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Determination of the impact of biostimulants on the content and uptake of sodium and aluminum in two varieties of Jerusalem artichoke

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ABSTRACT

Jerusalem artichoke tubers are characterized by their high nutritional value and are influenced by various factors, e.g., variety, biostimulant application, and environmental conditions. The aim of the three-year (2021–2023) study was to determine the sodium and aluminum contents and uptake in two Jerusalem artichoke varieties, under the influence of biostimulants B1 (Kaishi), B2 (Maral), B3 (Nutrigreen AD), and B4 (Vanadoo). Elemental analysis was performed using Inductively Coupled Plasma-Optical Emission Spectrometry. The results showed that both varieties had comparable sodium and aluminum contents. Biostimulant B2 increased the sodium content compared to the control variant, while reducing the aluminum content. Furthermore, the variety Albik exhibited higher sodium uptake and lower aluminum uptake than Rubik. Notably, B2 enhanced the sodium uptake in Albik, whereas B4 was most effective for Rubik. Aluminum uptake decreased in the Albik variety with biostimulant B3, while all biostimulants raised the aluminum uptake in Rubik. The study indicates that biostimulants may beneficially influence the sodium and aluminum content and uptake in Jerusalem artichoke tubers, highlighting the need for further research.

Keywords: *Helianthus tuberosus* L., aluminum, sodium, growing season.

INTRODUCTION

In modern agriculture, sustainable development faces numerous challenges, with a critical issue being the need to increase the efficiency of crop production while minimizing the negative impact on the environment (Rehamn and Farooq, 2023). In response to these challenges, there is growing interest in using biostimulants, which can enhance plant growth and development, improve resilience to adverse environmental conditions, and optimize nutrient uptake (Du Jardin, 2015). Biostimulants are used in agricultural crops, horticultural crops, vegetable crops, and legumes. In the context of these applications, the Jerusalem artichoke (*Helianthus tuberosus* L.) is an interesting object of study due to its diverse chemical composition.

Jerusalem artichoke contains minerals like sodium, potassium, phosphorus, calcium, magnesium, iron, zinc, and various bioactive compounds (Kocsis, 2007; Slimestad et al., 2010; Wang, 2020a; Shariati et al., 2021).

Jerusalem artichoke can absorb both beneficial and potentially harmful components from the soil. The present study focused on analyzing the content and uptake of sodium and aluminum by Jerusalem artichoke tubers. Sodium occurs in plants in small amounts and plays only a limited role in metabolic processes. Adequate sodium levels can promote plant growth, while excess sodium and aluminum can have adverse effects (Kaspari, 2020; Ofoe et al., 2023; Ur Rahman et al., 2024). On the other hand, adequate sodium content in Jerusalem artichoke tubers may have a beneficial impact on consumer health, as sodium is an important mineral that supports various physiological functions of the body. Sodium intake below and above the standard can lead to adverse health effects (Farquhar et al., 2015; Mente et al., 2021). One example is the significant increase in the risk of cardiovascular disease with high sodium intake – every additional 1.0 g in the diet increases this risk by 6.0%, as shown in a meta-analysis by Wang et al. (2020b). This underlines the need to monitor its content in the diet and food. Aluminum has no important functions in the human body, and an excess is harmful. The main route of aluminum exposure in the population is diet. The acceptable weekly intake is 1.0 mg/kg body weight, but it is estimated that aluminum intake could be exceeded by a significant proportion of the European population (EFSA, 2008). The literature indicates that the exposure to aluminum can affect various systems: nervous, skeletal, circulatory, urinary, and respiratory systems. Therefore, controlling aluminum content in the diet and food is crucial due to its potential toxicity (Rahimzadeh, 2022; Renke et al., 2023).

The aim of this study was to analyze the effect of biostimulant use on the content and uptake of sodium and aluminum by tubers of two varieties of Jerusalem artichoke. The study was carried out over three years, making it possible to analyze the changes occurring in the plants over a long period under different environmental conditions. This research is essential not only from the point of view of agricultural optimization but also for health reasons.

