

## IMPACT OF GROWTH BIOSTIMULATORS AND HERBICIDE ON THE CONTENT OF ASCORBIC ACID IN EDIBLE POTATO TUBERS (*SOLANUM TUBEROSUM* L.)

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**Abstract.** The objective of the study was to define the impact of nursing methods with the application of growth biostimulators and herbicide on the content of ascorbic acid in edible potato tubers. A series of field experiments were carried out in the years 2015-2017 in the region of eastern Poland (52°02'N; 23°07'E). The examined factors included: factor I – three early cultivars of edible potato (Owacja, Bellarosa, Vineta), factor II – five methods of nursing with the application of growth biostimulators: GreenOK-Universal Pro and Asahi SL as well as their combination with the Avatar 293 ZC herbicide. The treatment methods applied in the experiment with the use of growth biostimulators and herbicide had a significant impact on the rise of the content of ascorbic acid in edible potato tubers in comparison with only mechanical treatment. The highest concentration of ascorbic acid (on average 193.88 mg kg<sup>-1</sup>) was marked in the tubers gathered from object 4., in case of which mechanical treatment has been made. Then the Avatar 293 ZC herbicide and the GreenOK Universal-PRO biostimulator were applied. The content of ascorbic acid in potato tubers was also significantly impacted by genetic characteristics of individual cultivars and weather conditions during the conduct of tests.

**Keywords:** nutrients, *Solanum tuberosum* L., GreenOK Universal-PRO, Asahi SL, Avatar 293 ZC

### Introduction

#### Experiment background

Conventional, intensive methods of plant production have a significant impact on the natural environment and such impact is most frequently a negative one. In particular, the „high-tech-agriculture” model may constitute a threat not only for the health of consumers but also for natural resources on which we are entirely dependent (Scherr and McNeely, 2008; Głodowska and Gałązka, 2018).

Presently, within plant production, including potato (*Solanum tuberosum* L.) cultivation an increasing level of attention is drawn not only to the size of crops but also to the health-related qualities, while agricultural practice continues to evolve towards ecological, balanced cultivation systems, which are at the same time environment friendly (Bulgari et al., 2015).

In modern agriculture various types of agroecosystem friendly preparations have become commonly applied which are classified as growth biostimulators. They limit the application of agro-chemicals and thus, contribute to the development of balanced methods of plant production (Radkowski and Radkowska, 2013; Calvo et al., 2014; Du Jardin, 2015).

### **Growth biostimulators**

According to the definition of The European Biostimulant Industry Council (EBIC), growth biostimulators are preparations which are applied on a plant, seeds or a root zone in order to stimulate the natural processes, increasing the effectiveness of use of nutrients, tolerance to abiotic stress and/or quality of crops. Their activity does not depend on the content of nutrition elements. Biostimulators do not directly counteract pests, therefore they are not classified as pesticides (European Biostimulants Industry Council, 2012; Matyjaszczyk, 2015). These preparations do not also act as fertilisers, while their main role is to control and accelerate the life processes of plants and to increase their resistance to abiotic stress (Matyjaszczyk, 2015). In the opinion of Calvo et al. (2014), interest in the use of biostimulators in agricultural practice continues to increase and the global market of these preparations may in 2018 reach the level above 2 241 million dollars.

Growth biostimulators constitute preparations of natural or synthetic origin the chemical content of which is characterized by a number of bioactive organic and non-organic components such as: effective micro-organisms, humus substances, extracts from seaweed and fruits, enzymes, phytohormones, chitin, chitosan, polyoligosaccharides and chemical elements, inorganic salts (including phosphonates), phenolic compounds, antitranspirants and other substances of stimulating properties (Hamza and Suggars, 2001; Kauffman et al., 2007; Khan et al., 2009; Du Jardin, 2012; Przybysz et al., 2014).

Biostimulators contribute to an increase and growth of plants for their entire life cycle: They improve some physicochemical properties of soil and support the growth of useful soil microorganisms, stimulating germination and plant growth (Vernieri et al., 2002; Yildirim et al., 2002). They impact bio-chemical processes, facilitate assimilation, translocation and the use of nutrients (Kauffman et al., 2007; Kunicki et al., 2010; Du Jardin, 2012; Calvo et al., 2014). They may increase tolerance of plants towards biotic and abiotic stress as well as accelerate their regeneration (Ziosi et al., 2013).

Growth biostimulators may also impact the nutritional value of arable crops, including also the content of ascorbic acid (Dudaš et al., 2016; Mikos-Bielak et al., 1999a, b).

### **Ascorbic acid – Albert Szent-Györgyi**

In 1928, Albert Szent-Györgyi – Hungarian scientist, biochemist, laureate of the Nobel prize (1937) extracted and identified vitamin C from pepper plant (ascorbic acid (C<sub>6</sub>H<sub>8</sub>O<sub>6</sub>) – Latin: *acidum ascorbicum*). This compound was named ascorbic acid since its shortage or lack in nourishment leads to the development of scurvy (Latin: *scorbutus*). Five years later the first synthetic ascorbic acid was obtained (Gábor, 1982; Szarka and Lőrincz, 2013; Szendrei and Háznagy-Radnai, 2013).

