JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2024, 25(2), 190–202
https://doi.org/10.12911/22998993/176248
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Received: 2023.11.13
Accepted: 2023.12.02
Published: 2024.01.01

Effect of Biostimulants on the Content and Uptake of Selected Macronutrients in Jerusalem Artichoke Tubers (*Helianthus tuberosus* L.)

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ABSTRACT

The aim of the study was to determine the effect of biostimulants on the content and uptake of selected macronutrients (phosphorus, calcium, magnesium and potassium) in tubers of two varieties of Jerusalem artichoke. The experiment was conducted in a two-factor arrangement (split-plot) with three replications in 2021–2022 at an individual farm in Międzyrzec Podlaski, Poland. The effect of two factors was studied. The first-order factor was two varieties of Helianthus tuberosus: 'Albik' and 'Rubik', and the second-order variants of biostimulant application: Kaishi, Maral, Nutrigreen AD, and Vanadoo. The effectiveness of the application of individual biostimulants in the cultivation of two varieties of Jerusalem artichoke was compared with the control object (without the application of biostimulants). The variety 'Rubik' accumulated the most phosphorus, calcium and potassium and the variety 'Albik' accumulated magnesium. Biostimulants increased the concentration of phosphorus, magnesium and calcium, and decreased potassium compared to topinambur tubers harvested from the control object. Macronutrient content in tubers of the tested varieties. Helianthus tuberosus can be ranked in descending order: potassium > phosphorus > calcium> magnesium. The cultivar 'Albik' was characterized by the highest macro-nutrient uptake capacity. The application of biostimulants increased the uptake of phosphorus, magnesium, calcium and potassium compared to the control. The content and uptake of phosphorus, calcium, magnesium and potassium were influenced by climatic conditions.

Keywords: varieties, Jerusalem artichoke, minerals.

INTRODUCTION

Helianthus tuberosus L. (known as Jerusalem artichoke or Jerusalem artichoke JA) is commonly found in several varieties, differing in morphology such as shape, color and tuber size. The quality of JA tubers is primarily related to chemical composition (Sawicka et al., 2021). Jerusalem artichoke tubers, depending on the variety, consist of 80% water, about 15% carbohydrates and 1-2% protein (Stanley et al., 2007). Jerusalem artichoke is a source of inulin (whose values range from 8-21% of dry weight (Van Loo et al. 1995). Low in the tubers of *Helianthus tuberosus* L. are starch and fats, which are found only in trace amounts (Whitney and Rolfes, 1999). Jerusalem artichoke tubers are distinguished by their high macronutrient content of about 3.4–8.4% by dry weight (Harmankayaet et al., 2012). Macronutrients such as phosphorus, calcium, magnesium and potassium are components taken up by plants in relatively large quantities at various stages of development. These elements mainly have building and physiological functions in the plant, as well as determining dietary value. Applied biostimulants have a positive effect on macronutrient content and uptake, plant growth and yield, and increased resistance to biotic and abiotic stresses (Shahrajabian et al., 2021; Del Buono, 2021, De Vries et al., 2020, Fiorentino et al., 2018, Drobek et al., 2019). The use of biostimulants can be considered an effective and sustainable crop supplementation to mitigate environmental problems associated with over-fertilization (Bulgari et al., 2014; Halpern, 2015).

Research hypothesis: assume that the content of macronutrients depends on the cultivated varieties and applied variants of biostimulants, as well as on climatic conditions. The aim of the study was to determine the content and uptake of selected mineral nutrients in two varieties of Jerusalem artichoke under the application of biostimulants, comparing to the control variant under varying climatic conditions.

MATERIALS AND METHODS

The experiment was conducted in the central-eastern part of Poland (Międzyrzec Podlaski) location (51°59' N, 22°47' E) in a two-factor arrangement (split-plot) with three repetitions. In the years from 2021 to 2022 of conducting the experiment there were varied weather conditions (Table 1). The variables analyzed were 'Albik' and 'Rubik' varieties and four biostimulant variants: Kaishi, Maral, Nutrigreen AD, Vanadoo and a control object without biostimulant application. The varieties under study were bred at the Plant Breeding and Acclimatization Institute in Radzikow, listed in the National Register of Varieties in Poland in 1997. The cultivar 'Albik' is characterized by oval oblong tubers, creamy skin and white flesh, while the cultivar 'Rubik' is characterized by pale red tubers with an even egg shape and white flesh (Sawicka et al., 2021). Tubers were planted on Haplic Luvisol loamy sand in the first decade of April at a spacing of 30 x 65 cm, in plots of 25 m2, the preceding crop being triticale. Topinambur each year was fertilized with organic fertilizers. Soil samples were taken from each plot for chemical analysis. Analyses were performed at the Regional Research Center EKO-AGRO-TECH of John Paul II University in Biała Podlaska. The harvested tubers were dried at 105°C until they reached dry weight using the dryer-weight method. Then, the test material was mixed thoroughly and transferred quantitatively to a Teflon vessel. 6 ml of 65% HNO3 and 1 ml of 36% HCl were added to mineralize the sample. The sample was heated in a microwave oven (Anton Paar) at 110 °C for 5 min, 220 °C for 20 min and 70 °C for 25 min. The contents of the digestion vessels were filtered on 150 mm diameter quality strainers (Chemland) into phalcones, where the solution was then diluted to 50 ml with distilled water. The resulting dilution was analyzed using an ICP-OES spectrometer (Spectroblue) (LST EN 15510:2017). Macronutrients (P, Ca, Mg and K) were quantified by reference to the calibration curve of a multi-element standard solution (VHG, Standard, LGC) in its linear range. The results of the study were statistically tested using variance analysis. The significance of the sources of variation was tested with the 'F' Fisher-Snedecor test, and the assessment of the significance of differences with the significance level *P ≤ 0.05* between the compared averages using the multiple Tukey ranges. Statistical calculations were made based on a proprietary algorithm written in Excel in accordance with a mathematical model (Trętowski and Wójcik 1991).

ble 1. Weather conditions for 2021 to 2022

Years	Months								IV-XI
	IV	V	VI	VII	VIII	IX	X	XI	
	Air temperature (°C)								
2021	6.6	12.4	20.4	22.7	17.1	12.9	12.0	5.0	13.63
2022	5.2	13.6	19.9	19.3	21.0	11.7	12.8	7.5	13.87
Multiyear mean 1987-2000	7.8	12.5	17.2	19.2	18.5	13.1	7.9	4.0	14.7
	Rainfall (mm)								
2021	42.0	29.5	33.8	50.0	95.4	42.1	52.7	34.0	379.5
2022	31.5	31.1	26.5	95.7	39.3	94.3	73.5	13.6	405.5
Multiyear sum (1987-2000)	38.6	44.1	52.4	49.8	43.0	47.3	24.3	20.2	275.2
	Sielianinov's hydrothermic coefficients								
2021	2.13	0.79	0.55	0.73	1.86	1.09	1.45	1.42	1.25
2022	1.60	2.30	1.80	1.60	0.30	2.70	1.91	0.61	1.60