MATERIALS AND METHODS

The research material consisted of tubers from a field experiment. The research was conducted in 2021–2023 in central-eastern Poland. The experiment was conducted in a two-factor system (split-plot) with three replications. The first order factor included two varieties of Jerusalem artichoke: 'Albik,' characterized by oval, oblong tubers with creamy skin and white flesh, with yields ranging from 24–34 $t \cdot ha^{-1}$, and 'Rubik' with egg-shaped tubers with pink skin and white flesh, with yields in the range 23–40 $t \cdot ha^{-1}$. The second-order factor consisted of four biostimulant variants: Kaishi (B1), Maral (B2), Nutrigreen AD (B3), Vanadoo (B4), and a control variant without biostimulant (C) (Fig. 1).

Throughout the entire study period, no diseases or pests were observed during the growing season. The Jerusalem artichoke was harvested in the second decade of November. The study analyzed the variability of weather conditions affecting the growth and development of plants during the study period (Fig. 2).

Analyses were carried out at the EKO-AGRO-TECH Regional Research Centre in Biała Podlaska. The elemental content was analyzed using an ICP-OES spectrometer (Spectroblue EOP, Ametek), according to LST EN 15510:2017 standard. The sodium and aluminum contents were quantified using a calibration curve developed with a multi-element standard solution (VHG, Standard, LGC) in its linear range. Statistical analysis of the