Ascorbic acid is an organic chemical compound from the group of unsaturated polyols; it is essential for the functioning of living organisms. Vitamin C belongs to the most commonly known vitamins with multidirectional functions. It is an activator of various enzymes, performing a key role in cellular respiration. It also plays a role in the course of many metabolic processes. It participates in production of collagen and the basic proteins in the whole organism (bones, cartilages, tendons, ligaments). It helps the wounds, breaks to heal, inhibits the healing of bruises, occurrence of haemorrhage and gum bleeding, activates our immunological system stimulating the growth and

effectiveness of T and B type immunological cells as well as other white blood cells (Moszczyński and Pyć, 1999; Huang et al., 2002; Nowak, 2004; Janda et al., 2015; Carr and Maggini, 2017). It participates in the synthesis of hormones and transmitters (Moszczyński and Pyć, 1999). Ascorbic acid is one of the strongest water-soluble antioxidants which performs the protective function against cancer diseases (Asensi-Fabado and Munné-Bosch, 2010). It is necessary in prevention of circulatory system diseases – it regulates the production of cholesterol in liver and its transformation into bile acids (it decreases the general level of “bad” LDL cholesterol in blood, increasing the volume of “good” HDL cholesterol) (Nowak, 2004; Janda et al., 2015).

Human beings do not possess metabolic pathways leading to the synthesis of C vitamin, therefore it must be provided on an ongoing basis by means of nourishment (Tabatabaei-Malazy et al., 2014). Vitamin C appears in the greatest volumes in fresh vegetables and fruits, thus it is extremely important to enrich our diet in these products.

Within our everyday diet, the cheapest and most widespread source of vitamin C are the edible potato tubers. This stems from the fact that edible potato is cultivated in approx. 160 countries worldwide and it is consumed on a daily basis by over a billion of persons (Bishwoyog et Swarnima, 2016; Baranowska, 2018). Content of vitamin C in potato tubers amounts to from 11.5 to 27.8 mg 100 g<sup>-1</sup> (Grzezińska and Kierebiński, 1990; Kris-Etherton et al., 2002; Love and Pavek, 2008).

One must underline that in the course of preparation of meals and potato preserves, losses in the content of ascorbic acid occur, caused mainly by the operations of high temperature, enzymes, oxygen and light. Already the peeling process of potatoes causes a 6% loss of ascorbic acid. Once we chop the peeled potatoes before boiling, losses of vitamin C will be even more substantial. The largest losses occur as a result of slicing or dicing the tubers (15-16%), whilst the smallest – as a result of cutting into poles (9%). Losses of vitamin C during technological processes may range between: 27 and 33% - blanching process, up to 50% boiling in water, up to 83% - frying of crisps. However, the greatest losses of ascorbic acid (up to 93%) occur in the course of production of dry potato cubes. In order to minimize the losses of vitamin C it is most beneficial not to peel or cut the tubers, but rather wash them thoroughly prior to boiling (boiling with an addition of a small amount of hot water and kitchen salt in accothermal dishes, pressure cookers, microwaves or steaming is recommended). One ought to further limit to the minimum the time of operations of destructive factors impacting the content of vitamin C, such as high temperature (Rytel and Lisińska, 2007; Janda et al., 2015). Despite the losses of ascorbic acid in the course of preparation of meals or potato preserves, potato is one of the main sources of vitamin C in human diet due to the significant volumes in which it is consumed. Consumption of 200 g of potatoes covers daily demand for vitamin C in approx 50% (Leszczyński, 2000).

### ***Purpose of the experiment***

Sparse and ambiguous so far empirical results of studies on the impact of growth biostimulators on the chemical composition of edible potato tubers, including also the content of ascorbic acid incline to carrying out further studies.

The purpose of the experiment was to specify the impact of five methods of treatment with the application of growth biostimulators and herbicide on the content of ascorbic acid in tubers of three cultivars of edible potato. Research hypothesis assumes that plant-care procedures with the use of growth biostimulators and herbicide will impact the content of ascorbic acid in edible potato tubers.

## Materials and methods

### *Location of the experiment*

The field experiment was conducted in the years 2015-2017 in the region of eastern Poland (Fig. 1), in the Biała Podlaska Commune (52°02'N; 23°07'E) in the Lublin Voivodship, on acidic light soil.



*Figure 1. Location of the experiment*

### *Experiment and plant material*

The experiment was performed in the split-plot system, as two-factor in three replications. The influence of two factors was tested:

- I. Factor – three early edible potato cultivars: Bellarosa, Owacja, Vineta,
- II. Factor – five methods of treatment with the application of growth biostimulators and herbicide:
  1. Standard object – mechanical treatment (without biostimulators and herbicide),
  2. From sprouting of potato plants – mechanical treatment and after sprouting – GreenOK Universal-PRO bioactivator, three times to leaves: at a dose of  $0.10 \text{ dm}^3 \text{ ha}^{-1}$  – peak-end of sprouting (phase BBCH 13-19) +  $0.15 \text{ dm}^3 \text{ ha}^{-1}$  – covering of interrows (phase BBCH 31-35) +  $0.15 \text{ dm}^3 \text{ ha}^{-1}$  – flower bud break (phase BBCH 51-55),
  3. From sprouting of potato plants – mechanical treatment, and after sprouting – Asahi SL bioactivator, three times to leaves at a dose of  $0.50 \text{ dm}^3 \text{ ha}^{-1}$  – peak-end of sprouting (phase BBCH 13-19) +  $0.50 \text{ dm}^3 \text{ ha}^{-1}$  – covering of interrows (phase BBCH 31-35) +  $0.50 \text{ dm}^3 \text{ ha}^{-1}$  – flower bud break (phase BBCH 51-55),
  4. From sprouting – mechanical treatment, and after the final shaping of ridges and just before sprouting Avatar 293 ZC herbicide at a dose of  $1.5 \text{ dm}^3 \text{ ha}^{-1}$  (phase BBCH 00-05). After sprouting – three applications of GreenOK Universal-PRO bioactivator at a dose of  $0.10 \text{ dm}^3 \text{ ha}^{-1}$  – peak-end of sprouting

- (phase BBCH 13-19) + 0.15 dm<sup>3</sup> ha<sup>-1</sup> – covering of interrows (phase BBCH 31-35) + 0.15 dm<sup>3</sup> ha<sup>-1</sup> – flower bud break (phase BBCH 51-55),
5. From sprouting – mechanical treatment, and after the final shaping of ridges before sprouting of potato plants – Avatar 293 ZC herbicide at a dose of 1.5 dm<sup>3</sup> ha<sup>-1</sup> (phase BBCH 00-05).

The characteristics of the potato varieties and preparations used in the experiment are presented in *Tables 1* and *2*.

**Table 1.** Characteristics of varieties of potatoes grown in the experiment. (Source: Plant Breeding and Acclimatization Institute – National Research Institute)

Variety	Year of inscription to variety register	Breeder of variety	Yield t ha <sup>-1</sup>	Colour of skin	Colour of pulp
Bellarosa	2006	Europlant, Pflz. GmbH Germany	38.3	Red	Yellow
Owacja	2006	PMHZ Strzekećin Poland	41.4	Yellow	Light yellow
Vineta	1999	Europlant, Pflz. GmbH, Germany	39.1	Yellow	Yellow

**Table 2.** Characteristics of biostimulators and herbicide applied in the experiment. (Source: information disclosed by agents' manufacturers)

Name of preparation	Holder of the authorization	Content of active substances
<b>GreenOK Universal-PRO</b> – natural fertilizer with biostimulating effect	Latvian Institute of humic substances Brivibas Street 144, Riga, Latvia, LV-1012	Humus substances ≤ 20 g dm <sup>3</sup> (NPK 0.13-0.09-0.7), dry mass 22 g dm <sup>3</sup> , humidity 96%, organic substances 3%, pH 7-9
<b>Asahi SL</b> – growth regulator (known under the name of Atonik in Poland)	Asahi Chemical Europe s.r.o., Lužná 591/4 – Vokovice, 160 00 Praha 6, The Czech Republic	Sodium para-nitrophenolate (substance of nitrophenoles group) – 3 g dm <sup>3</sup> (0.3%) sodium orto-nitrophenolate (substance of nitrophenolates group) – 2 g dm <sup>3</sup> (0.2%) sodium 5-nitroguaiacolate (substance of nitrophenolates group derivatives) – 1 g dm <sup>3</sup> (0.1%)
<b>Avatar 293 ZC</b> – herbicide	FMC Chemical sprl, Boulevard de la Plaine 9/3, B-1050 Brussels, The Kingdom of Belgium	Clomazone (substance of isoxalodine group) – 60 g dm <sup>3</sup> (5.13%) metribuzin (substance of triazinones group) – 233 g dm <sup>3</sup> (20.64%)

In autumn, before the experiments, natural manure fertilization was used at a dose of 25 t ha<sup>-1</sup>, as well as mineral fertilization with phosphorus 44.0 kg P ha<sup>-1</sup> (triple superphosphate 46%) and potassium 124.5 kg K ha<sup>-1</sup> (potassium salt 60%), and during spring – nitrogen fertilization (ammonium nitrate 34%) at a dose of 100 kg N per 1 ha. Potato tubers were planted in the second decade of April (in 2015 and 2016) and in the third decade of April (in 2017). Protection treatment against diseases and pests was used in accordance with the plant protection recommendations. In the period of vegetation, potato crops were protected by means of insecticides: Actara 25 WG (thiamethoxam 250 g kg<sup>-1</sup>) at a dose of 0.08 kg ha<sup>-1</sup>, Calypso 480 SC (tiachlopyrd 480 g dm<sup>-3</sup>) at a dose

of  $0.1 \text{ dm}^{-3} \text{ ha}^{-1}$  and fungicides: Copper Max New 50 WP (copper  $500 \text{ g kg}^{-1}$ ) at a dose of  $2.0 \text{ kg ha}^{-1}$  Dithane Neo Tec 75 WG (mancozeb  $750 \text{ kg ha}^{-1}$ ) at a dose of  $2.0 \text{ kg ha}^{-1}$ . Harvest was performed in the phase of full technological maturity of tubers.