RESULTS AND DISCUSSION

Content and uptake of phosphorus in JA

Phosphorus is involved in all vital processes taking place in the plant, it is necessary for the proper course of photosynthesis, respiration, metabolism, and especially in the formation of proteins and spare substances (Grzebisz and Szczepaniak, 2003; Fotyma, 2011). P deficiency causes serious disturbances in the vital functions of plants, resulting in the weakening of the development and functioning of various organs, especially the root system. Phosphorus content in 'Albik' was 3.249 g kg1 dry weight and 3.370 kg ha^{-1} in 'Rubik' for the control object (Fig.1). Thus, it can be assessed that the mineral content varies slightly depending on the variety of Jerusalem artichoke. Sawicka et al, (2021) in their study found that phosphorus content varied for varieties but the variety 'Albik' was more abundant in P than 'Rubik'. The average concentration of phosphorus in Jerusalem artichoke tubers is reported at 3892 mg kg^{-1} dry weight (Danilčenko et al., 2013; USDA, 2018). The application of biostimulant variants increased the phosphorus content of Jerusalem artichoke compared to the control object. The biostimulants caused JA plants to be well nourished and resistant to stresses, and showed greater tolerance to water shortages (Rouphael and Colla, 2020). The biostimulant Maral had the greatest effect on increasing the content of the element, with 21.91% higher P content observed in the Albik variety and 16.20% in the Rubik variety compared to the control object. On the other hand, the smallest difference in the content of this element was observed with the biostimulants Vanadoo in the Albik cultivar (P content higher by 10.62% compared to the control object) and Nutrigreen AD in the Rubik cultivar (phosphorus content higher by only 7.77% compared to the control object) (Fig. 1). Figure 2 shows the phosphorus content of the Jerusalem artichoke tuber by year of study. The content of this element in 2022 in both the control object and after the application of each type of biostimulant is higher than in 2021. The indicated results were influenced by weather conditions in the years in question (Table 1). The highest amount of phosphorus was recorded in the warmest and least humid 2022 year of the study, which was optimal according to the Sielianinov coefficient.

Interestingly, the phosphorus content of the control site increased by 13.58% in 2022 compared to the previous year. A similar increase in the content of the element in subsequent years can be observed in the variant with the Kaishi biostimulant (an increase of 13.88%), however, with the application of Vanadoo, the P content in subsequent years differed by only 2.58%. It is noteworthy that only the application of the Kaishi biostimulant showed strongly similar effects on the element content – P concentration higher by 11.10% compared to the control object in 2021

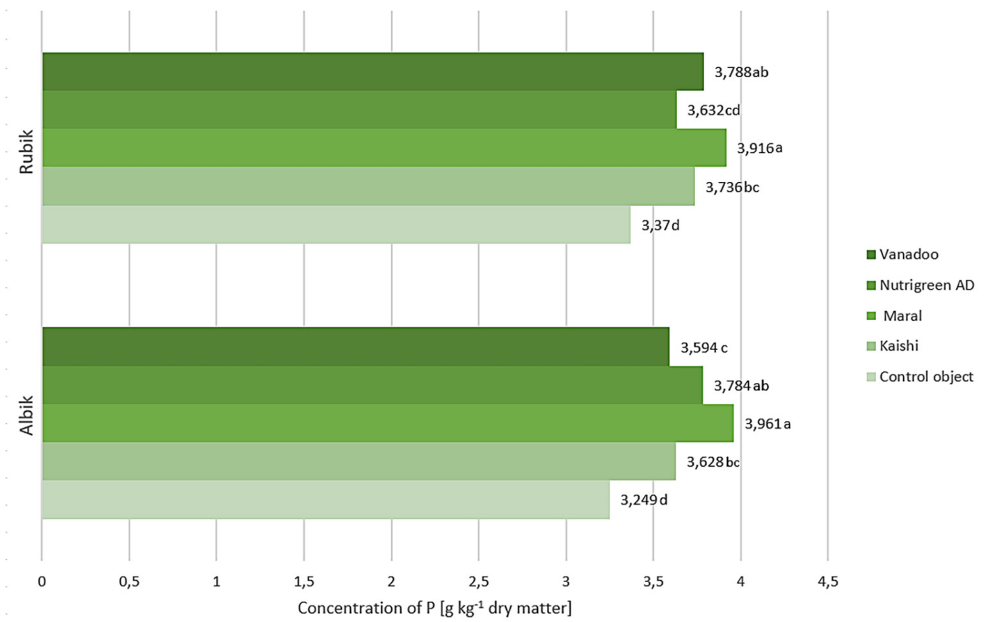

Figure 1. Phosphorus content as influenced by biostimulant application in two cultivars 'Albik' and 'Rubik'

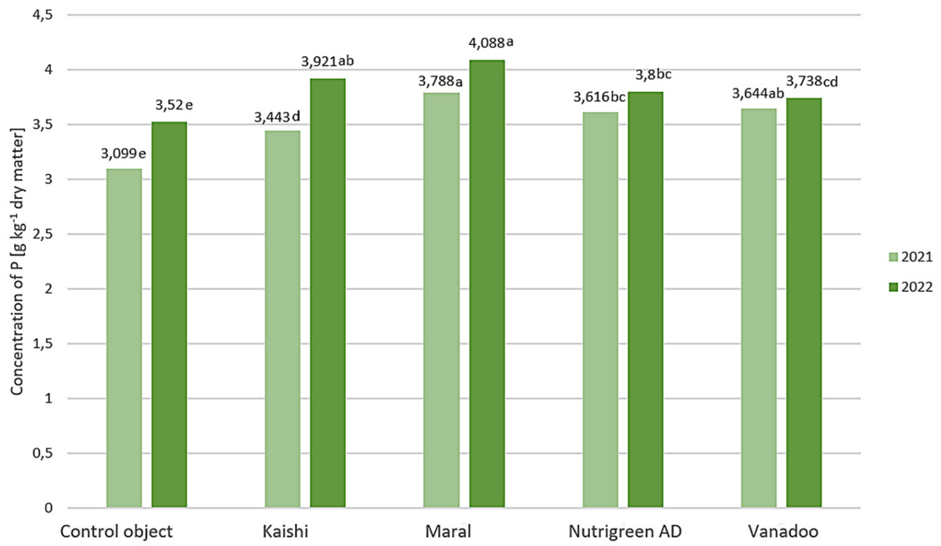

Figure 2. Phosphorus content of Jerusalem artichoke tuber under the application of biostimulants in 2021–2022

and by 11.39% in 2022. The other biostimulants (Maral, Nutrigreen AD, Vanadoo) were characterized by a greater effect on elemental content in 2021 compared to the following year. The uptake by Jerusalem Artichoke (JA) of inorganic compounds from the soil solution, i.e. mineral elements, is the basis for proper growth and development of land plants. Chemical analyses of the plant's structure have shown the presence of about 50 different elements included in its composition, but only 13, such as nitrogen, potassium, calcium, magnesium, phosphorus, sulfur, chlorine, iron, copper, boron, zinc, manganese, molybdenum, are considered essential for its life (Boron, 2021)

