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Evaluation of the Effect of Biostimulants on Palatability and Flesh Darkening of Raw and Cooked Tubers of *Helianthus tuberosus*

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ABSTRACT

The purpose of the conducted research was to evaluate the effect of four biostimulants on the palatability and darkening of the flesh of raw and cooked tubers according to a 9-degree scale of two varieties of 'Albik' and 'Rubik' of Jerusalem artichoke – JA (*Helianthus tuberosus* L.). Field trials were conducted in 2021–2022 with biostimulants on an individual farm in Międzyrzec Podlaski, Poland. The experiment was established using the randomized sub-block (split-plot) method. 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, 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 methods of applying biostimulants did not change the palatability and darkening of the flesh of cooked tubers, and raw tubers after 1 hour, but had a significant effect on the darkening of the flesh of raw tubers 10 minutes after cutting. The raw and cooked flesh of the 'Albik' variety darkened the least, and this variety proved to be the most palatable on a scale of 1–9.

Keywords: flesh darkening, flavor, abiotic stress, tuber sunflower.

INTRODUCTION

Jerusalem artichoke JA (*Helianthus tuberosus* L.), a plant native to North America, belongs to the *Compositae* (*Asteraceae*) complex family. It is characterized by high yield potential (Krochmal-Marczak et al., 2022; Register. arimr. gov. pl, 2023; Sawicka, 2016), good tolerance to frost, drought, poor soil as well as strong resistance to pests and plant diseases, with minimal or no fertilizer requirements compared to conventional agricultural crops (Slimestad et al., 2010; Lakíc et al., 2018). In Poland, this species is commonly referred to as topinambur (Yang et al., 2015). In recent years, the interest of producers and nutritionists in this species has increased due to the quality of the tubers, which have become a raw material for the production of functional food ingredients such as inulin, oligofructose and fructose (Ma et al., 2011; Puyanda et al., 2020). In Poland in 2022, topinambur cultivation was about 2,000 hectares (Register. arimr. gov. pl, 2023). The concept of tuber quality of *Helianthus tuberosus*, in addition to high nutrient content, especially carbohydrates and protein, includes good culinary properties (taste, aroma, color, texture, low tendency to darken raw and cooked tubers). JA tubers, compared to potato tubers, are juicier, sweeter and more tender, in addition, they are characterized by high nutritional and energetic value and a wide variety of shapes (Trawczyński, 2020). Topinambur is resistant to biotic and abiotic stresses (Yang et al., 2015). Nutrient and water deficiency during the growing season of *Helianthus tuberosus* and other stresses caused changes related to darkening of the flesh of raw and cooked tubers and deterioration of the taste of topi-nambura.

Biostimulants were used to obtain better quality JA tubers and improve yield. The main advantages of biostimulators include stimulation of tuber growth and development, control and acceleration of vital processes, and enhancement of plant resistance to stress conditions. In addition, biostimulators increase the effectiveness of plant protection measures and plant nutrition by providing the plant with essential nutrients, as well as accelerate plant regeneration after a stress factor (Yang et al., 2015; Kołodziejczyk and Gwóźdź, 2022). Due to their mode of action, they are safe for humans, animals and the environment (Caradonia et al., 2022). Despite the fact that topinambur easily adapts to the environment (Gao et al., 2020; Fang et al., 2018), has low requirements and is resistant to stresses, the application of biostimulants in the study (El-Anany, 2020) had a beneficial effect on tuber yield. The research hypothesis was as follows: assume that the improvement of selected characteristics of consumption quality (palatability and darkness of flesh of raw and cooked tubers after 10 minutes and after 1 hour) was influenced by the application of biostimulants. The purpose of this study was to determine the effect of using biostimulators on the palatability and flesh darkening of raw and cooked topinambur tubers.

MATERIAL AND METHODS

The study material came from a field experiment located in central-eastern Poland (Międzyrzec Podlaski) (51°59' N and 22°47' E), in 2021–2022, shown in Figure 1. The experiment had a two-factor design with randomized blocks, in three replications, as a two-factor design: first factor – varieties ('Albik' and 'Rubik'), second factor – variants of foliar application of biostimulants (Kaishi, Maral, Nutrigreen AD, VANADOO) at three dates at a dose of 2.0 dm·ha-1 and a control variant (Table 1). All tillage treatments were carried out according to the principles of the latest agrotechnology. The forecrop under topinambur was winter triticale. Before winter, natural fertilization was applied with manure 25 t·ha-1 then plowed with pre-winter plowing. JA tubers were planted in spring in the second decade of April at a depth of 8 cm. The plot area was 18 m^2 Before planting, harrowing and mineral fertilization were performed. Fertilization with nitrogen in the form of urea (46%) at a rate of 80 kg·ha-1, phosphorus fertilizer in the form of triple superphosphate (48%) at a rate of 70 kg P2O5·ha-1, and potassium fertilizer in the form of potassium salt (60%) at a rate of 124 kg K·ha-1. Harvesting was carried out in the second decade of November. During harvesting the fresh weight yield of tubers was determined. Approximately 5 kg were sampled for testing in the laboratory.