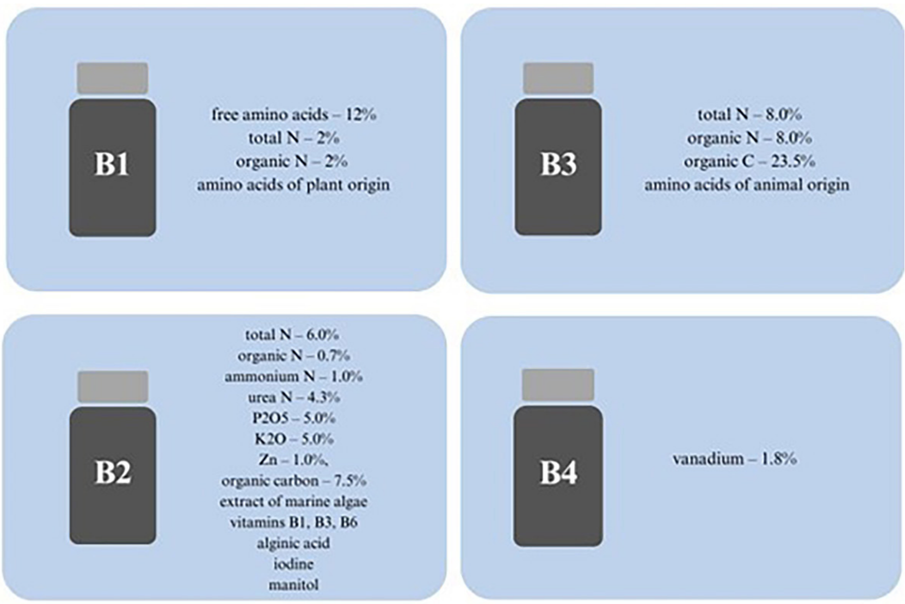

Figure 1. The composition of the biostimulants used

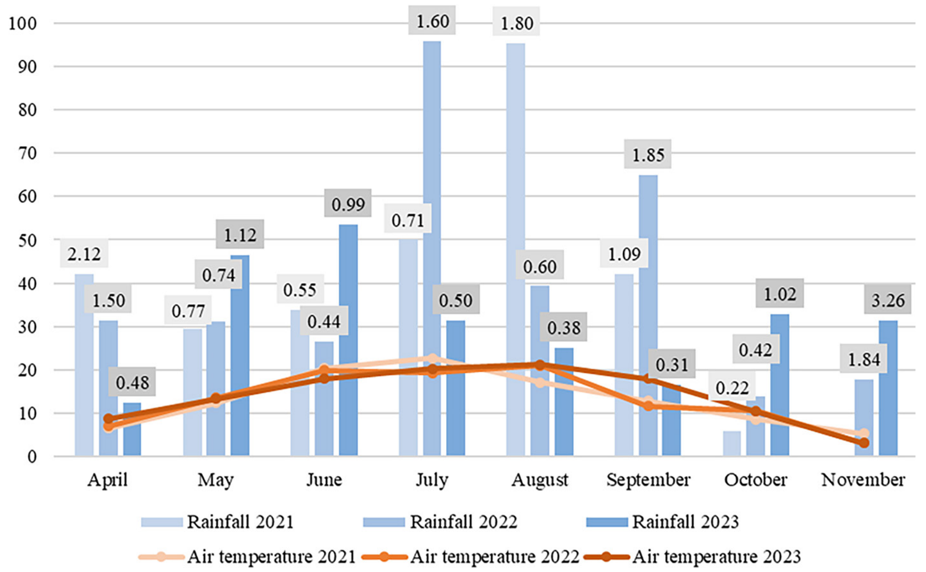

Figure 2. Sows the monthly mean temperatures and rainfall totals from 2021–2023. The value of the Sielianinow index was calculated from these data (Skowera et al., 2014)

results was performed using analysis of variance (ANOVA). The Fisher-Snedecor F-test was used to assess sources of variation, whereas the significance of differences between means was assessed using the Tukey Honest Significance Differences (HSD) post hoc test. A significance level of $p \leq 0.05$ was set. A novel algorithm, developed in Excel, was used to perform statistical calculations according to the principles of the mathematical model proposed by Trętowski and Wojcik (1991).

RESULTS AND DISCUSSION

The results were discussed by divisions of the two elements analyzed, sodium and aluminum, allowing a detailed interpretation of the results of each component. This approach provided a clearer understanding of the influence of the applied biostimulants and experimental conditions on the content and uptake of these elements in the Jerusalem artichoke cultivars studied. Table 1 presents the average sodium content and sodium uptake in the tubers of two Jerusalem artichoke varieties, Albik and Rubik, based on the data collected over three years of experimentation (Tab. 1).

The sodium content of the Jerusalem artichoke tubers ranged from 1.937 to 2.155 g·kg^{-1} DM. Similar sodium content results were also obtained in another study, where the average sodium content was 1.840 g·kg^{-1} DM (Sawicka and Kalembasa, 2013). However, in a study by Sawicka et al. (2021), the average sodium content

Table 1. The effect of biostimulants on sodium content and uptake in tubers of two cultivars of Jerusalem artichoke

Biostimulants	Sodium content (g·kg^{-1} DM)			Sodium uptake (kg·ha^{-1})		
	Albik	Rubik	Mean	Albik	Rubik	Mean
C	1.884	1.991	1.937	16.098^{b}	11.567^{b}	13.832^{b}
B1	2.107	2.047	2.077	18.197^{b}	13.800^{ab}	15.998^{ab}
B2	2.213	2.097	2.155	21.778^{a}	14.350^{ab}	18.064^{a}
B3	2.080	2.002	2.081	18.744^{ab}	14.182^{ab}	16.463^{ab}
B4	2.048	1.925	2.016	19.607^{ab}	14.749^{a}	17.178^{ab}
Mean	2.066^{A}	2.040^{A}	2.053	18.885^{A}	13.729^{B}	16.307

Note: Differences between the applied biostimulants are marked by lowercase letters, and differences between varieties 'Albik' and 'Rubik' are indicated by uppercase letters. Different letters indicate the significant differences between the results at p <0.05. Abbreavations: C – Control variant; B1 – Kaishi; B2 – Maral; B3 – Nutrigreen AD; B4– Vanadoo.

was lower, at 0.160 g·kg^{-1} DM. Additionally, other authors reported even lower values, ranging from 0.018 to 0.040 g·kg^{-1} fresh weight (Kays and Nottingham, 2007). The differences in the obtained values may be attributed to varying cultivation systems, as the compared experiment was conducted under an organic farming system (Sawicka et al., 2020), and to the fact that sodium was determined in fresh weight in another study (Kays and Nottingham, 2007).

