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Selected morphological and physiological traits of *Helianthus tuberosus* L. and their relationship with yield under the application of biostimulants

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ABSTRACT

Jerusalem artichoke (*Helianthus tuberosus* L.) is a plant with high yield potential. Biostimulants can increase the quality and quantity of the raw material obtained. The aim of this study was to evaluate the effects of the application of four biostimulants on the relationship between plant height, chlorophyll content (SPAD index), and yield of Jerusalem artichoke plants. The field study was conducted for three years in a split-plot design with three replicates. The first factor considered was two cultivars of Jerusalem artichoke (Albik and Rubik), while the second factor was the biostimulant application variants (B1, B2, B3, B4) and the control variant (C). The biostimulant variants used in the experiment increased chlorophyll content (by 5.6%), plant height (by 6.8%), and total yield (by 28.7%) compared to the control variant. In addition, the mean values of plant height and SPAD indices showed significant positive correlations with tuber yield at all time points, highlighting the importance of morphological and physiological traits for yield prediction. The investigated traits varied depending on cultivar and crop year, indicating the need for further research.

Keywords: plant height, photosynthetic pigment, Jerusalem artichoke.

INTRODUCTION

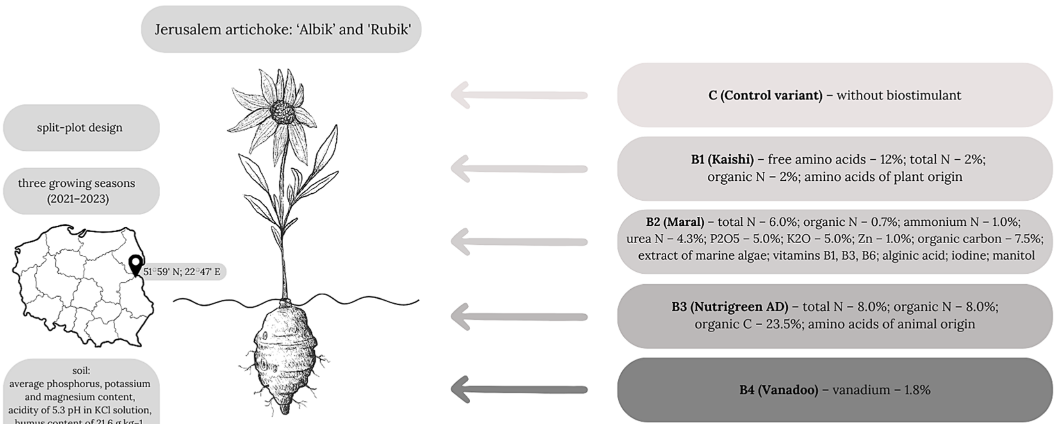
Jerusalem artichoke is a versatile tuberous plant that finds applications not only in the food industry but also in the production of medicines, cosmetics, biofuels, and feed (Chauhan et al., 2025). It is a source of valuable components, including inulin, which has been shown to have health benefits (Dubkova et al., 2021), and is widely used as a prebiotic and functional food (Puangbut et al., 2015; Ruttanaprasert et al., 2016a).