The cultivar 'Albik' as well as 'Rubik' had the lowest phosphorus uptake in the control facility (22.211 kg ha^{-1} dry weight and 15.838 kg ha^{-1} dry weight, respectively). This means that each of the biostimulants caused an increase in the uptake of the macronutrient (Askari-Khorasgani 2019). The greatest increase in uptake in both varieties of Jerusalem artichoke can be observed after the application of the biostimulant Maral. The uptake in 'Albik' increased by 41.02%, and in 'Rubik' by 31.73% compared to the control object. The smallest difference in uptake was observed after application of biostimulant Kaishi (Figure 3). In each of the analyzed variants, the value of elemental uptake, expressed in kg ha^{-1} dry weight, decreased in 2022 compared to 2021 (Figure 4). The biostimulant Maral, which showed the greatest increase in P uptake, also saw the greatest difference in the amount of elemental uptake in both years of the experiment. In 2021, the uptake was 30.068 kg ha^{-1} dry weight, while in 2022 it was only 22.118 kg ha^{-1} dry weight.

Content and uptake of calcium in JA

According to the literature, calcium is one of the main macronutrients found in the Jerusalem artichoke tuber, Ca deficiency causes deformation of young leaves, dying of flower buds (Sawicka and Kalembasa, 2013). According to Fotyma (2011), the average calcium content is 1864 mg kg^{-1} dry weight. Our research reports an average Ca content of 2,137 g kg^{-1} dry weight in the control plant in 'Albik' and 2,232 g kg^{-1} dry weight in 'Rubik' (Figure 5). A varied response of varieties to the applied biostimulants was observed. In both 'Albik' and 'Rubik' cultivars, the greatest difference in the content of the macronutrient was observed after the application of the biostimulant Maral (Ca content higher by 24.44% and 25.40%, respectively). On the other hand, it can be assessed that the biostimulant Kaishi did not significantly affect the concentration of calcium in the potato tuber. The difference in Ca content is 3.18% for the Albik variety and only 1.34% for the Rubik variety. The other biostimulators - Nutrigreen AD and Vanadoo had an average effect on increasing the nutrient content, however, the effect is much more pronounced for the 'Rubik' variety (Figure 5).

The analysis of the calcium content of the Jerusalem artichoke tuber in 2021–2022 (Figure 6) allows us to observe a different trend from the phosphorus content presented in the same years (Figure 2). This time the content, of the

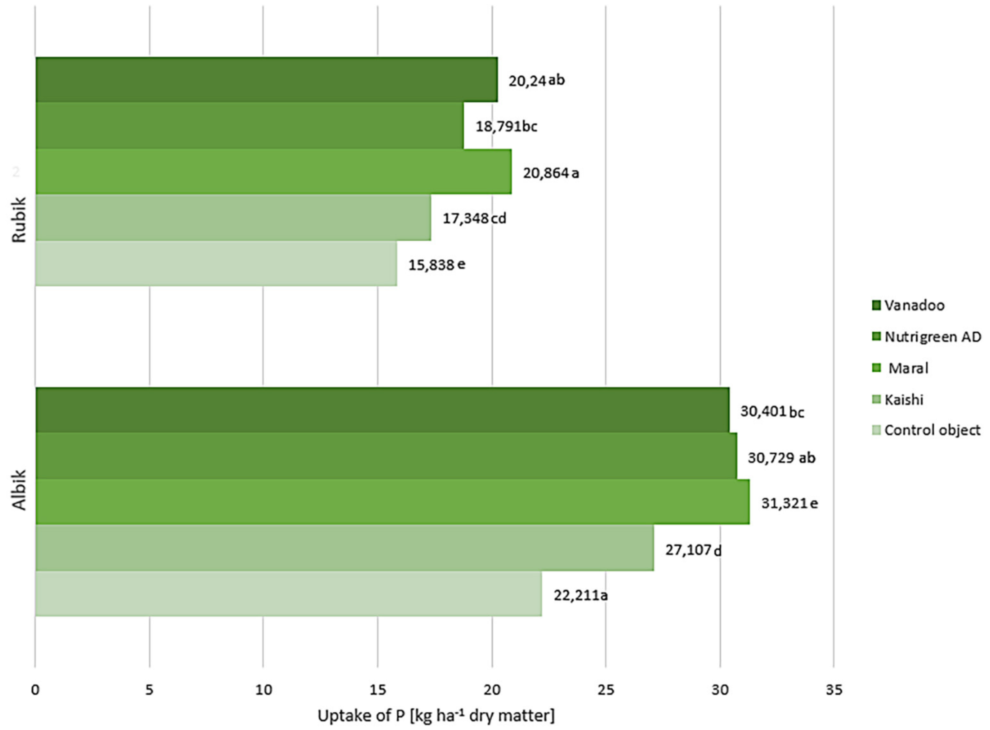

Figure 3. Phosphorus uptake as influenced by biostimulant application in two cultivars 'Albik' and 'Rubik'

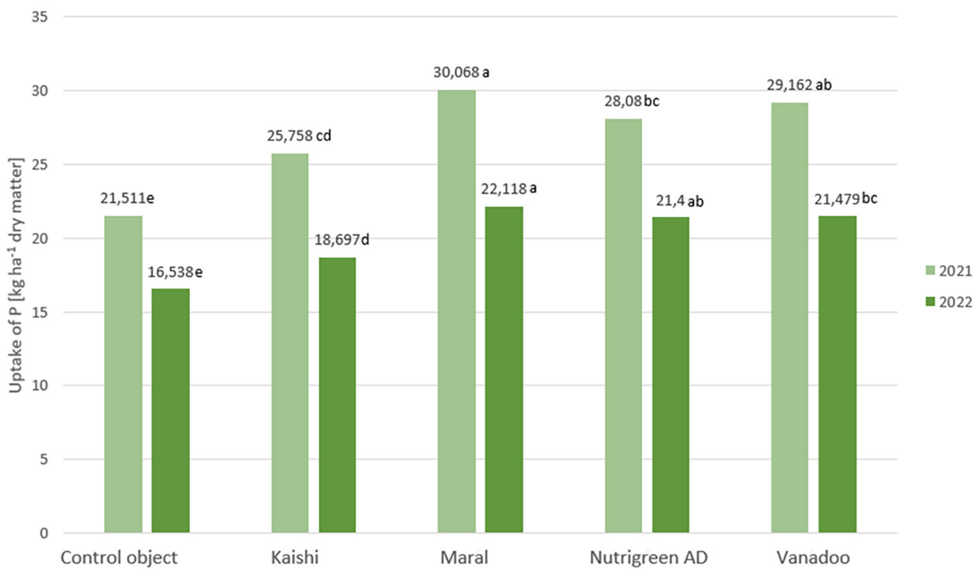

Figure 4. Phosphorus uptake under the influence of applied biostimulants in 2021–2022