The average sodium content of Jerusalem artichoke tubers of the varieties Albik and Rubik showed similar values (2.066 and 2.040 g·kg^{-1} DM, respectively). In another study, both varieties had similar contents of this macronutrient, but the values were lower compared to the results obtained in this paper, with 0.170 g·kg^{-1} DM recorded in the Albik variety and 0.150 g·kg^{-1} DM in the Rubik variety (Sawicka et al. 2021). On the other hand, values at a similar level were found in the above-ground parts of Jerusalem artichoke, with the Albik variety having a sodium content of 1.730 g·kg^{-1} DM and the Rubik variety 1.950 g·kg^{-1} DM (Sawicka and Kalembasa, 2013).

The average content of this macronutrient did not change significantly under the influence of the applied biostimulant and remained in the range of 2.048-2.213 g·kg^{-1} DM in the Albik variety and 1.925–2.097 g·kg^{-1} DM in the Rubik variety. Biostimulant B2 increased the sodium content the greatest extent in both Albik (by 17.5%) and Rubik (by 5.3%). There are no studies investigating the effect of biostimulants on the sodium content of Jerusalem artichoke tubers. However, there are several papers in the literature on using biostimulants to cultivate various crops. In a study on potatoes, the application of plant biostimulants did not affect sodium content (Dziugieł and Wadas, 2020), while in the case of carrot roots, an increase in sodium content was reported (Kwiatkowski et al., 2015). The results emphasize the need for further studies on the effect of biostimulants on sodium content in Jerusalem artichoke tubers and other plant species to understand the mechanisms modifying sodium accumulation entirely.

JA plants under biostimulants have developed sophisticated perceptual mechanisms to cope with harsh environmental conditions, such as drought or salinity, which reduce transpiration and nutrient uptake. With the degree of drought, root elongation is continuous in order to seek groundwater, while in the case of salinity, ionic stress also occurs and roots start to accumulate large amounts of ions, mainly Na^{2+} (Ma et al., 2022); in addition, they have salt exclusion mechanisms and others concentrate salt in vacuoles (Khan et al., 2020).

Different results were observed for sodium uptake, with mean values between 13.832 and 18.064 kg·ha^{-1}. The mean sodium uptake in the tubers of the Jerusalem artichoke variety Albik (range 18.197–21.778 kg·ha^{-1}) was significantly higher than that of the variety Rubik (range 13.800–14.749 kg·ha^{-1}), corresponding to a difference of 37.6%. In a study by Németh and Izsáki (2006), Jerusalem artichoke tubers of a different variety had about three times lower sodium uptake values (5.120 kg·ha^{-1}.).

A significant effect of applying biostimulants on sodium uptake by Jerusalem artichoke tubers was observed. In the Albik variety, the application of biostimulant B2 contributed to the greatest extent to an increase in the uptake of this macronutrient by 35.3%. In the Rubik variety, on the other hand, the application of biostimulant B4 had the greatest effect on increasing sodium uptake, which amounted to 27.5%. However, it should be noted that there are no studies on the impact of biostimulants on sodium accumulation in Jerusalem artichoke tubers in the available literature, which emphasizes the need for further research in this area.