Soil characteristics

Soil samples were taken annually before the start of the experiment in accordance with the current standard, and soil physicochemical analyses are shown in Figure 2.

Meteorological conditions

Summary of monthly precipitation (in the form of a bar graph) and air temperature (in the

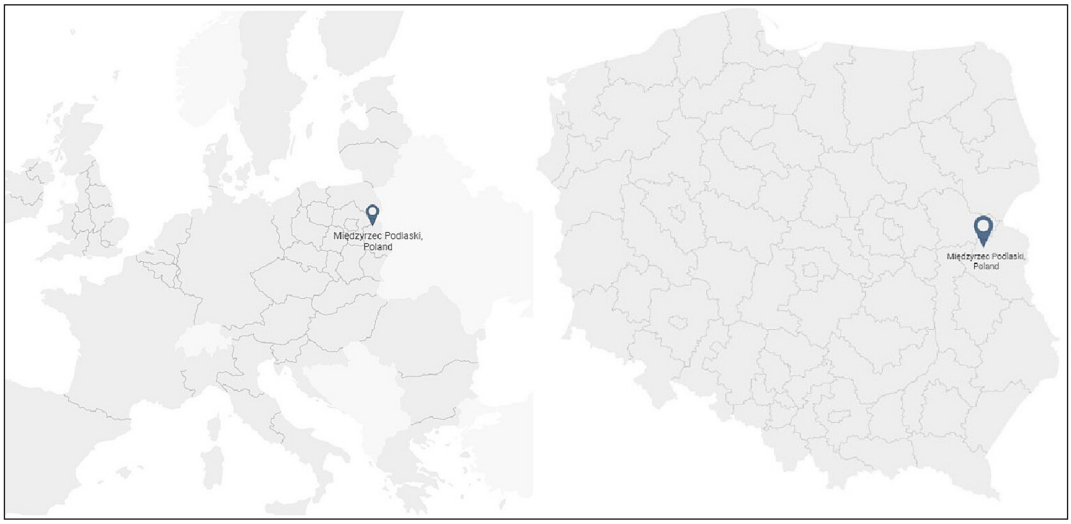

Figure 1. Location of conducting the field experiment, Międzyrzec Podlaski, (51°59ˈN and 22°47ˈE), Poland

Table 1. The factor of the experiment

Cultivar	Characteristics and origin
Albik	Bred by Prof. S. Góral at the Plant Breeding and Acclimatization Institute in Radzików i registration in 1997 (Gacek, 1998). The variety late. Tubers are spherical in shape with white flesh, cream skin. The cultivar yields 24-34 t ha^{-1}. Tubers are difficult to separate from the root, as they are set on short, nodeless stalks (Fig. 3a).
Rubik	Bred by Prof. S. Góral at the Plant Breeding and Acclimatization Institute in Radzików i registration in 1997 (Góral, 1998). The variety late has a machete shape, red-purple skin and white flesh. The cultivar yields 23-30 t ha^{-1} (Sawicka, 2016). Green weight yield is twice that of tubers (Piskier, 2009) (Fig. 3b).
Preparations	Operation and composition
Kaishi	Free amino acids - 12%, total N - 2%, organic N - 2%, contains amino acids produced by enzymatic hydrolysis of plant-derived proteins, stimulates plant growth and development and promotes root system development.
Maral	NPK+Zn (6-6-5+1% Zn), Composition Total nitrogen N - 6% including organic N - 0.7%, Ammonium N - 1% Urea N - 4.3%, P2O5 - 5%, K2O - 5%, Zn -1%, organic carbon- 7. 5%, in addition, it contains extract of marine algae: Acophyllum Nodosum, Laminaria, Digitata, Fucus, phytohormones: gibberellins, cytokines, auxins, betaine, amino acids, vitamins: B1, B3, B6, alginic acid, iodine, manitol. It stimulates the natural ability of plants to defend themselves against stress, improves the efficiency of stomata and pollen volatility, improves the quantity and quality of the crop.
Nutrigreen AD	Total N - 8%, organic N - 8%, organic C - 23.5%. Contains amino acids of animal origin which are formed by enzymatic process, stimulates vegetative growth of plants, stimulates yield.
Vanadoo	Vanadium 1.8%, affects tuber yield and quality, increases sugar synthesis 2.5 times.