macronutrient (Ca) is lower in 2022 than in the previous year. The formation of the mineral content of plants is due, among other things, to the weather conditions accompanying the crop (Table 1). According to the Sielianinov coefficient, 2021 was relatively dry. The average calcium content was 2,260 g kg^{-1} dry weight in 2021 and 2,109 g kg^{-1} dry weight in 2022, respectively. The biostimulant Maral caused the highest calcium accumulation. Indeed, the concentration of Ca content was 2,904 g kg^{-1} dry weight, 28.5% higher than the control object in 2021, while in 2022 it was 2,532 g kg^{-1} dry weight (20.06% more than the control object). The other biostimulants did not significantly affect the calcium concentration in topinambur. Calcium uptake in 'Albik' and 'Rubik' increased under the application of each biostimulant (Askari-Khorasganiet et al., 2019).

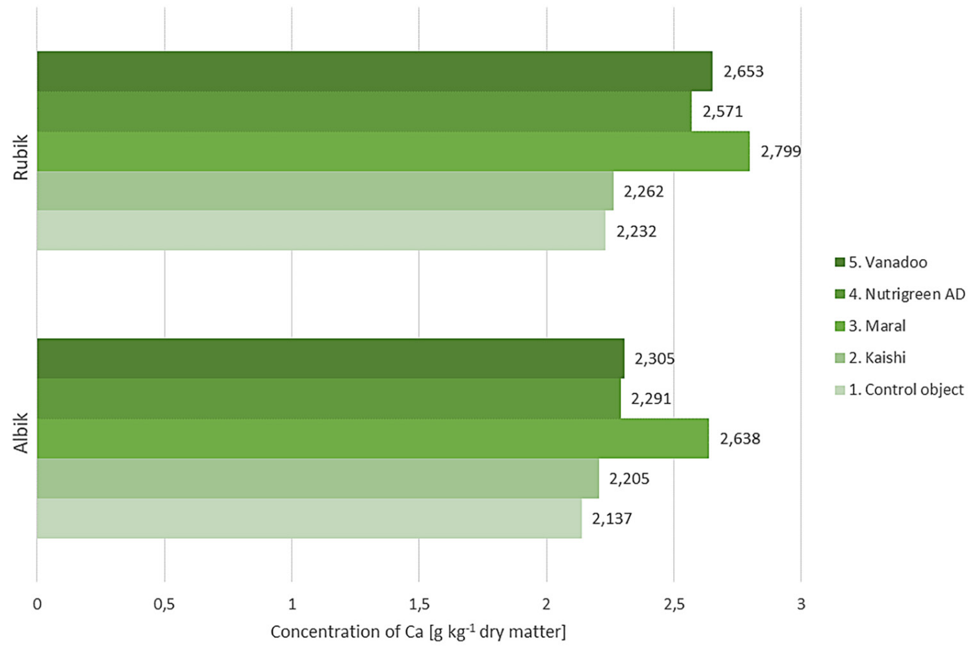

Figure 5. Calcium content under the influence of biostimulants in two cultivars 'Albik' and 'Rubik'

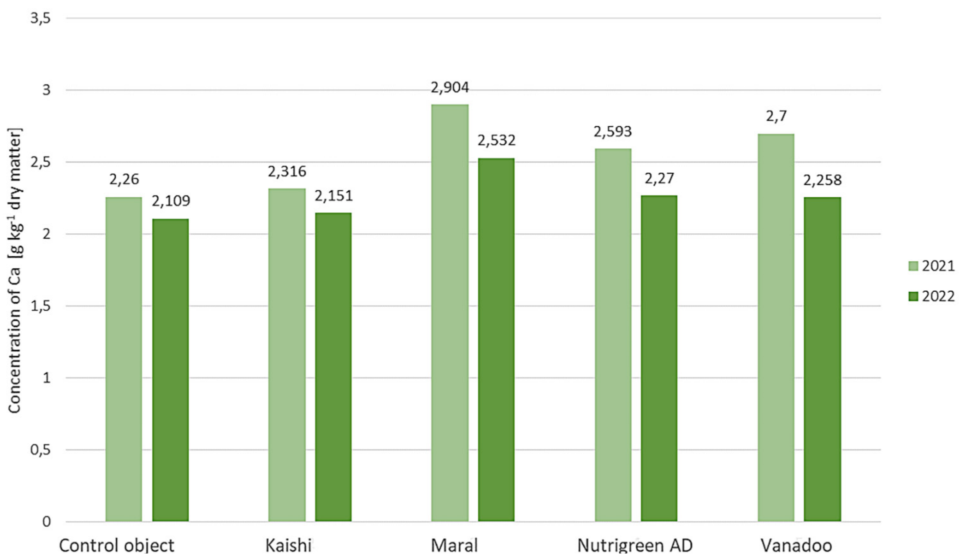

Figure 6. Calcium content under the influence of applied biostimulants in 2021-2022

The largest increase in both varieties of *Helianthus tuberosus* L. was observed in the variants of application of the biostimulant Maral (an increase of 52.56% for 'Albik' and 51.57% for 'Rubik' against the control object). The smallest difference in the uptake of the macronutrient compared to the control object was observed after the application of the biostimulant Kaishi. On average, the biostimulants caused 26.61% higher calcium uptake in 'Albik' and 21.44% higher uptake in 'Rubik'(Figure 7). In all sites in the experiment conducted, the uptake was higher in 2021, which was relatively dry according to the Sielianinov coefficient (Table 1). The biggest difference in uptake in years can be observed when Vanadoo biostimulant was applied (Fig. 8).