Changes in sodium content and uptake in Jerusalem artichoke tubers in three years of the experiment, under the influence of biostimulants used, were analyzed (Fig. 3). Comparing the data from the three years of the experiment, the average sodium content of the Jerusalem artichoke tubers showed no significant differences for either the Albik (Fig. 3a) or Rubik (Fig. 3b) varieties. In both varieties, the biostimulant B2 influenced the highest sodium content in Jerusalem artichoke tubers in all experiment years.

In contrast to the sodium content, the uptake of this macronutrient by Jerusalem artichoke tubers depended on the duration of the experiment and variety. In the Albik variety, higher values of sodium uptake were recorded in 2021 and 2023, while in the Albik variety, biostimulator B2 showed the highest effect on sodium accumulation every year of the experiment. In the Rubik variety, on the other hand, biostimulant B4 had the greatest influence on the uptake of this macronutrient.

In the three-year experiment conducted by Sawicka et al. (2021), the sodium content in the last year of the study was lower compared to the

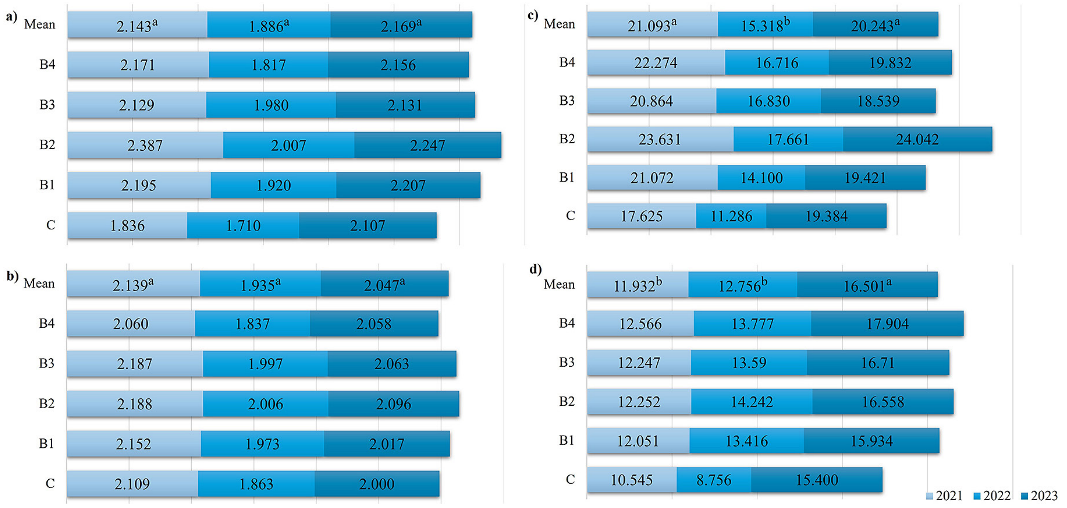

Figure 3. The effect of biostimulants on sodium content in tubers of (a) Albik and (b) Rubik and sodium uptake in tubers of (c) Albik and (d) Rubik over the period from 2021 to 2023. **Note:** Differences between years are marked by lowercase letters. Different letters indicate the significant differences between the results at $p < 0.05$. Abbreavations: C – Control variant; B1 – Kaishi; B2 – Maral; B3 – Nutrigreen AD; B4 – Vanadoo