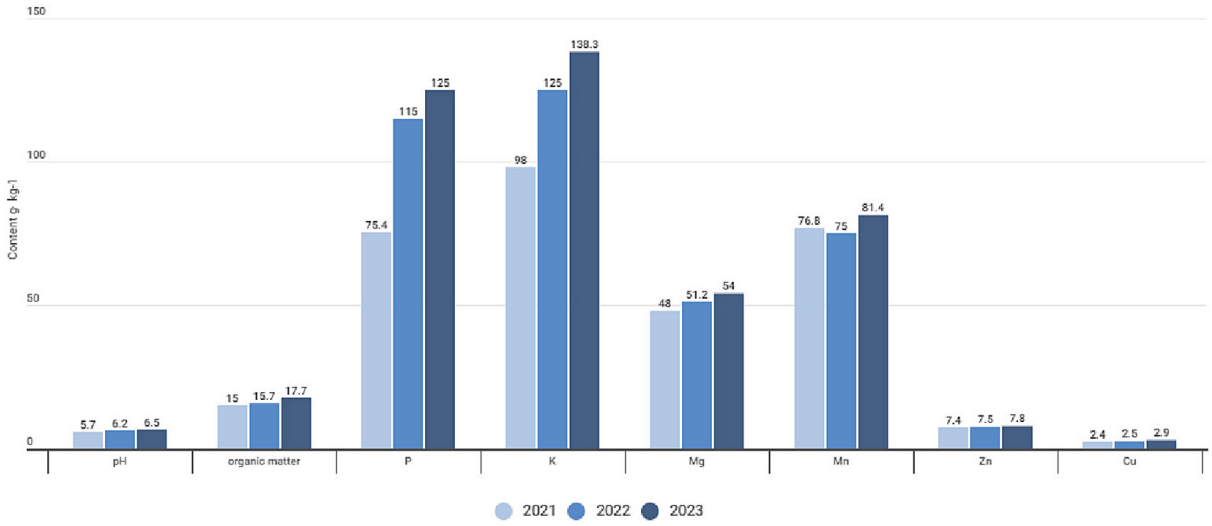

Figure 2. Soil parameters

a)

b)

Figure 3. Tubers of *Helianthus tuberosus* cultivar 'Albik' (a) and 'Rubik' (b)

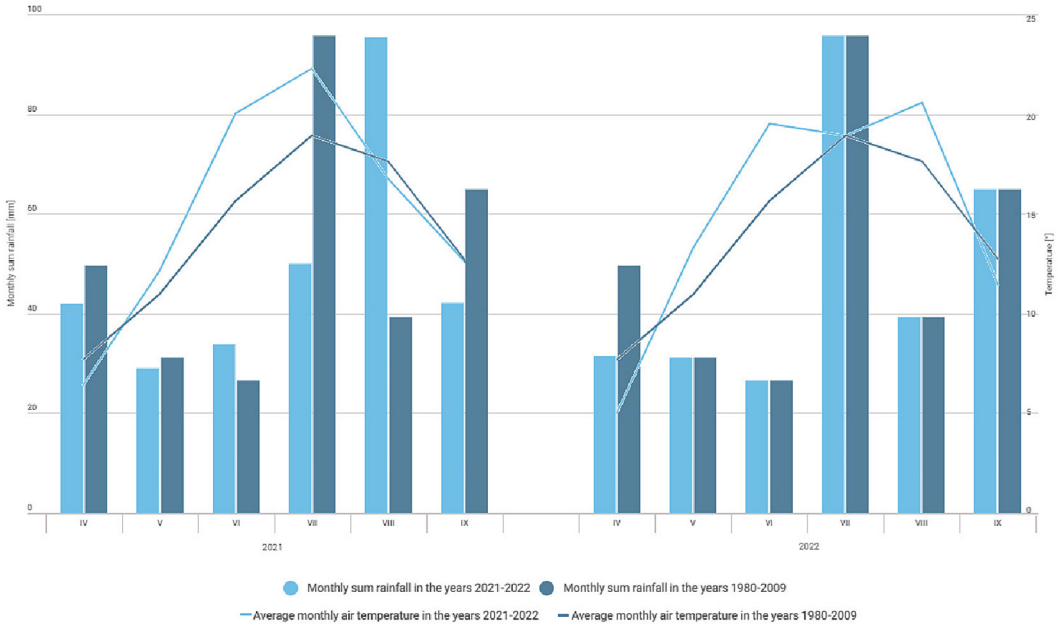

Figure 4. A comparison of monthly precipitation and air temperature for 2021-2022 and 1980-2009 averages

form of a line graph) in the years of conducting the experiment and averages from 1980-2009 during the JA growing season (Fig. 4.).

Chemical analysis

Analysis of palatability and flesh darkening of raw and cooked Helianthus tuberosus tubers was carried out by a team of five people, 2 days after tuber harvesting. Twenty intact tubers of medium-sized Jerusalem artichoke were each taken for testing. Determination of the darkening of the flesh of the raw tubers was made after they were cut 10 minutes and 1 hour after cutting, using a nine-point inverted scale from the table, in which 9 means unchanged color, i.e. no darkening, and 1 means the darkest darkening. The darkening of the flesh of cooked tubers was evaluated 10 minutes and 1 hour after cooking according to the 9º, Danish color scale, where 9 means unchanged color, 1 means strong darkening, black flesh. Tastiness was evaluated using a nine-point scale, where a score of 9 means very good and 1 means very bad (Roztropowicz, 1999).

Statistical analysis

The results of the study were statistically processed using analysis of variance. The significance of differences at $P < 0.05$ between the compared averages was assessed using Tukey's multiple intervals. Significance of sources of variation was tested using the Fischer-Sendecor test (Koronacki, 2009).