Content and uptake of magnesium in JA

Magnesium is absorbed by *H. tuberosus* plants in large quantities. It is the central atom of chlorophyll, determining leaf color and the course of metabolism (Terzic et al., 2011). The content of magnesium in the control objects was

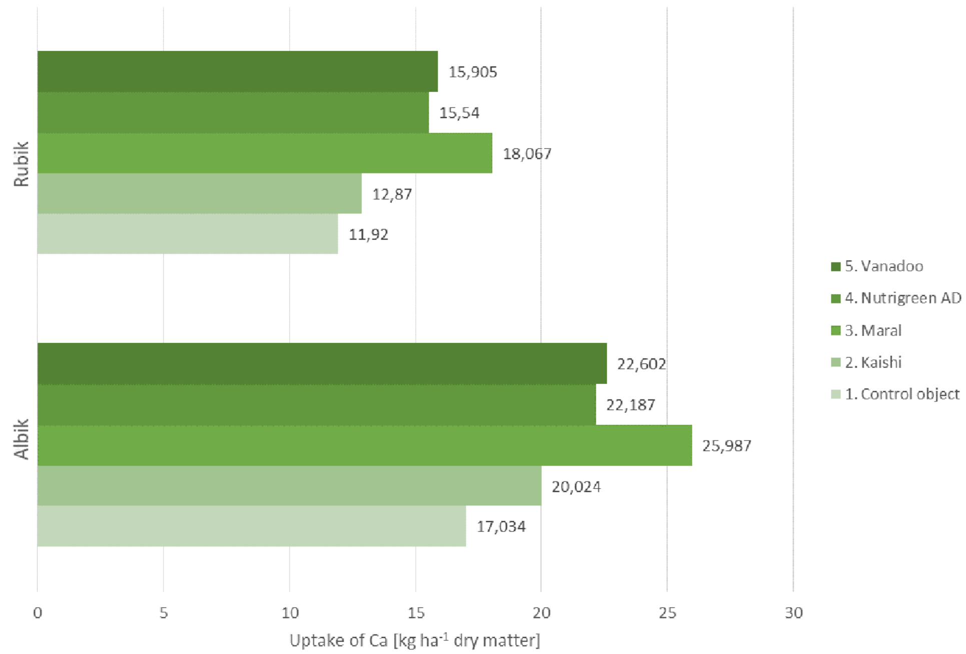

Figure 7. Calcium uptake as affected by biostimulant application in two cultivars 'Albik' and 'Rubik'

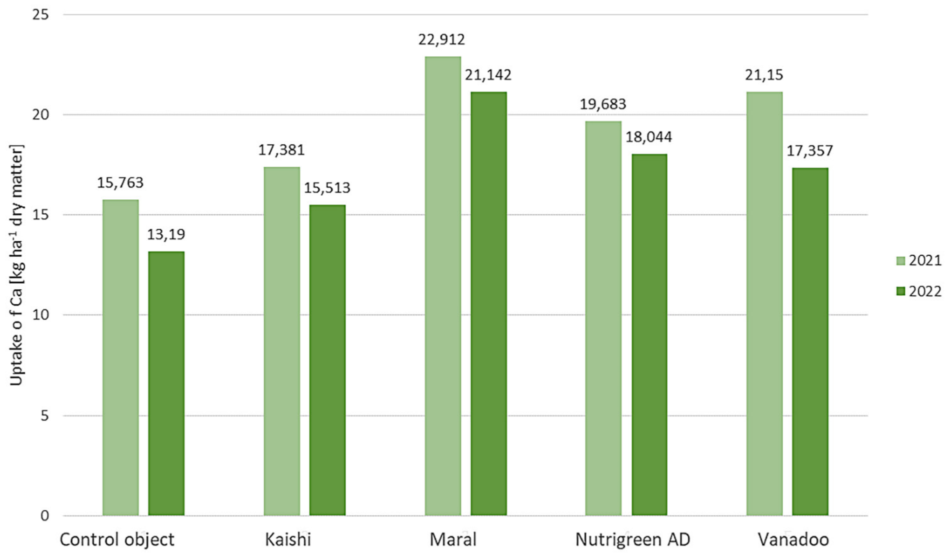

Figure 8. Calcium uptake under the influence of applied biostimulants in 2021–2022

significantly different depending on the variety of Jerusalem artichoke - (0.735 g kg^{-1} dry weight in the variety 'Albik' and 0.565 g kg^{-1} d.m. in the variety 'Rubik') (Figure 9). As in the case of the previously mentioned elements (P and Ca), the application of agrotechnical treatments increased the concentration of Mg in the tuber of *Helianthus tuberosus* L. compared to the control object.

However, the Jerusalem artichoke tubers in the experiment are poor in magnesium, as the average content of this macronutrient reported in the literature is 1897 mg kg^{-1} d.m. (Fotyma, 2011). The highest content of Mg can be observed in topinambur treated with the biostimulant Maral (the values are higher by 25.17% for the cultivar 'Albik' and 23.54% for the cultivar 'Rubik'). The application of biostimulant Kaishi did not cause a significant difference in the content of this macronutrient.

Significant interaction of varieties with weather conditions during JA vegetation was proved. Figure 10 shows the concentration of magnesium in two varieties of Jerusalem artichoke under the influence of applied biostimulants. In both 2021 and 2022, the highest magnesium content can

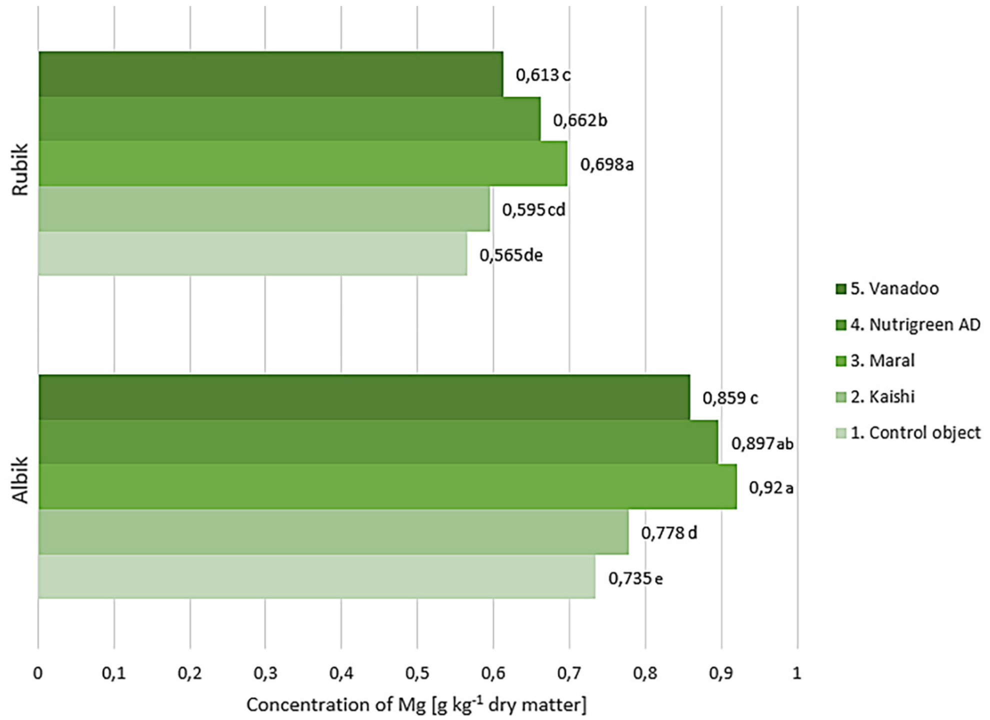

Figure 9. Magnesium content as influenced by the application of biostimulants in two cultivars 'Albik' and 'Rubik'

