12). The

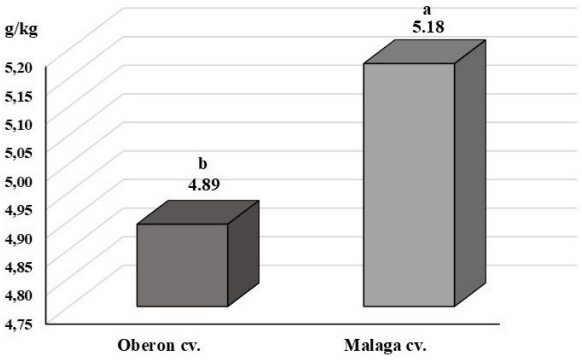

Figure 11. Fe content in cultivated varieties

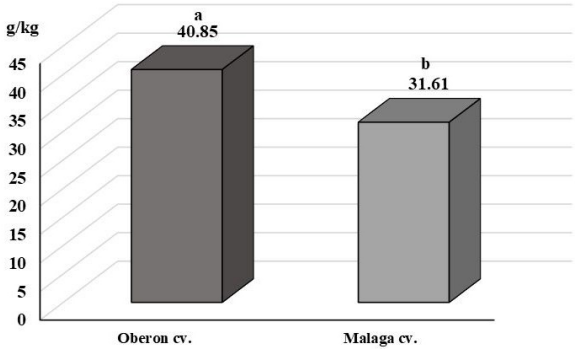

Figure 12. Effect of varieties on Fe uptake by potato

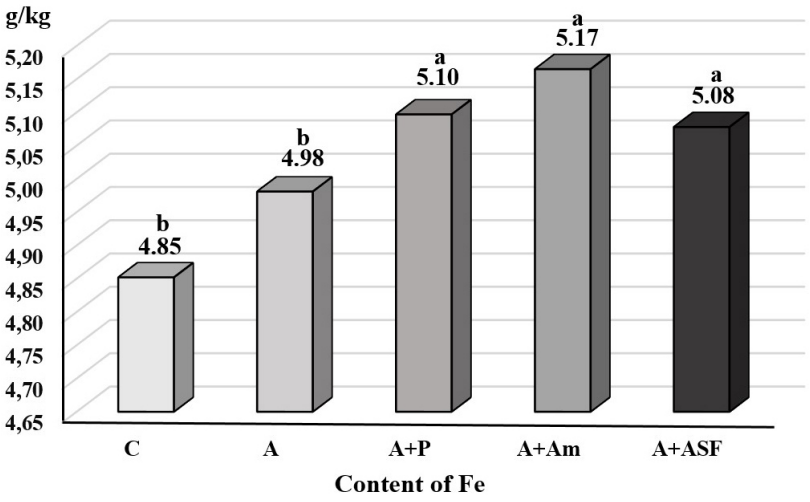

Figure 13. Effect of applied treatments on Fe concentration

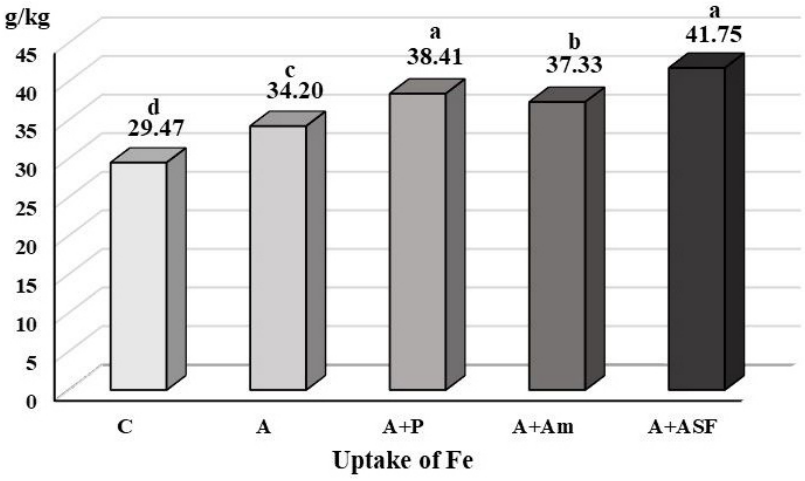

Figure 14. Uptake Fe by potato tubers

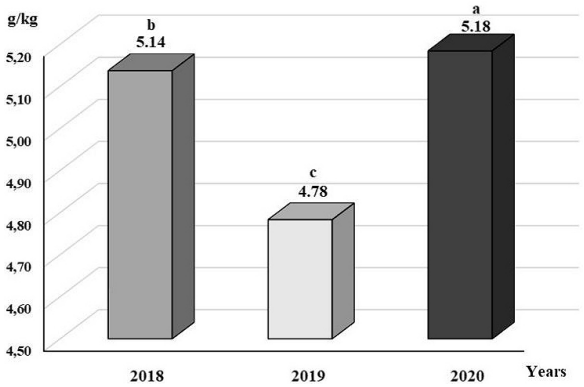

Figure 15. Effect of years of research on Fe content in potato tubers

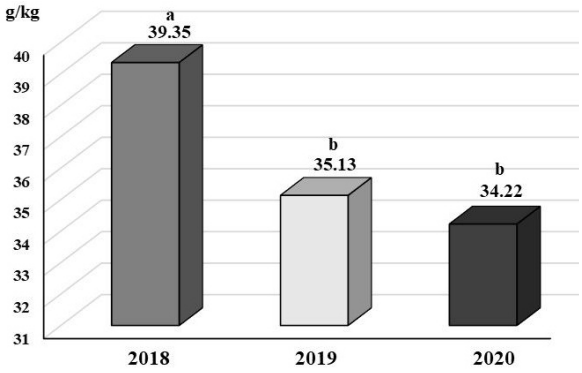

Figure 16. Effect of years of research on Fe uptake in potato tubers

biostimulants used in the experiment significantly increased both the iron content and its uptake by the potato crop, compared to the control facility (Figures 13, 14).

Singh (2022) pointed out the dependence of iron content on plant variety. In a study Mahmouds et al. (2019), the Fe content was higher in potato plants sprayed with plant growth stimulants compared to control plants. Foliar spraying with an amino acid mixture (2.5 $cm^3 \cdot dm^{-1}$) or chitosan (5.0 $cm^3 \cdot dm^{-1}$) was the most effective treatment for improving in iron content and iron uptake with yield. In our experiment, weather conditions during the study years influenced iron accumulation and uptake by the tuber crop. Tubers harvested in the dry 2020 were characterized by the highest iron content, while significantly lower values were found in the other growing seasons (Figures 15, 16). Mahmouds et al. 2019 showed that tubers with the highest Fe content were harvested in the warm and low humidity season.

Nutritional value of potato

Research and calculations by Babaali et al. (2020) showed that Na from processed and unprocessed foods accounted for more than 100% of the required level in the total diet and ranged from 2100 $mg \cdot d^{-1}$ in Cameroon, 2150–3603 $mg \cdot d^{-1}$ in New Zealand, 2300 $mg \cdot d^{-1}$ in France, 2843 $mg \cdot d^{-1}$ in Iran to 3812 $mg \cdot d^{-1}$ in Italy. In our study, consumption of 100 grams of potatoes met the daily requirement for this ingredient at 1%, while a