RESULTS AND DISCUSSION

Darkening of the flesh of raw tubers of Helianthus tuberosus after 10 minutes

The evaluation of the darkening of the flesh of raw tubers of Helianthus tuberosus in the tests performed 10 minutes after cutting the tubers averaged 8.73 degrees on a 9-point scale. There was a significant effect of variants of biostimulant application and weather conditions during the growing seasons (Fig. 4.). The flesh of Jerusalem artichoke tubers darkened the least after application of the biostimulants Maral and Vanadoo. These biostimulants contributed to a decrease in darkening compared to the control object. The applied biostimulants in each variant caused a reduction in the darkening of raw tuber flesh after 10 minutes, resulting in a decrease in abiotic and biotic stress (Skiba, 2014; Lakic et al., 2007). Lower flesh darkening of the tested varieties characterized the 'Albik' variety, as it contained fewer phenolic compounds in its composition and is thus less prone to darkening (Wszelaczyńska, 2004; Florkiewicz et al., 2007). Darkening of raw tuber flesh was considered by many authors as a genetic trait (Sawicka and Krochmal-Marczak, 2007; Honauz et al., 2005). No significant effect of varieties on the evaluated trait of consumption value was shown. It was shown that the tubers darkened to the greatest extent in 2022, which turned out to be the coldest and wettest year (Fig. 4). The tubers harvested in 2021 were less prone to darkening.

The effect of weather conditions on this trait was noted by (Hamouz et al., 2005). There was no interaction of years with modes of biostimulant application, varieties with modes of biostimulant application, or years with experimental factors. The authors (Florkiewicz et al., 2007; Sawicka and Krochmal-Marczak, 2007; Wszelaczyńska, 2004; Sawicka, 2002), reported that the tubers of the cultivar 'Albik' contain in their composition about 22 mg 100 g-1 fresh weight of phenolic acids, the content of which in the tubers of the tested cultivars varied depending on the applied biostimulants in the years of the study, causing oxidation, which is responsible for the darkening of freshly peeled tubers of Helianthus tuberosus (Danielcenko et al., 2013; Cieślik et al., 2005; Cieślik et al., 2003)(Fig. 5. and Fig. 6.).

Darkening of the flesh of raw tubers of Helianthus tuberosus after 1 hour

The evaluation of the flesh darkening of JA raw tubers, made one hour after cutting, averaged 7.77 degrees on a 9-point scale. The flesh

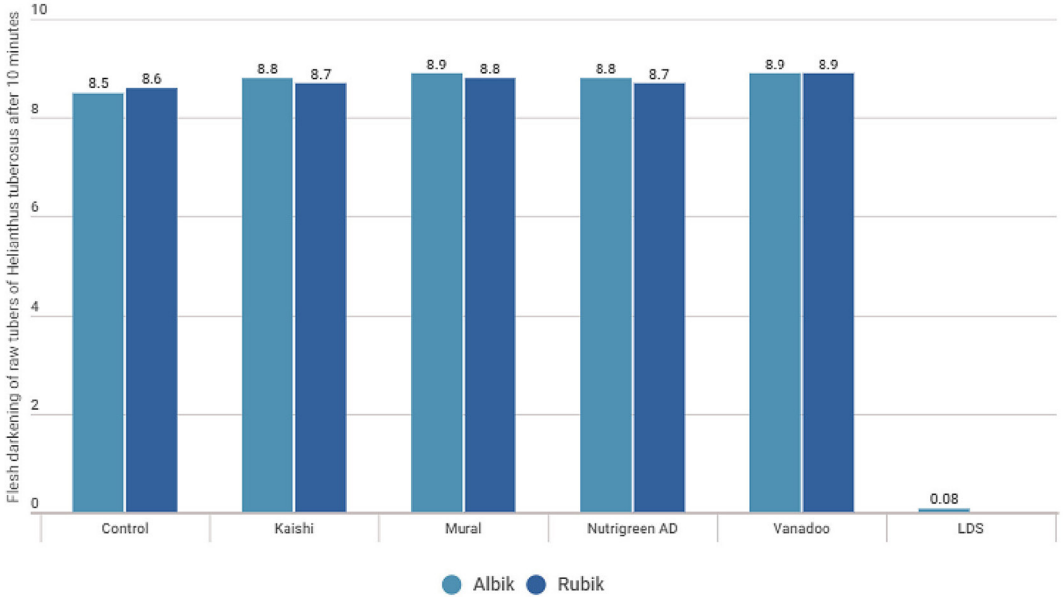

Figure 5. Darkening of the flesh of raw 'Albik' and 'Rubik' tubers after 10 minutes at individual sites