be observed in *Helianthus tuberosus* L. treated with the biostimulant Maral. Tubers after application of this biostimulant were characterized by 28.91% higher magnesium content in 2021 and 20.79% higher in 2022. This means that the magnesium content after the application of this biostimulant is dependent on weather conditions, which were different in the years of the experiment. On the other hand, the lowest difference in Mg concentration was shown after using the Kaishi biostimulant compared to the control object. Magnesium uptake differed significantly between topinambur varieties (Fig. 11). It can be noted that the cultivar 'Albik' was characterized by about twice as much uptake in each object compared to the cultivar 'Rubik'. In both varieties, the greatest increase was observed after the application of the biostimulant Maral, and the

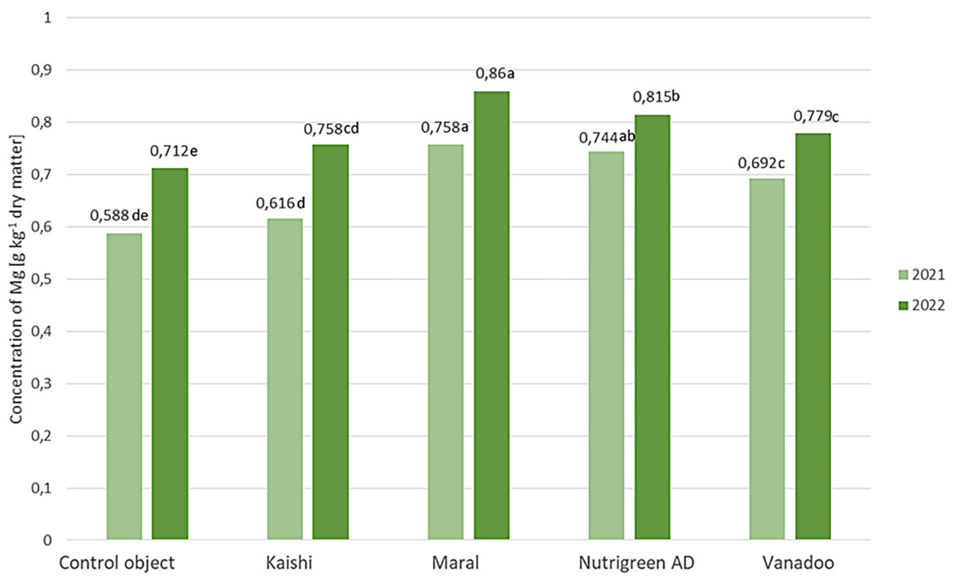

Figure 10. Magnesium content under the application of biostimulants in 2021–2022

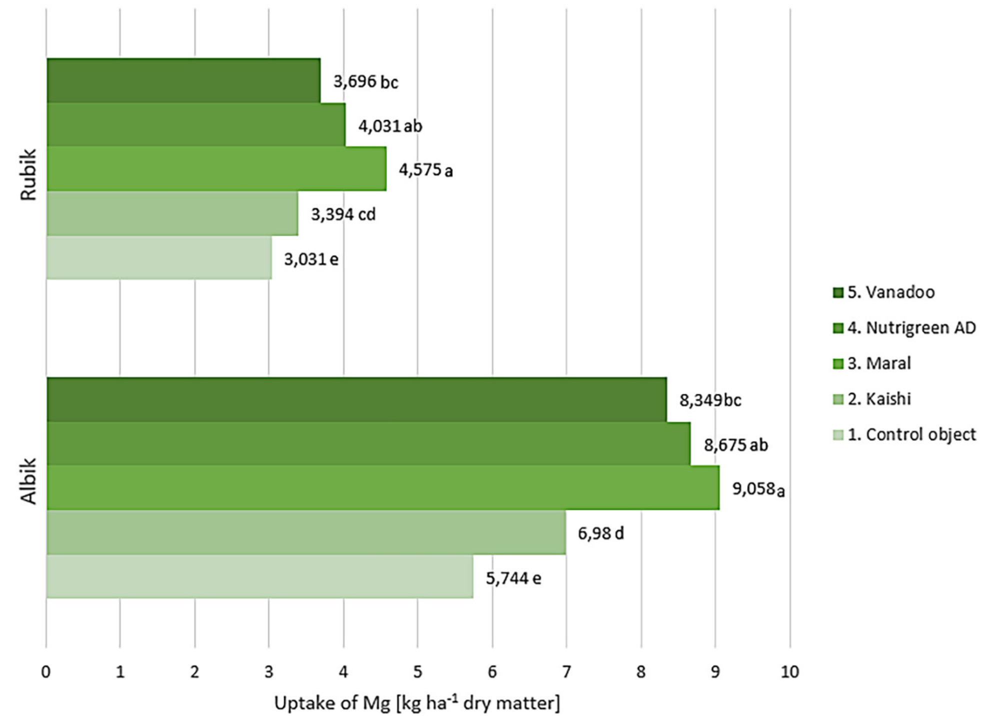

Figure 11. Magnesium uptake as affected by biostimulant application in two cultivars 'Albik' and 'Rubik'

least in the case of the biostimulant Kaishi. Magnesium uptake, unlike the previously discussed elements phosphorus and calcium, increased in 2022 compared to 2021 (Figure 12). In the control facility, Mg uptake increased by only 0.284 kg ha^{-1} dry weight, while after application of the Kaishi biostimulant, the difference between the years' uptake of the macronutrient was as much as 0.958 kg ha^{-1} DM.