two previous years. The authors pointed out that the content of components in Jerusalem artichoke tubers may depend on various factors, including climatic conditions. The results obtained in the conducted study could also have been influenced by weather conditions, especially during tuber accumulation. The months in which nutrients are intensively accumulated, namely August, September, and October, are decisive in this respect. One indicator that describes these conditions is the Sielianinow index, calculated from the monthly rainfall ratio to average monthly air temperature (Skowera et al., 2014). In 2021, the value of the Sielianinow index in these months was 1.80 (classified as quite humid), 1.09 (quite dry), 0.22 (extreme dry). In 2022, on the other hand, these values were 0.60 (very dry), 1.85 (quite humid), and 0.42 (very dry) in the following months. In 2023, these coefficients indicated drier conditions of 0.38, 0.31 (both extreme dry), 1.02 (quite dry). The higher values of the Sielianinow index in 2021 (in August and September) indicate sufficient water availability, which could have directly contributed to the increased sodium uptake of the Jerusalem artichoke tubers of the Albik variety. In the same months in 2023, higher sodium uptake values were observed in the Albik and Rubik cultivars, despite significantly drier weather conditions. In October, the Sielianinow index was 1.02 (quite dry), which may have partially mitigated the negative impact of the drought in August and September. In 2022, the lowest sodium uptake values were observed in both varieties, possibly related to drought in two critical months, August and October. The observed results suggest that the Albik variety may have a higher sodium accumulation capacity and highly tolerate adverse weather conditions. In contrast, the Rubik variety may need more time to adapt to environmental conditions, which resulted in a gradual increase in sodium accumulation in subsequent years.

In the conducted study, the aluminum content of the Jerusalem artichoke tubers ranged from 53.09 to 60.84 mg·kg^{-1} DM (Tab. 2). In the study by Ekholm et al. (2007), a lower aluminum content (7.00 mg·kg^{-1} DM) was reported in the edible parts of Jerusalem artichoke. In a study by Sawicka et al. (2013), several times higher aluminum values were reported in the above-ground parts of Jerusalem artichoke. The elemental content may vary depending on the analyzed part of the Jerusalem artichoke. Studies have shown that the content of toxic elements, such as cadmium and lead, is higher in roots and above-ground parts than in tubers (Jasiewicz and Antonkiewicz, 2002; Willscher et al., 2017). Also, lower values of cadmium 0.13 mg·kg^{-1} fresh weight, lead 0.26 mg·kg^{-1} fresh weight (Judprasong et al., 2018), and cadmium 0.52 mg·kg^{-1} DM were recorded in Jerusalem artichoke tubers (Harmankaya et al., 2012). The lower values for these metals may result from analyzing the peeled, edible parts of the Jerusalem artichoke, which may show a lower accumulation of these elements compared to whole tubers.

The average aluminum content of the Jerusalem artichoke tubers did not change significantly

Table 2. The effect of biostimulants on aluminum content and uptake in tubers of two cultivars of Jerusalem artichoke

Biostimulants	Aluminum content (mg·kg⁻¹ DM)			Aluminum uptake (kg·ha⁻¹)		
	Albik	Rubik	Mean	Albik	Rubik	Mean
C	59.96	61.72	60.84	492.84[a]	333.47[b]	413.16[a]
B1	53.49	60.64	57.06	454.82[ab]	395.42[a]	425.12[a]
B2	48.15	58.04	53.09	460.65[ab]	385.57[a]	423.10[a]
B3	49.36	59.59	54.47	442.60[b]	391.10[a]	416.87[a]
B4	50.12	59.65	54.88	478.52[ab]	426.93[a]	452.72[a]
Mean	52.22	59.93	56.07	465.88[A]	386.50[B]	426.19

Note: Differences between the applied biostimulants are marked by lowercase letters, and differences between varieties ‘Albik’ and ‘Rubik’ are indicated by uppercase letters. Different letters indicate the significant differences between the results at $p < 0.05$. Abbreavations: C – Control variant; B1 – Kaishi; B2 – Maral; B3 – Nutrigreen AD; B4 – Vanadoo.