Pole consuming 240 grams of tubers per day meets the sodium requirement at 2.4%. Wang et al. (2020) found that high dietary sodium intake is a potential risk factor for cardiovascular disease and kidney disease, and that the main sources of salt are processed foods and convenience foods, as well as salt added during food preparation and cooking and at the table. Salt is a combination of sodium and chlorine, and table salt contains about 40% sodium by weight.

The iron content of potato tubers treated with biostimulants averaged 50.35 $mg \cdot kg^{-1}$ DM, and the daily standard for this element, according to the recommendations of the Academy of Food Science and Nutrition in the US, is 8 mg. Consumption of 100 grams of potatoes covers the daily requirement for iron at about 12% of the daily requirement.

CONCLUSIONS

The content and uptake of sodium (Na) and iron (Fe) with tuber yield depended significantly on the varieties grown, the application of herbicide and organic fertilizers: PlonoStart, Aminoplant, Agro-Sorb Folium compared to the control variant under varying climatic conditions. A higher concentration (Na and Fe) was found in tubers of Malaga variety than in Oberon variety, while a higher uptake with tuber yield of the determined components (Na, Fe) was recorded in Oberon variety, which was due to the higher yield of this variety. The applied mixtures of herbicide with biostimulants increased the content and uptake of (Na, Fe) compared to tubers harvested from the control object. The mixture of herbicide with biostimulant Agro-Sorb Folium showed the most favorable effect. The content of labeled mineral nutrients was significantly shaped by weather conditions in the years of the study, and only an upward trend was noted after the application of biostimulants.

Conclusions of the study suggest that the use of biostimulants in potato cultivation may contribute to increasing the mineral content of tubers, which may have a beneficial effect on covering the daily macro- and micronutrient requirements of the human body.

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