Content and uptake of potassium in JA

Potassium has an important impact on the quality of the crop. In plant cells, potassium is found in both the cytoplasm and cell sap, mainly in the vacuole. Potassium's role in photosynthesis and plant water management is essential mainly for growth and yield formation. Potassium plays an important role in muscle contraction and nerve

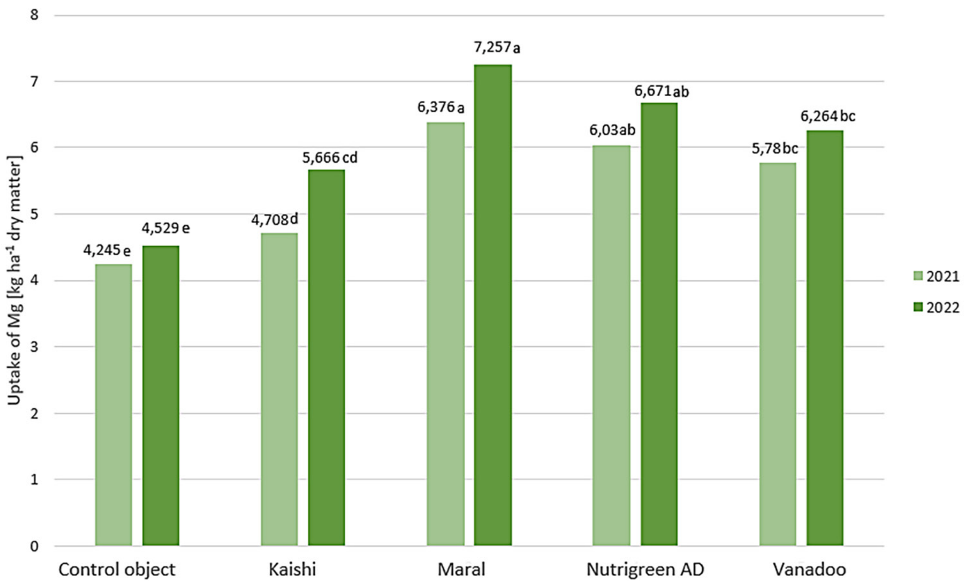

Figure 12. Magnesium uptake under the influence of applied biostimulants in 2021–2022

transmission, as well as in maintaining the body's normal electrolyte balance and pH (Rodrigues et al., 2007, Gaoet al., 2011). When there is a deficiency of potassium in the diet, muscle activity, as well as nerve activity, can deteriorate. Potassium is the mineral compound found in topinambur at the highest concentration, and its average content according to Fotyma (2011) was 23356 mg kg^{-1} DM. This time, in the vast majority of the studied objects, the application of biostimulants resulted in a decrease in its content compared to the control object (Fig.13). The exception is the application of the biostimulant Vanadoo in the cultivar 'Rubik', however, the concentration of K is higher only by 0.089 g kg^{-1} d.m. than the concentration of the element in the control object. It is noteworthy that the biostimulant Maral, which was characterized by the highest difference in the increase in the content

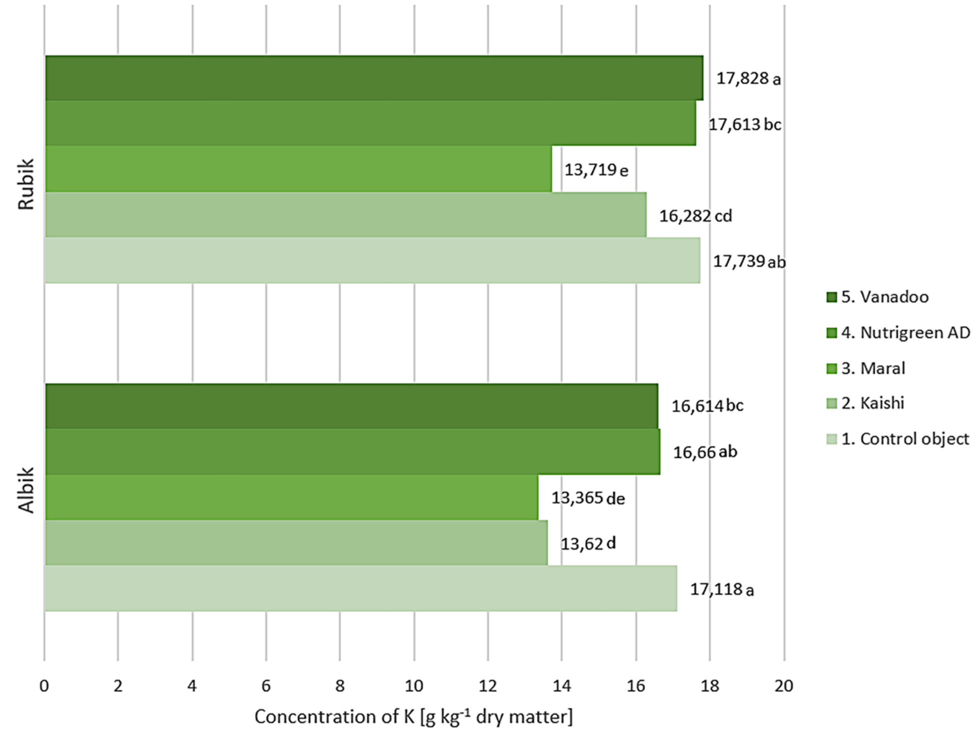

Figure 13. Potassium content as influenced by biostimulant application in two cultivars 'Albik' and 'Rubik'

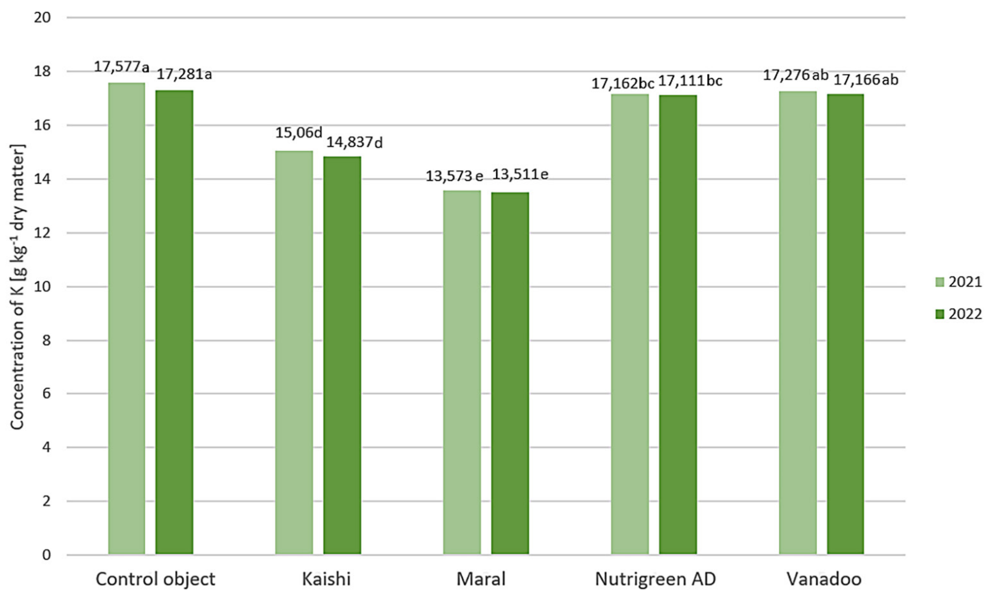

Figure 14. Potassium content under the application of biostimulants in 2021–2022

of elements such as P, Ca and Mg compared to the control objects, this time caused the highest decrease in the concentration of the macronutrient K (by 21.92% in the cultivar 'Albik' and by 22.66% in the cultivar 'Rubik').Both the tubers of the control object and those after biostimulant application were characterized by slightly higher potassium content in 2021 than in 2022 (Fig.14). The greatest decrease in K concentration was observed in 2022 after application of the biostimulant Maral. At that time, the concentration of the element was only 13.511 g kg^{-1} DM. The uptake of potassium is similar to that of other macronutrients – the highest increase in both varieties relative to the control object was observed after the application of the biostimulant Maral, and the lowest increase when Kaishi was applied (Fig.15). Despite the different reference value (control object) in both