under the influence of the applied biostimulant, remaining in the range of 48.15–53.49 mg·kg^{-1} DM in the Albik variety and 58.04–60.64 mg·kg^{-1} DM in the Rubik variety. In both varieties, the application of the biostimulant B2 contributed most to the decrease in the content of this element. In cultivar Albik, biostimulants reduced aluminum content in the range of 10.8–19.7%, while in cultivar Rubik, the reduction in aluminum content was lower at 1.8–6.0%. There is a lack of literature on the effect of biostimulants on aluminum content in plants. However, reports indicate differential effects of biostimulants on the content of potentially toxic elements in different species. Applying a biostimulant in aubergine cultivation did not influence the content of lead and cadmium; however, an increase in mercury content in the fruit of this plant was observed (Majkowska-Gadomska et al., 2016). Conversely, biostimulants reduced the cadmium and lead levels in pumpkin leaves and roots (Rady et al., 2023). Overall, biostimulants can enhance plant tolerance to potentially toxic elements through mechanisms such as antioxidant system stimulation, reactive oxygen species uptake, and stress-responsive gene expression induction (Sharma, 2023). The effect of biostimulants on the content of individual metals in plants requires further research, which will consider several factors, including the type of biostimulant used, plant species, and cultivar, as well as environmental conditions, including precipitation, temperature, and soil contamination.

Similar to sodium uptake, the aluminum uptake by Jerusalem artichoke tubers varied. The mean values from the two varieties ranged from 413.16 to 452.72 kg·ha^{-1}. The Rubik variety (range 333.47–426.93 kg·ha^{-1}) had significantly lower aluminum uptake than the Albik variety (442.60–492.84 kg·ha^{-1}). This is consistent with the results of another study in which the aboveground parts of the Albik variety had higher uptake of nickel, lead, and cadmium compared to Rubik, except for chromium uptake, where no significant differences were observed between varieties (Antonkiewicz et al., 2018).

The cultivar Albik was characterized by higher aluminum uptake, but the application of biostimulants resulted in a 2.9–10.2% reduction in the uptake of this element. The biostimulant B3 proved to be the most effective in this respect. In Rubik, on the other hand, despite the lower values recorded, the application of each biostimulant variant increased the aluminum uptake by 15.6–28.0%. The lack of literature on the effect of biostimulants on aluminum uptake by Jerusalem artichoke tubers makes it challenging to directly relate the results of this study to previous reports. The observed difference in the responses of the two varieties to the application of biostimulants may indicate varietal differentiation in response to these preparations.

The effect of applied biostimulants on aluminum content and uptake in the two varieties of Jerusalem artichoke during the three years (Fig. 4). The lowest aluminum content in both varieties was recorded in 2023 (Fig. 4a and 4b). The Albik variety also showed a lower aluminum content in 2021, while the Rubik variety had similar values in 2021–2022. The biostimulant B2 reduced the aluminum content to the greatest extent in both varieties of Jerusalem artichoke in all experimental years.

The lowest aluminum uptake was recorded in 2023 and the highest in 2022 in the Albik and Rubik varieties. In cultivar Albik, biostimulant B1