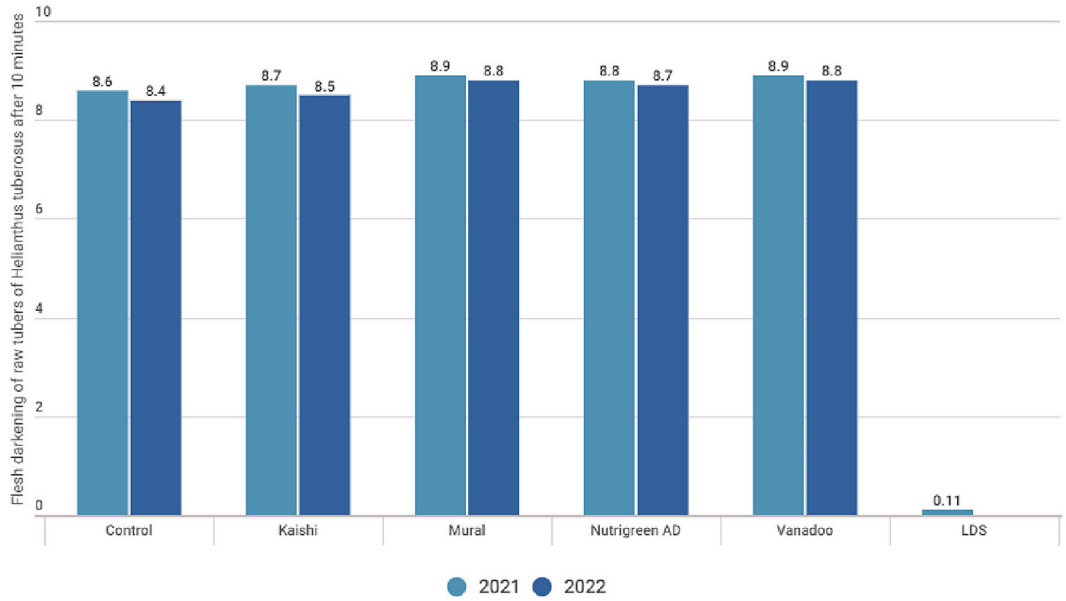

Figure 6. Darkening of the flesh of raw JA tubers after 10 minutes at individual sites in the years of the experiment

darkened by 0.96 degrees compared to the flesh darkening after 10 minutes. The flesh of the tested cultivars 'Albik' and 'Rubik' developed similarly, reaching an average of 7.78 degrees on a nine-degree scale. Significant differences were noted between the biostimulant variants used and the years of study (Fig. 8). The oxidation processes of phenols, i.e. tyrosine and phenolic acids (chlorogenic and coffee acids) occurring in raw Jerusalem artichoke tubers with the participation of enzymes (polyphenol oxidase) cause enzymatic darkening of raw tuber flesh after peeling (Wszelaczyńska, 2004). This process was prevented by the biostimulants used, which allowed Helianthus tuberosus to fight stress as well as contained the reducing substances ascorbic acid and citric acid (Skiba, 2014). The least darkening of the flesh was observed in the tubers treated with the Vanadoo and Maral biostimulants (Fig. 7.). It was observed that the flesh of the tubers darkened to the greatest extent in 2022. Less susceptible to darkening were the tubers harvested in 2021. The effect of weather conditions on this trait was noted by (Hamouz et al., 2005). The demonstrated interaction of years with varieties demonstrates the different response of varieties to weather conditions prevailing in the growing seasons (Fig. 4.).

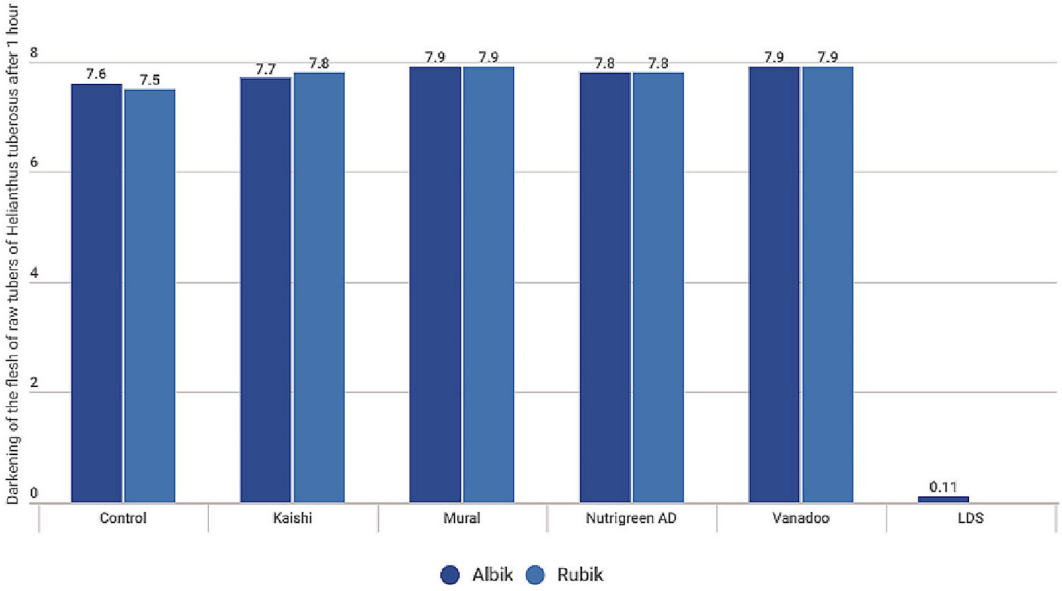

Figure 7. Darkening of the flesh of raw 'Albik' and 'Rubik' tubers after 1 hours at individual sites