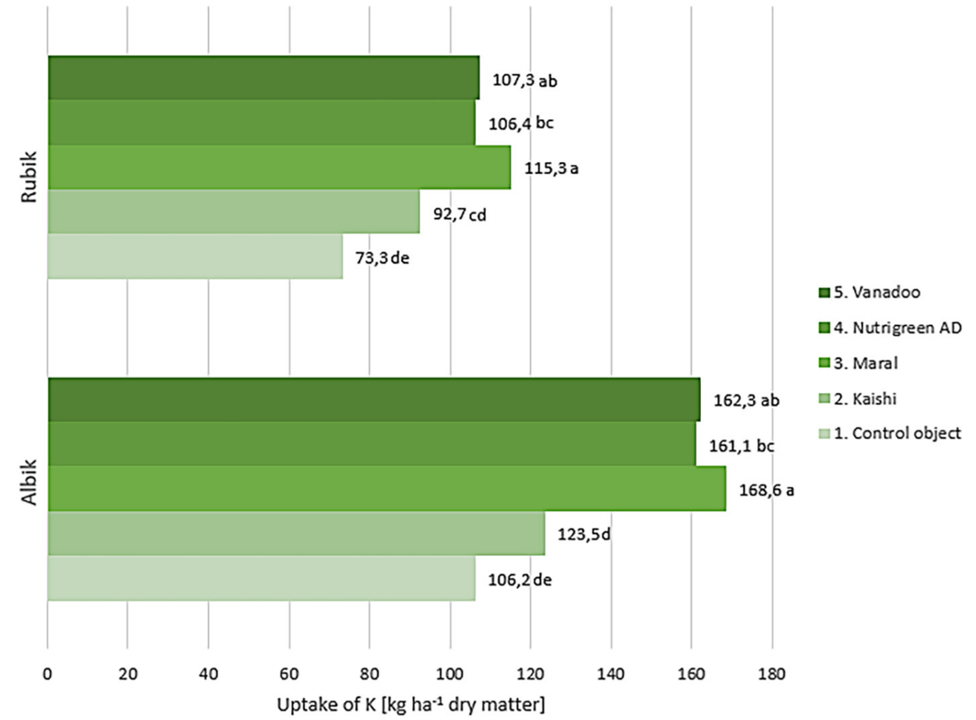

Figure 15. Potassium uptake under the effect of biostimulant application in two cultivars 'Albik' and 'Rubik'

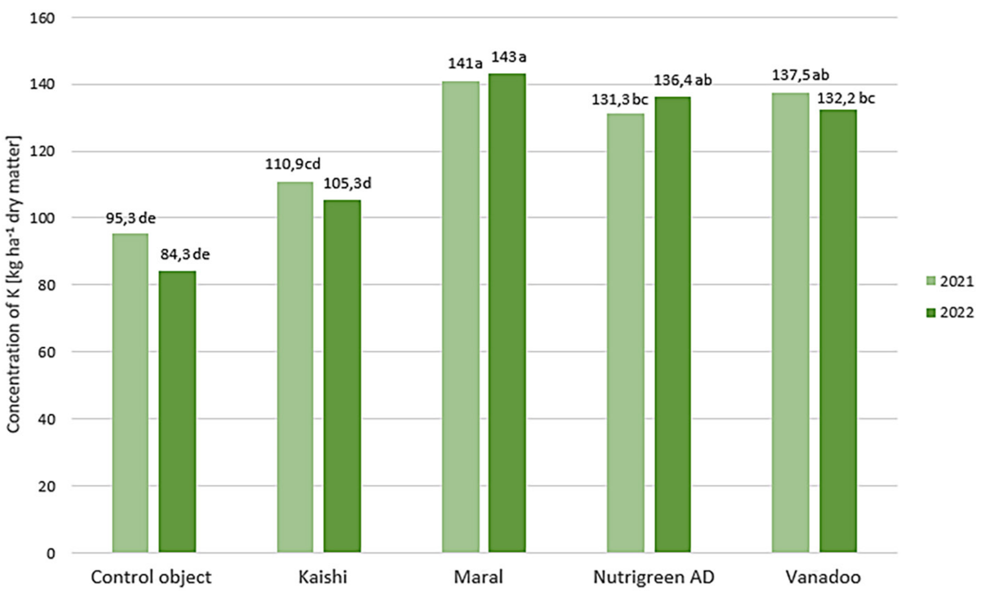

Figure 16. Potassium uptake under the influence of applied biostimulants in 2021–2022

varieties - a similar effect of biostimulant Maral was found. The 'Albik' variety took up 58.76% more Mg than the control object, while the 'Rubik' variety took up 57.30%. Potassium uptake varied from 2021 to 2022 (Fig.16). The control site, as well as the biostimulants Kaishi and Vanadoo, were characterized by higher K uptake in 2021, while Maral i and Nutrigreen AD in 2022.

CONCLUSIONS

Analysis of the content of selected macronutrients in Jerusalem artichoke tubers under the application of biostimulant variants and comparison to the control object allows assessing the effect of biostimulants on tuber quality. Weather conditions significantly affect the uptake and content of nutrients in the plant. Adverse weather conditions, such as high air temperature or heavy rainfall alternating with drought, have a negative effect on the soil as a result of which there is a hindered uptake of macronutrients into the topinambur tuber. A higher content of macronutrients such as P, Ca, Mg and K is desirable, which is why biostimulants are used to increase the plant's resistance to stress factors. The analysis of the effect of selected biostimulants (Kaishi, Maral, Nutrigreen AD and Vanadoo) revealed a trend that almost all tubers of *Helianthus tuberosus* L. after biostimulant application are characterized by higher P, Ca and Mg content, while lower K content compared to the control object. Moreover, the biostimulant Maral, which was defined as having the most favorable effect on phosphorus, calcium and magnesium content (the highest percentage difference in elemental content to the control objects) simultaneously caused the greatest decrease in potassium content in the Jerusalem artichoke tuber. On this basis, it is not possible to choose a single biostimulant with the most favorable effect on the content of macronutrients in the tuber.

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