Helianthus tuberosus L. is a species with high yield potential that can reach a height of up to 4 m, depending on the variety. The plant forms numerous side shoots and has a different number of leaves on each shoot. Chlorophyll, the most important photosynthetic pigment, reacts with and absorbs visible light during photosynthesis (Nardi et al., 2021). Its content per unit leaf area (chlorophyll density) indicates the photosynthetic and growth capacity of many crops. It is a key parameter for assessing the growth performance of plants (Ruttanaprasert et al., 2016b). The photosynthetic rate is correlated with the chlorophyll concentration of the leaves. The SPAD meter provides a quick, simple, and practical method for measuring chlorophyll content (SPAD index) in leaves. There is a correlation between chlorophyll content in Jerusalem artichoke leaves, plant height, and total yield (Li et al., 2019). Biostimulants activate and regulate defence mechanisms through their action. They can be applied directly into the leaves, into the soil near the root system. Biostimulants on the basis of proteins and amino acids can penetrate directly into the leaf tissue and enter the cells. Protein hydrolysate-based biostimulants enter the plant cell by diffusion processes through membrane pores, while microorganism-based fractions penetrate tissues and form symbiotic or mycorrhizal associations. When biostimulants reach the leaves or roots, they are displaced and distributed to other parts of the plant (Rai et al., 2021). Biostimulants intensify chlorophyll synthesis, and accelerate plant growth and the development of the root system even under unfavorable conditions (Ertani et al., 2018; Yakhin et al., 2017; Popko et al., 2018). A study by Soppels et al. (2019) showed that plant-derived preparations increase chlorophyll content and stimulate plant growth. On the other hand, the results of De Pascale et al. (2018) and Rouphael et al. (2017) indicate that certain values of the SPAD index are a good indicator of the efficiency of nutrition with biostimulants to maximize yields. Adequate fertilization with biostimulants allows the full exploitation of production potential by promoting plant nutrition and reducing the adverse effects of abiotic stress (such as drought, salinity, suboptimal temperatures, or low soil fertility) (Carrão et al., 2016; Calvo et al., 2014). In Jerusalem artichoke cultivation, their use leads to higher and qualitatively better yields, plant growth, and increased chlorophyll content (Puangbut et al. 2022). In addition, biostimulants stimulate the development of leaves, stems, and roots and replenish nutrients lost due to drought, agrotechnical errors, and fluctuating temperature conditions. Therefore, these formulations have great potential to mitigate the effects of abiotic stress factors exacerbating climate change while maintaining high crop productivity and quality, which is crucial for food and nutritional security (Franzoni et al. 2022). The aim of this study was to evaluate the influence of biostimulants, cultivars, and research years on the relationship between morphological-physiological traits and yield of Jerusalem artichoke.

MATERIAL AND METHODS

The experiment involved two varieties of Jerusalem artichoke and four biostimulant application variants (B1, B2, B3, B4), along with a control variant (C). A detailed schematic of the experimental design is presented in Figure 1.

The agrotechnical treatments applied in the experiment were carried out by the requirements of good agricultural practice. The soil of the experiment was tawny soil with the granulometric composition of sandy loam. The following soil parameters were determined: P – 35.2–41.0, K – 102.1–125.1, Mg – 36.6–42.1, and the content of total forms (mg kg^{-1} soil): Mn – 56.7–328.0, Cu –1.85–3.10, Zn – 18.45–36.52, and Fe – 5029.2–4200.0. The biostimulants were applied according to the manufacturer's recommendations. No pests or diseases were observed during the study period. Chlorophyll content was measured three times at 10-day intervals (II, II, III terms) in each year of the experiment. Measurements were



Agrotechnical treatments	Specification	Dates
Fertilization	mineral fertilizers: 43.0 kg ha-1 P (46% TSP triple superphosphate), 124.5 kg ha-1 K (60% potassium salt) and 100 kg ha-1 N (34% ammonium salt)	autumn, spring – before planting
Planting of topinambur tubers	spacing 0.65 x 0.30 m	second week of April
Weed control	mechanical weeding and biostimulants (Kaishi, Maral, Nutrigreen AD, Vanadoo)	after planting to rows closure
Harvesting of topinambur tubers	physiological maturity	first week of November

Figure 1. Experimental design, including the applied biostimulant variants and conducted agrotechnical treatments

performed using a hand-held SPAD-502 Plus meter (Konica Minolta, Osaka Japan), which measures light absorption by leaves at 650 and 940 nm and was made available for research by the Regional Research Centre EKO-AGRO-TECH in Biała Podlaska. The measurements (10 measurements) were taken on the upper leaves of the fourth or fifth joint from the tips of the plants at the stage of tuber formation, around 9 o'clock of a fully developed leaf. Jerusalem artichoke was harvested at the time of technological maturity of the tubers, i.e., before the onset of frost; then all tubers were weighed. The tuber yield was calculated based on fresh weight as tons per ha.

The study analyzed the variability of weather conditions (mean rainfall and air temperature), from which the hydrothermal index (K) value was calculated (Fig. 2) (Skowera et al., 2014).

The results of the investigations represent the average of the three years of the study. The results obtained were statistically using the analysis of variance (ANOVA). The Fisher-Snedecor F-test was performed to evaluate the differences in the parameters studied, while the significance of the differences between the means was evaluated using the Tukey Honest Significance Differences (HSD) test. The relationship between plant height, SPAD index, and yield was analyzed using Pearson's linear correlation coefficient. A significance level of $p \leq 0.05$ was assumed. All calculations were made in Excel 2016 using the authors' algorithm by using the mathematical model:

$$Yijl = m + ai + gl + e/1/il + bj + abij + e/2/ijl \quad (1)$$

Yijl means value of characteristic researched: I means the level of A (cultivars) j means the level of B (cultivars) in the first replication, m means the experimental average, ai means the effect of i-level of A (cultivars), gl means the first replication effect, e/1/il means the random effect of a (cultivars) with replications, bj means the effect of j-level of B (variants), abij means the interaction effect of A (cultivars) and B (variants), e/2/ijl means random error.