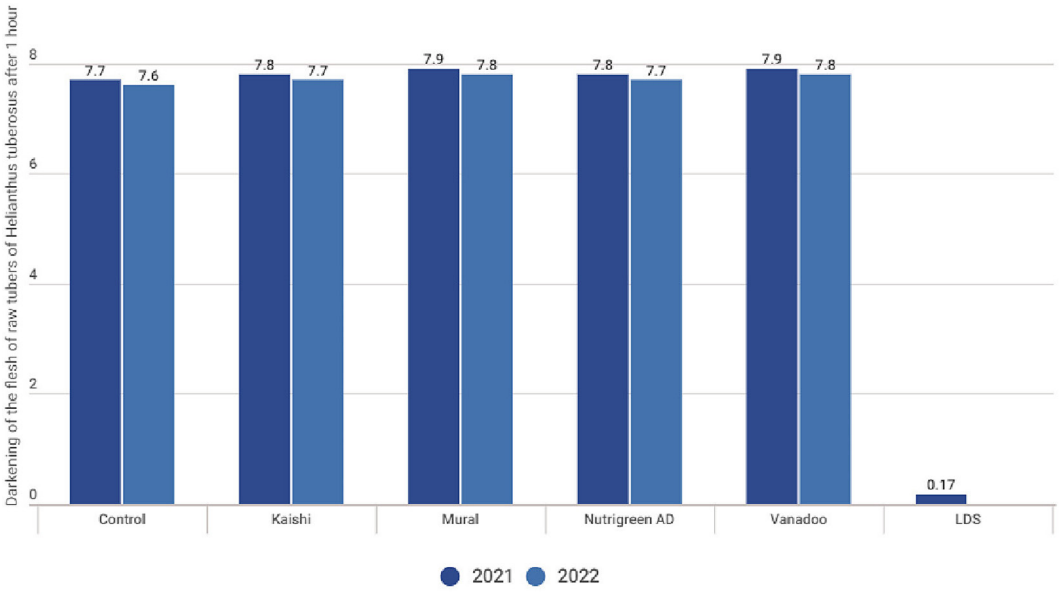

Figure 8. Darkening of the flesh of raw JA tubers after 1 hour at individual sites in the years of the experiment

Darkening of the flesh of cooked Helianthus tuberosus tubers after 10 minutes

The darkening of the flesh of cooked Jerusalem artichoke tubers is one of the important characteristics from the consumer's point of view and depends on the distribution of pigment in the tuber. This darkening is caused by chemical changes in the tuber, but is not the result of enzymatic oxidation processes as with raw tubers. It involves the fusion of chlorogenic acid with iron to darkly colored complexes of ferrodehydrochlorogenic acid (Wang-Pruski and Nowak, 2004). The darkening of the tubers was evaluated 10 minutes after cooking. This trait was influenced by varieties, variants of biostimulant application and weather conditions during the years of the study (Fig. 9 and Fig. 10.). The flesh of tubers of the 'Albik' variety evaluated 10 minutes after cooking darkened less than that of the 'Rubik' variety (Fig. 9.). This was reported in her study (Sawicka and Skiba, 2009). Cultivar 'Albik' reached the value of the trait in question at an average of 7.78 degrees on a nine-point scale. While analyzing the ways of application of biostimulants, lesser darkening of tubers

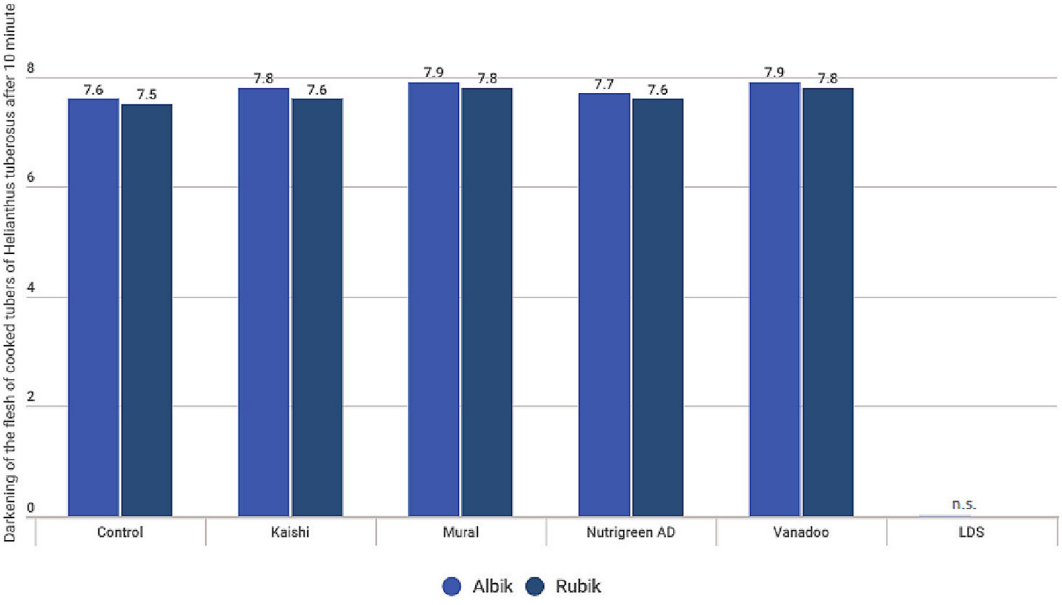

Figure 9. Darkening of the flesh of cooked tubers of raw 'Albik' and 'Rubik' after 10 minutes