### **Chemical analysis methods**

The content of ascorbic acid was marked in fresh mass of tubers via Tillmans method modified by Pijanowski which consists of reducing the colour solution of 2,6-dichlorophenolindophenol to colourless leuco compound by acid solution of ascorbic acid (Pijanowski et al., 1964; Rutkowska, 1981).

### **Statistical analysis**

The obtained results of research regarding the content of ascorbic acid of have been developed statistically by means of the analysis of variance method. Significance of variability sources was tested with the Fischler-Snedecor  $F$  test, and the assessment of significance of variance at the significance level  $p = 0.05$  between the compared averages using Tukey's range test.

### **Weather conditions**

Meteorological conditions in potato growing season have been presented in *Figures 2–5* and *Table 3*. The data come from the Meteorological Station of the Research Centre for Cultivar Testing (COBORU) in Słupia Wielka and they were compiled for the Cultivar Assessment Experimental Station situated near Biała Podlaska.

Meteorological conditions were characterized on the basis of monthly precipitation sums (*Figs. 2* and *3*), average air temperatures (*Figs. 4* and *5*), and hydrothermal coefficient of Sielianinov ( $K$ ) (*Table 3*) (*Eq. 1*):

$$K = \frac{P}{0.1 \sum t} \quad (\text{Eq.1})$$

$K$  – value of hydrothermal coefficient,  $P$  – sum of monthly rainfall,  $t$  – sum of daily air temperatures from a given month, where:  $P$  – signifies the monthly sum of rainfall,  $\sum t$  – monthly sum of air temperatures  $>0 \text{ }^\circ\text{C}$ .

Extremely dry and extremely humid conditions were distinguished, performing a division of values of Sielianinov coefficient ( $K$ ) into nine classes. The following divisions of values were applied: borderline dry  $K \geq 0.4$ , very dry  $0.4 < K \leq 1.0$ , dry  $0.7 < K \leq 1.0$ , rather dry  $1.0 < K \leq 1.3$ , optimal  $1.3 < K \leq 1.6$ , rather humid  $1.6 < K \leq 2.0$ , humid  $2.0 < K \leq 2.5$ , very humid  $2.5 < K \leq 3.0$ , borderline humid  $K > 3.0$  (Chereszkowicz, 1979; Skowera and Puła, 2004; Skowera et al., 2014)

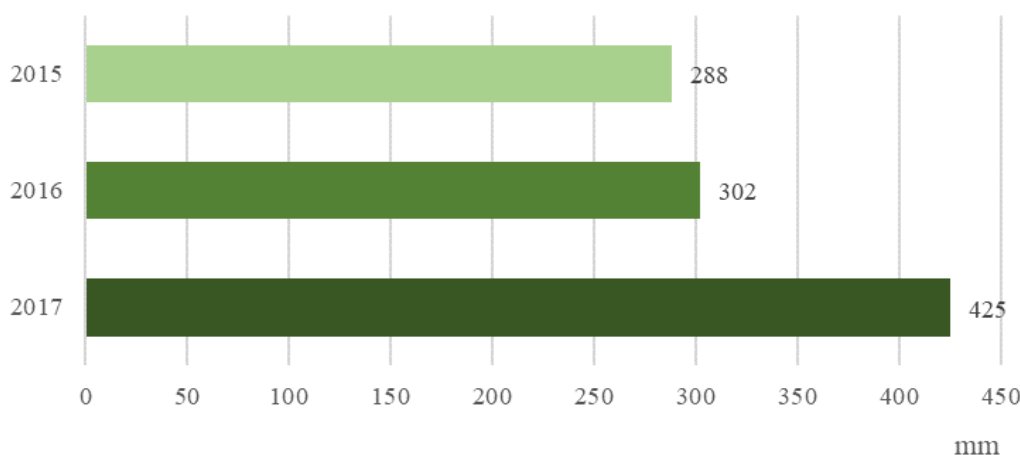
During the conduct of tests diverse meteorological conditions occurred (*Figs. 2–5* and *Table 3*). The lowest precipitation sum (288 mm) was recorded in 2015 with mean air temperature of  $15.7 \text{ }^\circ\text{C}$ . In this season, precipitation shortage occurred from June to August, while August was extremely dry with precipitation sum of 7 mm and high atmospheric air temperatures. This season was defined as dry ( $0.7 < K \leq 1.0$ ). Whilst, the highest precipitation sum was recorded in the growing season of 2017 (425 mm) in which the average air temperature was  $15.4 \text{ }^\circ\text{C}$ ; it was the coldest year in comparison with other years covered by the research. Within the growing season of 2016 the most humid months were: July with a sum of rainfall of 121 mm and high air temperatures

(on average: 19.8 °C) and June with a sum of rainfall 84 mm and average air temperature of 18.4 °C. This season was specified as rather dry ( $1.0 < K \leq 1.3$ ) (Figs. 2–5 and Table 3).