RESULTS AND DISCUSSION

The degree of greening measured by chlorophyll concentration is a plant trait often monitored under stress conditions to assess the effect of remaining green in plants (Tuberosa, 2012). In this study, variations in the tested factors were observed depending on the type of biostimulant applied, the cultivar, and the growing season and were assessed across three experimental dates spaced ten days apart. The SPAD index ranged from 50.35 to 75.04 units (Table 1). Comparatively lower values reported by Ruttanaprasert et al. (2012) and Puangbut et al. (2017) may be attributed to trials conducted under stress conditions or without biostimulant application.

The SPAD index varied significantly between Jerusalem artichoke cultivars. At the II term, the Albik cultivar exhibited a higher SPAD index, whereas the Rubik cultivar recorded a significantly lower value. Conversely, during the I and III terms, the Rubik cultivar exhibited higher SPAD index values (Table 1). Chaimala et al. (2023) reported similar cultivar-dependent differences in leaf greenness index. The present study also confirmed the absence of interaction between the tested cultivars and the biostimulant variants across all three measurement dates.

In the studies conducted, SPAD values depended on the biostimulant variants used. The preparations increased the SPAD index value compared to

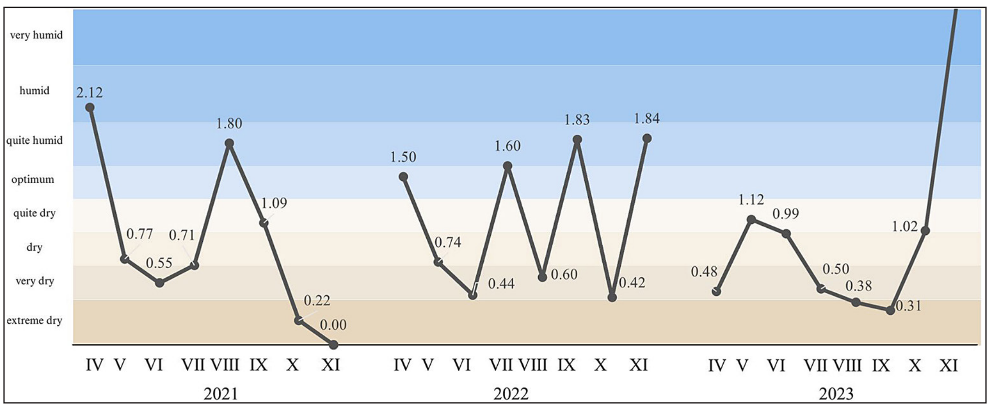


Figure 2. The hydrothermal index value during the three-year experiment

Table 1. Index SPAD depending on cultivar end on weather conditions during the years 2021–2023