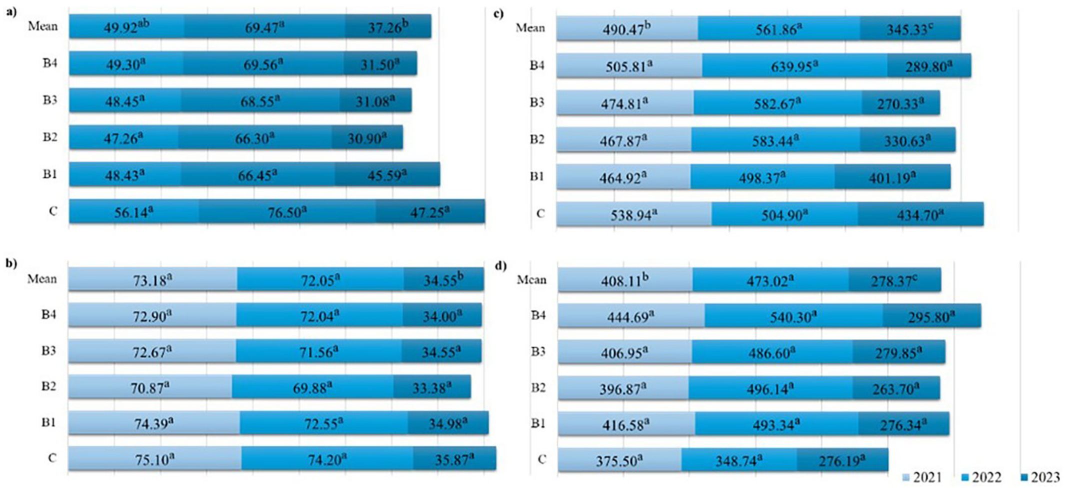

Figure 4. The effect of biostimulants on aluminum content in tubers of (a) Albik and (b) Rubik and aluminum uptake in tubers of (c) Albik and (d) Rubik over the period from 2021 to 2023. **Note:** Differences between years are marked by lowercase letters. Different letters indicate the significant differences between the results at $p < 0.05$. Abbreavations: C – Control variant; B1 – Kaishi; B2 – Maral; B3 – Nutrigreen AD; B4 – Vanadoo

Table 3. Mean daily intake of sodium and aluminum from Jerusalem Artichoke tubers

Element	Mean in dry matter (mg·kg^{-1})	Mean in fresh matter (mg·100 g^{-1})	Reference	Percent of reference
Sodium	2053.0	47.6	1500 mg·day^{-1}*	3.2
Aluminium	56.07	1.29	1 mg·kg bm^{-1} per week**	1.84***

Note: *[Jarosz et al., 2020], **[EFSA, 2008], ***for an individual with a body mass of 70 kg.

reduced the uptake of this element in each year of the experiment, whereas biostimulants B2, B3, and B4 in 2021 and 2023. In each year of the experiment, all applied biostimulators increased the aluminum uptake in the Rubik cultivar, excluding 2023 and biostimulators B1, B2, and B3, where the values were comparable to those obtained in the control object.

Both the lowest values for aluminum content and uptake were recorded in 2023. This could be explained by weather conditions and the plant's ability to adapt to environmental stress. Late summer and early autumn in 2023 were characterized by low rainfall and high temperatures. The Sielianinow index values were classified in the extreme and quite dry category. Such conditions may have limited the potential for aluminum accumulation in Jerusalem artichoke tubers. In addition, plant resistance to stress has an important influence on the aluminum accumulation process, as as the subsequent growing season progresses, plants can adapt to the harsh conditions (Ofoe et al., 2023). This adaptation may lead to a reduction in the content and uptake of aluminum, as plants exhibiting higher stress tolerance may reduce the accumulation of this element in response to adverse environmental conditions. Excessive intakes of sodium and aluminum can adversely affect health, so monitoring these components in food products is important. For this purpose, their intake was estimated, assuming that the analysis is based on 100 grams of product (Table 3).

According to Polish standards (Jarosz et al., 2020), the recommended intake level for sodium has been established at 1500 mg·day^{-1}. Consumption of 100 g of Jerusalem artichoke tubers will contribute to providing 3.2% of this nutrient in the diet. In contrast, based on the value determined by EFSA [2008], consuming the same amount of Jerusalem artichoke may supply 1.29 mg of aluminum, which, for a person weighing 70 kg, will account for less than 2.0% of the tolerable weekly intake. It is important to note that these calculations pertain to Jerusalem artichokes with the skin, and these values may change when analyzing only the edible parts of the tubers.

CONCLUSIONS

To the best of authors' knowledge, this is the first study analyzing the effect of biostimulant application on sodium and aluminium content and uptake in tubers of two Jerusalem artichoke varieties. The results of the study showed that the application of biostimulants can increase the content and uptake of beneficial elements such as sodium, while reducing potentially toxic elements such as aluminium. Variable response of Jerusalem artichoke tubers to the application of different biostimulant variants was observed, with the results also depending on the plant variety, the duration of the experiment and the prevailing weather conditions. The variability in results highlights the need for further research to precisely determine the mechanisms of action of biostimulants in the context of individual varieties, taking into account environmental and weather conditions that may modify their effectiveness.

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