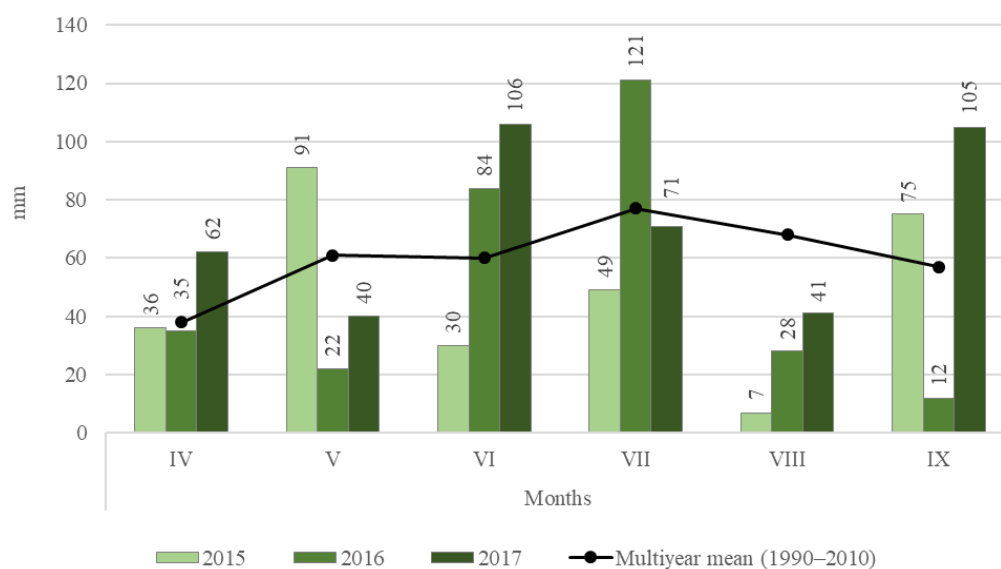
**Table 3.** Sielianinov's hydrothermic coefficient (K)

*Sielianinov's hydrothermic coefficients (K)							
Month/Year	IV	V	VI	VII	VIII	IX	Mean IV–IX
2015	1.43	2.28	0.59	0.80	0.11	1.66	0.99
2016	1.19	0.47	1.53	1.97	0.48	0.26	1.00
2017	2.68	0.93	1.97	1.24	0.66	2.37	1.50

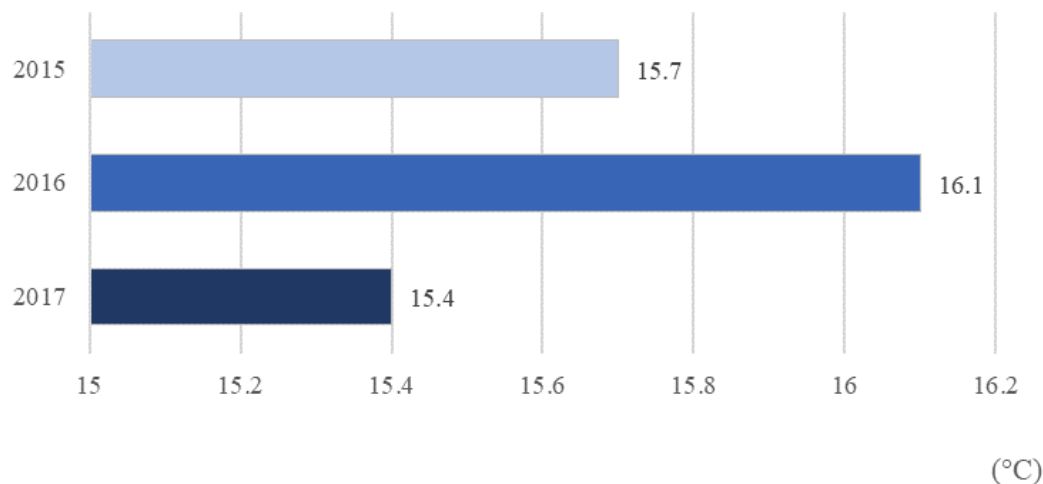
\*Sielianinov hydrothermal coefficient (K) – formula as in research methodology: Month's classification according to (Chereszkowicz, 1979; Skowera and Puła, 2004; Skowera et al., 2014): extremely dry  $K \geq 0.4$ , very dry  $0.4 < K \leq 0.7$ , dry  $0.7 < K \leq 1.0$ , quite dry  $1.0 < K \leq 1.3$ , optimal  $1.3 < K \leq 1.6$ , quite humid  $1.6 < K \leq 2.0$ , humid  $2.0 < K \leq 2.5$ , very humid  $2.5 < K \leq 3.0$ , extremely humid  $K > 3.0$