Biostimulants	Cultivars - Index SPAD – I term			Years		
	Albik	Rubik	2021	2022	2023	Mean
C	46.95^{A}	50.09^{A}	49.37^{A}	46.22^{A}	49.97^{A}	48.52^{a}
B1	47.90^{A}	51.71^{A}	50.88^{A}	47.58^{A}	50.97^{A}	49.81^{a}
B2	49.85^{A}	52.09^{A}	52.00^{A}	48.21^{A}	52.62^{A}	50.97^{a}
B3	50.30^{A}	52.99^{A}	52.55^{A}	49.18^{A}	53.22^{A}	51.65^{a}
B4	49.67^{A}	51.90^{A}	51.95^{A}	47.979^{A}	52.43^{A}	50.78^{a}
Mean	48.94^{a}	51.90^{b}	51.37^{a}	47.83^{b}	51.84^{a}	50.35
Biostimulants	Index SPAD – II term					
C	58.09^{A}	49.10^{A}	46.25^{A}	56.78^{A}	57.75^{A}	53.59^{c}
B1	60.11^{A}	50.39^{A}	48.12^{A}	59.27^{A}	58.37^{A}	55.25^{b}
B2	62.01^{A}	52.13^{A}	50.30^{A}	61.10^{A}	59.82^{A}	57.07^{a}
B3	60.81^{A}	51.62^{A}	49.22^{A}	60.19^{A}	59.25^{A}	56.22^{a}
B4	63.10^{A}	53.11^{A}	51.10^{A}	62.85^{A}	60.37^{A}	58.11^{a}
Mean	60.82^{a}	51.27^{b}	49.00^{b}	60.04^{a}	59.1^{a}	56.05
Biostimulants	Index SPAD – II term					
C	58.09^{A}	49.10^{A}	46.25^{A}	56.78^{A}	57.75^{A}	53.59^{c}
B1	60.11^{A}	50.39^{A}	48.12^{A}	59.27^{A}	58.37^{A}	55.25^{b}
B2	62.01^{A}	52.13^{A}	50.30^{A}	61.10^{A}	59.82^{A}	57.07^{a}
B3	60.81^{A}	51.62^{A}	49.22^{A}	60.19^{A}	59.25^{A}	56.22^{a}
B4	63.10^{A}	53.11^{A}	51.10^{A}	62.85^{A}	60.37^{A}	58.11^{a}
Mean	60.82^{a}	51.27^{b}	49.00^{b}	60.04^{a}	59.1^{a}	56.05
Biostimulants	Index SPAD – III term					
C	66.66^{A}	76.59^{A}	84.67^{A}	73.21^{A}	57.00^{A}	71.63^{b}
B1	68.84^{A}	78.42^{A}	86.67^{A}	74.96^{A}	59.27^{A}	73.63^{a}
B2	72.72^{A}	78.63^{A}	89.33^{A}	75.15^{A}	62.54^{A}	75.67^{a}
B3	73.53^{A}	80.35^{A}	90.50^{A}	76.48^{A}	63.83^{A}	76.94^{a}
B4	75.67^{A}	78.93^{A}	90.17^{A}	76.42^{A}	65.30^{A}	77.30^{a}
Mean	71.48^{c}	78.58^{b}	88.27^{a}	75.25^{b}	61.59^{c}	75.04

Note: C – ontrol variant; B1 – Kaishi; B2 – Maral; B3 – Nutrigreen AD; B4 – Vanadoo. Means followed by the same letters do not differ significantly at $p \leq 0.05$. Means in columns marked with capital letters refer to interactions between the factors. Means in the last column and in the last row (followed by lowercase) are for variants and cultivars.

the control variant, the average SPAD index value of the control variant from three measurements was 57.9 units and the average of all biostimulants was 61.1 units, indicating a 5.6% increase. The highest readings were recorded after the application of biostimulant B3 on the I term (6.5% increase compared to the control variant) and B4 on the II and III terms (8.4% and 7.9% increase, respectively) (Table 1). Similar effects of biostimulants on increasing chlorophyll content were reported in studies by other authors conducted on different plant species. An increase in the SPAD index following biostimulant application has also been observed in potatoes (Rakibuzzaman et al., 2021; Mystkowska, 2022), strawberries (Soppelsa et al., 2019), and spinach (El-Nakhel et al., 2022). The convergence of the results indicates the versatility of the action of biostimulants in improving plant physiological functions.

The study revealed a significant effect of the research years on the SPAD index. The highest SPAD values, averaging 88.27 units, were recorded in 2021 during the III term in August – a season characterized by a hydrothermal index of 1.8, indicating quite wet conditions. Conversely, the lowest SPAD values for the III term, averaging 61.59 units, were observed in 2023, a year marked by high humidity but the lowest mean air temperature and a K-factor of 0.39 in August, reflecting extreme drought conditions (Fig. 2).

No significant interaction was found between the study years and the biostimulant application variants concerning the SPAD index measured at the three-time points (Table 1). The impact of seasonal temperature variation on plant development and tuber yield was similarly confirmed by Puangbut et al. (2015). Furthermore, Ruttanaprasert et al. (2012) highlighted the influence of water stress on physiological traits, supporting the observed year-to-year variability in SPAD values.

The height of Jerusalem artichoke plants was determined by the cultivated varieties, biostimulant application variants, and weather conditions (Table 2). The highest plants were recorded in the Albik variety, and the lowest in the Rubik variety. The average height of Jerusalem artichoke plants in the study by Pinmongkhonkul et al. (2021) was lower (170.2 cm) compared to the results obtained in the present experiment, which can be attributed to the lack of biostimulant application, which has been shown to enhance plant growth. The biostimulants used significantly increased plant height, compared to the control object (by 6.8%). The highest height at the I and II terms was recorded after the application of biostimulant B2 (by 11.6% and 8.2%, respectively) (Table 2). Moreover, drought stress can alter physiological responses under biostimulant applications, which explains how plants can maintain high yields. A positive effect on plant height was also shown in the studies by Puangbut et al. (2022). Weather conditions during the growing season significantly differentiated plant height (Table 2). The highest plants were in 2021 and the lowest in 2023. The study showed that photosynthetic traits at the three measurement dates were strongly correlated with morphological traits, such as height, in all cultivars (Nasir and Toth 2021).