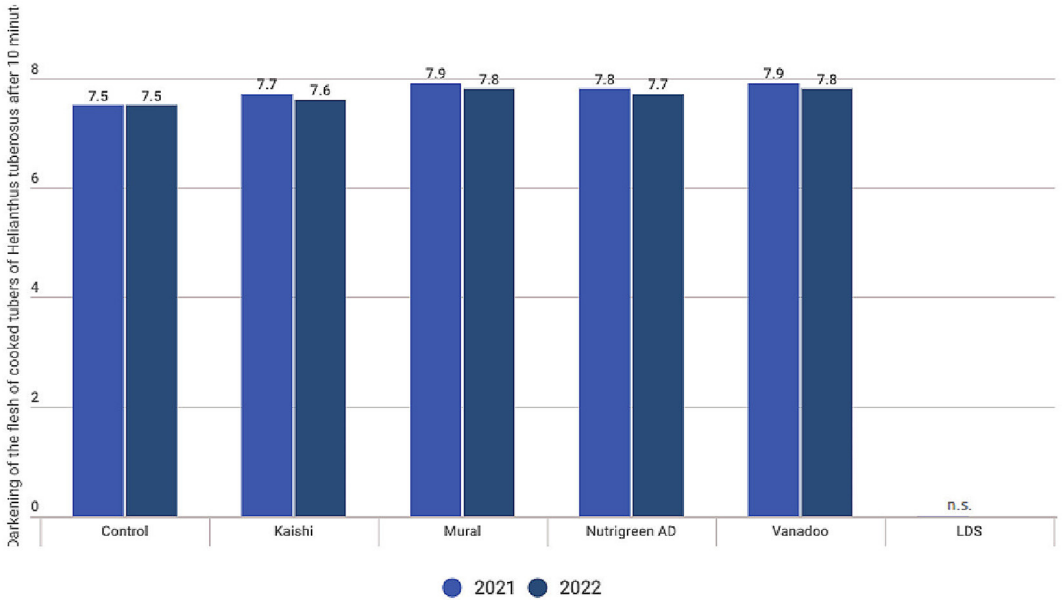

Figure 10. Darkening of the flesh of cooked tubers of raw JA tubers after 1 hour at individual sites in the years of the experiment

compared to the control object after the application of the Maral and Vanado biostimulants was observed (Fig. 9). The differences in flesh darkening ratings ranged from 0.1 to 0.3 points on a 9-point scale. Weather conditions in the years of conducting the experiment differentiated the analyzed trait. The tubers harvested in 2021 darkened less than in 2022 (Fig. 10.).

Darkening of the flesh of Helianthus tuberosus cooked tubers after 1 hour

Assessment of the flesh darkening of JA tubers cooked after 1 hour depended on the pigment in the tuber and the pH. The higher the pH, favoring the combination of iron with chlorogenic acid, the stronger the darkening of the flesh (Sawicka and Skiba, 2009). Tests on the flesh of cooked tubers showed that the 'Albik' variety was less prone to flesh darkening. The applied biostimulants caused less flesh darkening compared to the control object especially after the application of Maral and Vanado biostimulant (Fig. 11.). The differences in flesh darkening ratings ranged from 0.1 to 0.4 points on a 9-point scale. Weather conditions in the years of conducting the experiment differentiated the analyzed trait. The tubers harvested in 2021 darkened less than in 2022 by an average of

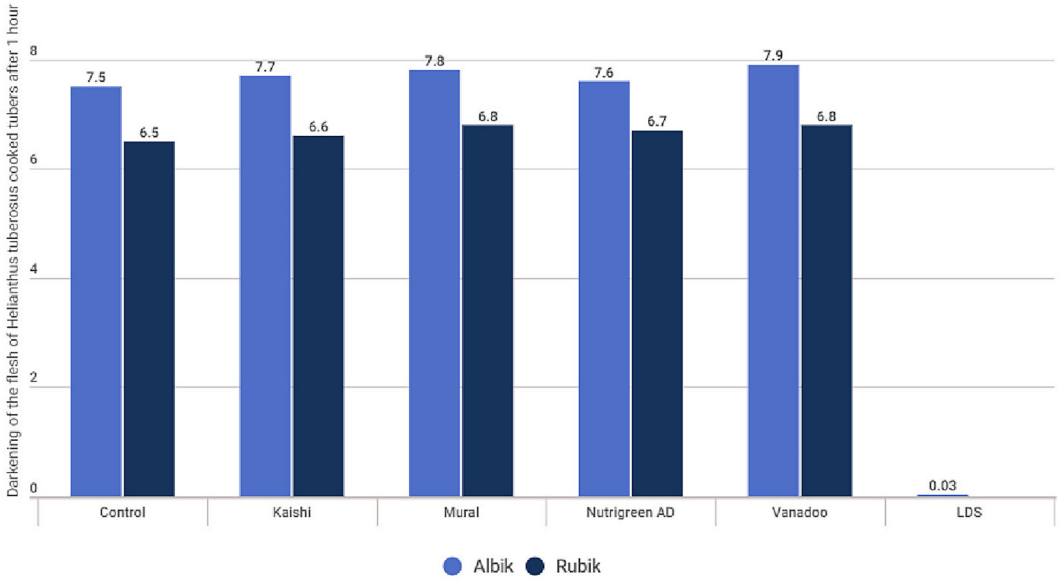

Figure 11. Darkening of the flesh of raw 'Albik' and 'Rubik' cooked tubers after 1 hour