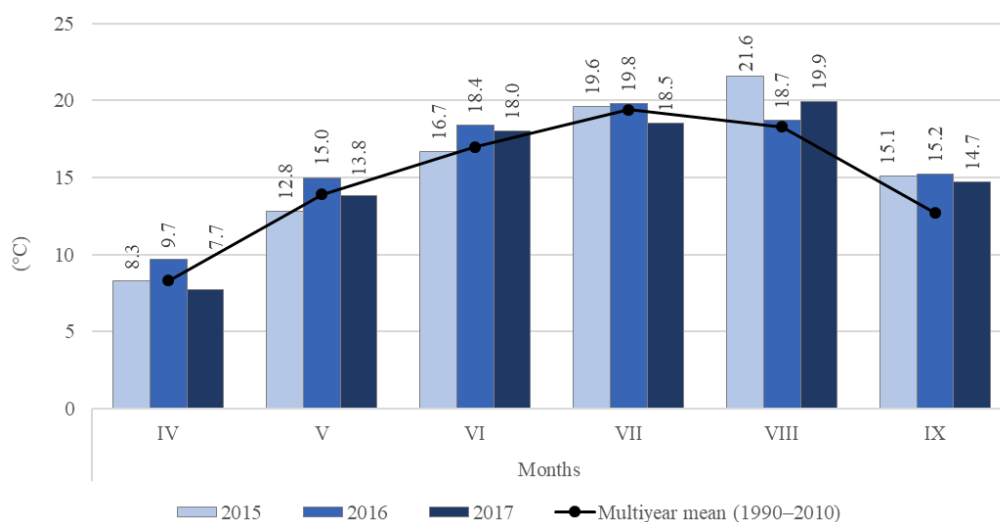
**Figure 2.** The sum of precipitation (IV-IX) for the years 2015-2017 (mm)



**Figure 3.** The sum of precipitation in the vegetation period of potato in 2015-2017 (mm)



**Figure 4.** The average air temperature (IV-IX) for the years 2015-2017 (°C)



**Figure 5.** Air temperature during the growing season of potato in 2015-2017 (°C)

## Results and discussion

As a result of the carried out research, it was proved that both applied cultivation methods ( $F(4;120) = 4.23$ ;  $p = 0.0031$ ), potato cultivars cultivated in the experiment ( $F(2;79.06) = 12.93$ ;  $p < 0.0001$ ), as well as meteorological conditions ( $F(2;120) = 170.99$ ;  $p < 0.0001$ ) that prevailed in particular research years had a significant impact on the content of ascorbic acid (Tables 4 and 5).

The cultivation methods applied in the experiment with the use of growth biostimulators and herbicide had a significant impact on the rise of content of ascorbic acid within potato tubers (object 2.-5.) in comparison with only mechanical treatment (object 1.) Statistically significant differences occurred also between object 3. and 4. ( $p = 0.0164$ ) (Table 4). The largest concentration of vitamin C was reported in tubers gathered from object 4., (on which mechanical treatment was applied from sprouting, followed by application of Avatar 293 ZC at a dose of  $1.5 \text{ dm}^3 \text{ ha}^{-1}$ , and after sprouting, triple application of bioactivator GreenOK Universal-PRO at a dose of  $0.10 \text{ dm}^3 \text{ ha}^{-1}$  +



0.15 dm<sup>3</sup> ha<sup>-1</sup> + 0.15 dm<sup>3</sup> ha<sup>-1</sup> (on average 190.06 mg kg<sup>-1</sup>). Positive impact of herbicides on the content of ascorbic acid was observed also in the research carried out by Zarzecka and Gugala (2003), Rymuza et al. (2013). Barabaś and Sawicka (2015) who noted a greater tendency to accumulate vitamin C after application of a mixture of herbicides Sencor 70 WG and Titus 25 WG, applied after sprouting of potato plants.

Mikos-Bielak et al. (1999a, b) applying growth regulator Mival (1 chloromethylsilatran) and Potejtin (mixture of sodium N oxide 2, 6 lutidine and succinic acid) noted an increased content of vitamin C in potato tubers (24 out of 37 tested cultivars). Trawczyński and Prokop (2017) post applying biostimulators obtained from marine algae: Fertiliser Gold and Fertiliser Axis obtained significantly larger content of vitamin C in tubers in comparison to the standard object. Similar results were obtained also by Dudaš et al. (2016) who applied preparation Bio-algeen S-90.

Whilst, according to the research carried out by Rudzińska-Mękal (2000) application of Moddus 250 ME regulator (ethyl trinexapac) and Atonik (polish name Asahi SL) – decreases the content of ascorbic acid in tubers regardless of the term and method of application. According to Mikos-Bielak (2005) one may assume that Atonik biostimulator not so much hinders biosynthesis of vitamin C but rather its transport to floral organs and spare organs.

**Table 4.** Content of ascorbic acid in fresh mass of edible potato tubers depending on the treatment methods and cultivars (average from the years 2015-2017) (mg kg<sup>-1</sup>)

Methods*	Cultivars			Mean
	Owacja	Bellarosa	Vineta	
1.	170.00	188.30	176.33	178.20 <sup>a,b,c,d</sup>
2.	176.33	195.60	183.33	185.08 <sup>a</sup>
3.	174.66	192.73	181.36	182.92 <sup>b,e</sup>
4.	183.66	199.83	186.70	190.06 <sup>c,e</sup>
5.	177.00	192.96	184.33	184.76 <sup>d</sup>
Mean	176.33 <sup>f</sup>	193.88 <sup>f,g</sup>	182.41 <sup>g</sup>	184.20

\*\*LSD<sub>0.05</sub> for: cultivars – 4.620; methods – 2.634; methods x cultivars – n.s.