Figure 3 shows the average tuber yield (t/ha) of two Jerusalem artichoke varieties (Albik and Rubik) depending on the applied biostimulant variant and the control variant over the three years of the study.

The Jerusalem artichoke is known for its high yield potential. Under optimal soil conditions and sufficient water availability, the fresh biomass yield can reach 200 t/ha, while the tuber yield can exceed 90 t/ha (Cieślik and Filipiak-Florkiewicz, 2000). In the study by Góral (1999), the tuber yield of Jerusalem artichoke ranged from 18.3 to 34.2 t/ha, whereas in the present study, the tuber yield for the control variant varied between 23.29 and 43.74 t/ha.

In the case of the Albik variety, the highest yield was observed in variant B4 in all years (an increase of 38.9% relative to the control variant), with the highest value obtained in 2021 (52.92 t/ha). The Rubik variety showed a lower

Table 2. Plant height Jerusalem artichoke depending on cultivar end on weather conditions during the years 2021–2023

Biostimulants	Plant height – I term					
	Cultivars		Years			
	Albik	Rubik	2021	2022	2023	Mean
C	190.40^{A}	199.73^{A}	198.75^{A}	206.35^{A}	180.15^{A}	195.08^{a}
B1	212.73^{A}	204.73^{A}	217.85^{A}	212.20^{A}	196.15^{A}	208.73^{a}
B2	223.40^{A}	209.40^{A}	228.75^{A}	221.90^{A}	202.20^{A}	217.61^{a}
B3	210.00^{A}	208.23^{A}	215.35^{A}	210.70^{A}	200.35^{A}	208.80^{a}
B4	206.80^{A}	198.50^{A}	212.55^{A}	211.70^{A}	183.70^{A}	202.65^{a}
Mean	208.66^{a}	204.12^{b}	214.65^{a}	212.57^{a}	192.51^{b}	206.65
Biostimulants	Plant height – II term					
C	203.40^{A}	214.10^{A}	197.20^{A}	205.30^{A}	178.60^{A}	208.75^{c}
B1	225.70^{A}	219.70^{A}	217.30^{A}	211.20^{A}	194.60^{A}	216.70^{b}
B2	236.30^{A}	224.70^{A}	228.70^{A}	217.10^{A}	200.70^{A}	225.90^{a}
B3	223.00^{A}	223.20^{A}	215.80^{A}	209.70^{A}	198.80^{A}	223.10^{a}
B4	219.80^{A}	223.50^{A}	211.50^{A}	210.70^{A}	182.70^{A}	221.65^{a}
Mean	221.64^{a}	221.04^{a}	214.70^{a}	210.80^{b}	191.00^{c}	221.65

Note: C – control variant; B1 – Kaishi; B2 – Maral; B3 – Nutrigreen AD; B4 – Vanadoo. Means followed by the same letters do not differ significantly at $p \leq 0.05$. Means in columns marked with capital letters refer to interactions between the factors. Means in the last column and in the last row (followed by lowercase) are for variants and cultivars