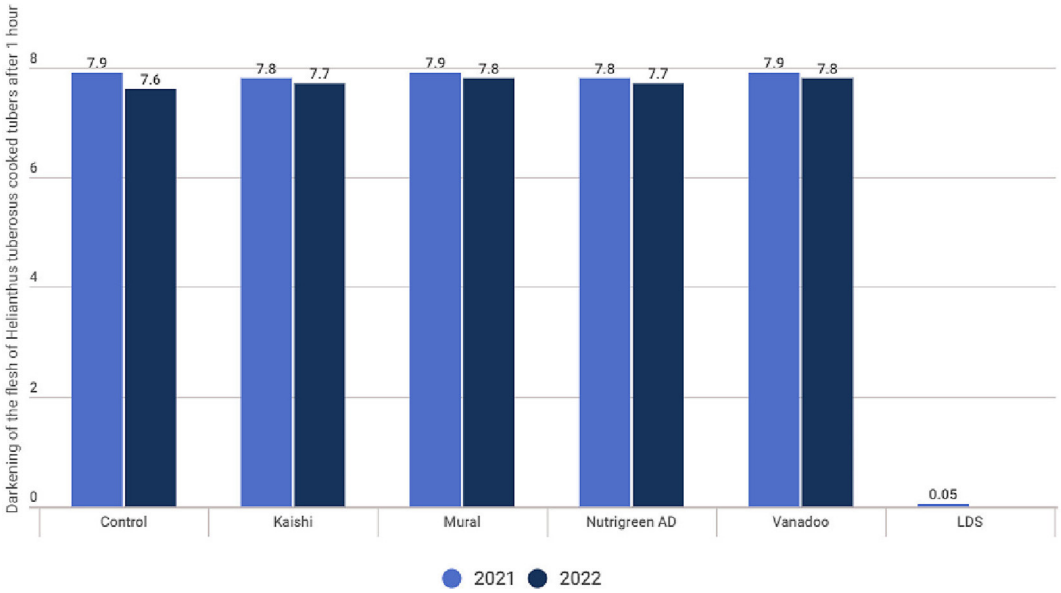

Figure 12. Darkening of the flesh of raw JA tubers after 1 hour at individual sites in the years of the experiment

Table 2. Tastiness of Helianthus tuberosus tubers

Objects	Cultivars		Years		Mean
	Albik	Rubik	2021	2022	
1. Control object	8.6	8.7	8.7	8.7	8.67
2. Kaishi	8.7	8.7	8.8	8.7	8.72
3. Maral	8.9	8.8	8.9	8.8	8.8
4. Nutrigreen AD	8.8	8.7	8.8	8.7	8.75
5. Vanadoo	8.9	8.8	8.9	8.8	8.85
Mean	8.78	8.74	8.82	8.74	8.77

Note: $LSD_{0.05}$ for: a – n.s., c – n.s., b – n.s., n.s. – non-significat. Explanation: a – cultivars, b – objects, c – years.

0.14 points on a 9-degree scale (Fig. 12.). The interaction of varieties with variants of application of biostimulants, and years with factors of the experiment was not proven.

Tastiness of *Helianthus tuberosus* tubers

Tuber palatability depended on the variety, variants of biostimulant application and meteorological conditions. The most palatable variety was 'Albik' and scored 8.78 points on a nine-point scale, while 'Rubik' was also characterized by good palatability with a value of 8.74 points (Tab. 2.). In a study by Wichrowska and Rogozinska (2010), palatability is a genetically determined trait and depends on the chemical composition of the tubers.. No deterioration in flavor was found in tubers harvested from objects sprayed with biostimulants compared to the control object. The tubers harvested in 2021 proved to be the tastiest, while those harvested in 2022, which was quite dry, were less tasty (Tab.2.). The authors (Wichrowska and Rogozinska, 2010; Wang-Pruski and Nowak, 2004) showed that palatability is a trait that depends on environmental interactions in the years of study and variants of the experiment. The interactions between years and varieties, years and biostimulant application variants, varieties and biostimulant application variants, and years and experimental factors were not proven.

CONCLUSIONS

The darkening of the flesh of raw and cooked tubers depended on varietal characteristics. The cultivar 'Albik' was less prone to flesh darkening in both cases. Darkening of the flesh of raw and cooked tubers is an undesirable feature in topinambur tubers intended for consumption. Variety 'Rubik' was characterized by a greater tendency to darken the flesh of raw and cooked tubers, so it may be predisposed to food industrial purposes. The applied biostimulants reduced the flesh darkening of raw and cooked tubers and improved the palatability of Jerusalem artichoke tubers with respect to the control object.

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