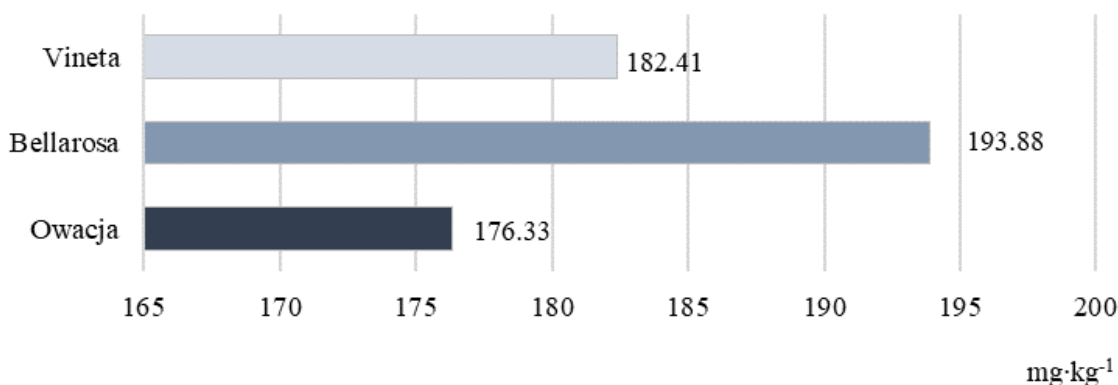
\*As in the experiment's methodology:

1. Standard object (without biostimulators and herbicide)
2. GreenOK Universal-PRO 0.10 dm<sup>3</sup> ha<sup>-1</sup> + 0.15 dm<sup>3</sup> ha<sup>-1</sup> + 0.15 dm<sup>3</sup> ha<sup>-1</sup>
3. Asahi SL 0.50 dm<sup>3</sup> ha<sup>-1</sup> + 0.50 dm<sup>3</sup> ha<sup>-1</sup> + 0.50 dm<sup>3</sup> ha<sup>-1</sup>
4. Avatar 293 ZC 1.5 dm<sup>3</sup> ha<sup>-1</sup> + GreenOK Universal-PRO 0.10 dm<sup>3</sup> ha<sup>-1</sup> + 0.15 dm<sup>3</sup> ha<sup>-1</sup> + 0.15 dm<sup>3</sup> ha<sup>-1</sup>
5. Avatar 293 ZC 1.5 dm<sup>3</sup> ha<sup>-1</sup>

\*\*LSD<sub>0.05</sub>: Least significant difference, n.s. – not significant

a, b, c, ... Values marked with the same letter differ significantly

It was noted that the content of vitamin C in potato tubers significantly depended on genetic conditions of the cultivars. Bellarosa cultivar gathered the greatest level of vitamin C (on average 193.88 mg kg<sup>-1</sup>), while Owacja gathered the smallest amount of it (on average 176.33 mg kg<sup>-1</sup>) (Fig. 6). Content of Vitamin C within Bellarosa tubers was substantially higher than in the tubers of the remaining cultivars (Bellarosa-Owacja  $p < 0.0001$ ; Bellarosa-Vineta  $p = 0.0054$ ). In case of the discussed feature no significant differences between Owacja and Vineta cultivars were observed ( $p = 0.1363$ ) (Table 4).



**Figure 6.** Average content of ascorbic acid in the wet weight of edible potato tubers depending on the variety (averages from 2015-2017) (mg·kg<sup>-1</sup>)

These results are compliant with the tests performed by Weber and Putz (1999), who carried out the tests with 26 German potato cultivars and noted that the content of vitamin C in tubers is determined by genetic factor. Also within the research by Wichrowska and Pobereżny (2008), Gugala and Zarzecka (2012) the content of vitamin C in tubers depended to a great degree on the genetic conditions of the analysed cultivars. In the opinion of Sowicka et al. (2014) differences in the content of vitamin C, in potato tubers are conditioned by phenotypic switching of cultivars which is a joint effect of genetic and environmental volatility.

A significant impact on the content of vitamin C in edible potato tubers was also assigned to atmospheric conditions in the years of research conduct (Table 5 and Fig. 7).

**Table 5.** Content of ascorbic acid in fresh mass of edible potato tubers depending on the treatment method and years of conduct of tests (average from years 2015-2017) (mg kg<sup>-1</sup>)

Methods*	Year			Mean
	2015	2016	2017	
1.	195.56	184.03	155.03	178.20 <sup>a,b,c,d</sup>
2.	203.53	191.03	160.70	185.08 <sup>a</sup>
3.	200.33	189.73	158.70	182.92 <sup>b,e</sup>
4.	206.36	194.73	169.10	190.06 <sup>c,e</sup>
5.	202.36	191.26	160.66	184.76 <sup>d</sup>
<b>Mean</b>	201.62 <sup>f,g</sup>	190.15 <sup>f,h</sup>	160.83 <sup>f,g,h</sup>	178.20 <sup>a,b,c,d</sup>