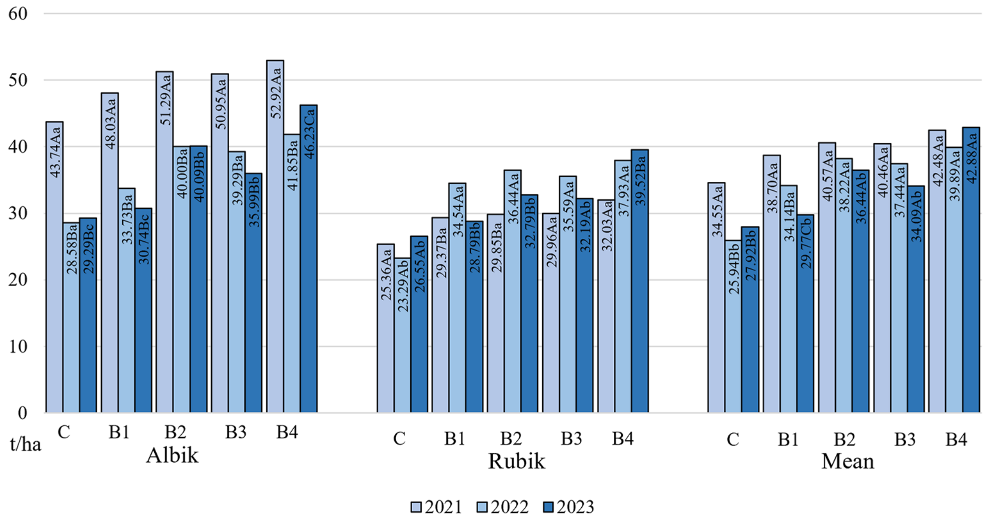


Figure 3. Tuber yield of Helianthus tuberosus L. depending on the variety and biostimulant variant in the years 2021–2023. Differences between the applied biostimulants are marked by lowercase letters, and differences between years are indicated by uppercase letters. Abbreavations: C – control variant; B1 – Kaishi; B2 – Maral; B3 – Nutrigreen AD; B4– Vanadoo

yield compared to Albik, with the most favorable change following the application of biostimulant B4 in all years (45.6% increase in yield), with the highest yield achieved in 2023 (39.52 t/ha).

The average yield values across all variants demonstrated the positive effect of biostimulants in enhancing yield compared to the control variant over all study years, with an average increase of 28.7%. Zhang et al. (2024) observed yield increases ranging from 20.22% to 105.22% in *Helianthus tuberosus* L. when fertilized with varying doses of potassium. Similarly, Sakr et al. (2024) reported comparable yield improvements in Jerusalem artichoke following foliar application of raffinose and dextrin. This suggests that the biostimulatory effect of the substances tested in this study may operate through similar mechanisms, such as increased plant sugar availability.

In the Albik variety, the yield obtained in 2022 and 2023 was lower compared to the first year of the experiment, which can be attributed to adverse weather conditions. During the initial growth period of the plant in May and June, the average K value was 0.66 in 2021 and 0.59 in 2022, which may have caused mild water stress. However, this should not have significantly impacted in Jerusalem artichoke, as it is known for its good tolerance to water shortages. In July and August, higher K values (1.26 and 1.10 on average) indicated improved conditions, which could have supported higher yields. Conversely, in 2023, extreme drought conditions occurred during the early tuberization phase. This likely resulted in stunted growth, reduced yields, and decreased tuber quality, as the plants did not receive enough water to sustain their growth and development. The variability in rainfall and temperature during critical stages of plant development may have influenced the efficiency of tuberization and, ultimately, the final yield.

It is worth noting that, while the Albik variety had lower yields in subsequent years of the experiment compared to 2021, the Rubik variety had significantly higher yields in the same years relative to the first year of the experiment. In 2022, Rubik's yield was highest in the B1, B2 and B3 variants, and in 2023 in the control and B4 variants. The genetics of the varieties indicate a different response to weather conditions, different sensitivity to water availability, temperature and precipitation at critical points in the growth of the two varieties of Jerusalem artichoke which may ultimately determine the different yields and their quality.

Correlations were observed between plant height, the SPAD index, and total tuber yield based on the average results of the three years of the study (Table 3). Significant positive correlations were found between plant height at the I and II terms and tuber yield, as well as between the SPAD index at the I, II, III terms and tuber yield. Similar findings were reported by Ruttanaprasert et al. (2016a), who also observed positive correlations between the SPAD index and the harvest

Table 3. Correlations between plant height and SPAD index and total tuber yield in 2021–2023

Parameter	Correlation coefficient
Plant height – I	0.9810
Plant height – II	0.9987
Index SPAD – I	0.9905
Index SPAD – II	0.9821
Index SPAD – III	0.9992

index. The relationships between plant height and average SPAD index values emphasize the importance of both morphological and physiological traits in yield prediction. These relationships may serve as a basis for optimizing Jerusalem artichoke cultivation strategies, particularly in biostimulant application.

CONCLUSION

The study demonstrated the impact of cultivars, biostimulants, and growing seasons on the physiological (SPAD value) and morphological (plant height) traits of Jerusalem artichoke. The application of biostimulants increased the SPAD leaf greenness index and plant height in the two cultivars compared to the control. Significant relationships were observed between plant height, SPAD index, and tuber yield, highlighting their relevance in assessing yield potential. Differences between cultivars and growing seasons emphasize the role of environmental factors. Further research is required to more precisely assess the influence of these factors on the variability of the studied traits.

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