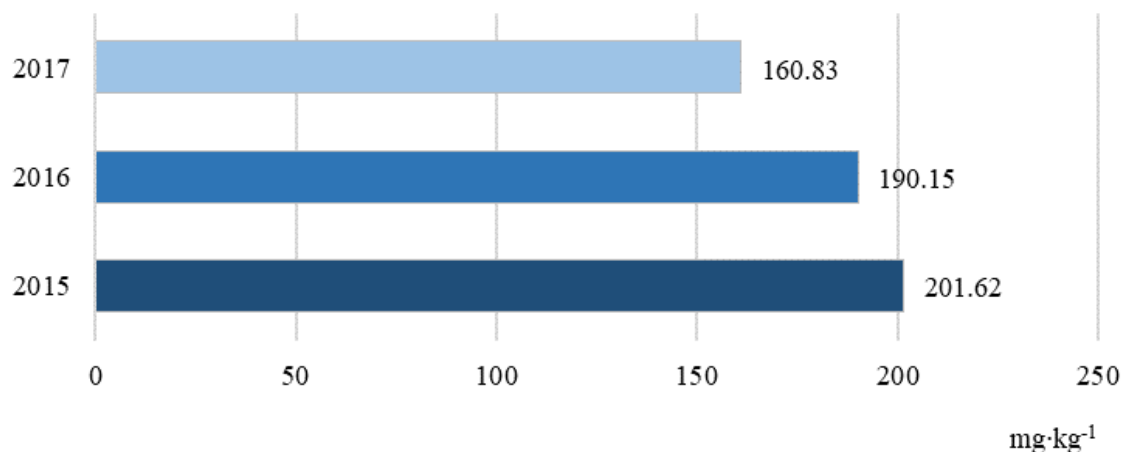
\*\*LSD<sub>0.05</sub> for: years – 4.620; methods – 2.634; methods x years – n.s.

\*As in the experiment's methodology:

1. Standard object (without biostimulators and herbicide)
2. GreenOK Universal-PRO 0.10 dm<sup>3</sup> ha<sup>-1</sup> + 0.15 dm<sup>3</sup> ha<sup>-1</sup> + 0.15 dm<sup>3</sup> ha<sup>-1</sup>
3. Asahi SL 0.50 dm<sup>3</sup> ha<sup>-1</sup> + 0.50 dm<sup>3</sup> ha<sup>-1</sup> + 0.50 dm<sup>3</sup> ha<sup>-1</sup>
4. Avatar 293 ZC 1.5 dm<sup>3</sup> ha<sup>-1</sup> + GreenOK Universal-PRO 0.10 dm<sup>3</sup> ha<sup>-1</sup> + 0.15 dm<sup>3</sup> ha<sup>-1</sup> + 0.15 dm<sup>3</sup> ha<sup>-1</sup>
5. Avatar 293 ZC 1.5 dm<sup>3</sup> ha<sup>-1</sup>

\*\*LSD<sub>0.05</sub>: Least significant difference, n.s. – not significant

<sup>a, b, c, ...</sup> Values marked with the same letter differ significantly



**Figure 7.** Average content of ascorbic acid in the wet weight of edible potato tubers in the years 2015-2017 (mg·kg<sup>-1</sup>)

The largest concentration of this component was noted in the growing season of 2015 (on average 201.62 mg kg<sup>-1</sup>), which was warm and characterized by the smallest volume of rainfall (288 mm) in comparison to the other tests. Whilst, the smallest concentration of ascorbic acid was noted in humid and cool season of 2017 (on average 160.83 mg kg<sup>-1</sup>). Statistically significant differences were observed in all medium pairs, that is between 2015 and 2016 ( $p < 0.0001$ ), between 2016 and 2017 ( $p < 0.0001$ ) and between 2015 and 2017 ( $p < 0.0001$ ) (Table 5). Similar results of tests were obtained by Mazurczyk and Lis (2001), Love and Pavék (2008). According to Trawczyński and Prokop (2016) years with moderate volume of rainfall and close to approximate with multiple year air temperature positively impact the content of vitamin Ca in potato tubers. Sawicka et al. (2014) they proved that the content of vitamin C is decided by the content of chlorophyll in leaves and the intensity of the photosynthesis process.

## Conclusions

Growth biostimulators continue to trigger an increasing interest both in science and agricultural practice. However, the impact of these preparations on the more crucial quality features of arable crops, including also on the content of ascorbic acid, has not yet been fully discovered and requires carrying out further scientific researches. Obtaining the results of own elaborations has allowed to note that treatment methods using growth biostimulators and herbicide significantly impacted the growth of content of ascorbic acid in potato tubers in comparison to the control object subjected to purely mechanical treatment. The content of ascorbic acid was substantially influenced also by genetic features of varieties as well as atmospheric conditions occurring in the subsequent years of conducting research. The greatest concentration of the discussed component was observed in Bellarosa variety of tubers whilst the smallest – in case of Owacja variety. Significantly higher content of ascorbic acid in the tubers of potato was noted in the growing season of 2015, which was characterized by the smallest sum of precipitation in comparison to the other years of research conduct.

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