Journal of Elementology ISSN 1644-2296

Zarzecka K., Gugała M., Mystkowska I., Sikorska A. 2021.
Modifications of vitamin C and total protein content in edible potato tubers under the influence of herbicide and biostimulants.
J. Elem., 26(4): 861-870. DOI: 10.5601/jelem.2021.26.3.2180

RECEIVED: 10 September 2021
ACCEPTED: 26 September 2021

ORIGINAL PAPER

MODIFICATIONS OF VITAMIN C AND TOTAL PROTEIN CONTENT IN EDIBLE POTATO TUBERS UNDER THE INFLUENCE OF HERBICIDE AND BIOSTIMULANTS*

Krystyna Zarzecka[1], Marek Gugała[1], Iwona Mystkowska[2], Anna Sikorska[3]

[1] Institute of Agriculture and Horticulture
Siedlce University of Natural Sciences and Humanities, Siedlce, Poland
[2] Faculty of Health Sciences
Pope John Paul II State School of Higher Education in Biała Podlaska, Poland
[3] Department of Agriculture
Vocational State School of Ignacy Mościcki in Ciechanów, Poland

Abstract

Three-year field research was conducted at Zawady Experimental Farm affiliated with the Siedlce University of Natural Sciences and Humanities in Siedlce. The experimental material consisted of potato tubers harvested in a field experiment set up in a split-plot arrangement with three replicates. The first experimental factor consisted of two table potato cultivars: Malaga and Oberon, and the second factor included five methods of weed control using the herbicide Avatar 293 ZC (the herbicide contained clomazone and metribuzin) and biostimulants: 1) control – without the herbicide or biostimulants, 2) the herbicide clomazone + metribuzin (Avatar 293 ZC), 3) the herbicide clomazone + metribuzin (Avatar 293 ZC) and the biostimulant PlonoStart, 4) the herbicide clomazone + metribuzin (Avatar 293 ZC) and the biostimulant Aminoplant, 5) the herbicide clomazone + metribuzin (Avatar 293 ZC) and the biostimulant Agro-Sorb Folium. Vitamin C content and total protein content were determined in potato tubers. The vitamin C content in fresh tubers was determined using the Tilman's method modified by Pijanowski. The total protein content was calculated from the nitrogen content assayed with the Kjeldahl method and multiplied by 6.25. An application of either the herbicide alone or combined with a biostimulant contributed to a significant increase in both the vitamin C content and total protein content compared with control tubers. The cultivar Oberon revealed a higher potential ability to accumulate chemical components compared with cv. Malaga.

Keywords: chemical composition of tubers, cultivars, growth regulators, *Solanum tuberosum* L.

Krystyna Zarzecka, PhD, Institute of Agriculture and Horticulture, Siedlce University of Natural Sciences and Humanities, Str. Prusa 14, 08-110 Siedlce, Poland, e-mail: kzarzecka@uph.edu.pl
* The research was carried out under the research project No. 31/20/B financed from a science grant by the Ministry of Science and Higher Education of Poland.

INTRODUCTION

After wheat and rice, potato (*Solanum tuberosum* L.) is the most popular staple food consumed by humans worldwide. The crop is grown on all the continents, in 195 countries, 166 of which classify potato as a vegetable (Dzwonkowski 2017, Beals 2019). Potato tubers are consumed processed in a variety of ways: boiled, roasted, fried, as a snack, fries or starch (Grudzińska et al. 2016). It is a significant source of carbohydrates, protein, vitamin C and B6, minerals, fibre and phenolic compounds (Hamouz et al. 2009, Wierzbowska et al. 2015, Djaman et al. 2021). Owing to their composition, potatoes provide key nutrients to diet. In Poland, the annual potato consumption is 90 kg per capita (Dzwonkowski 2020). According to Leszczyński (2012), a portion of 200 g tubers consumed per day covers 50% of daily demand for vitamin C. Also, potato protein is characterized by a high nutritional value as it contains all exogenous amino acids and is the only plant protein whose value is comparable to proteins of animal origin. The quality of potato tubers is affected by various factors, in particular genetic, agrotechnological and environmental factors. An application of herbicides and herbicides + biostimulants in potato cultivation reduces weed infestation but it can also alter tuber chemical composition. Barbaś and Sawicka (2015) observed a tendency for potatoes to accumulate more vitamin C following an application of the herbicides Sencor 70 WG and Titus 25WG, whereas Pszczółkowski et al. (2019) reported such findings after applying various bioproducts. Other authors observed a beneficial effect of herbicides and biostimulants on the total protein concentration (Wierzbowska et al. 2015, Mystkowska 2018, Zarzecka et al. 2020). Numerous reports have pointed to the fact that biostimulants regulate physiological processes, improve crop plant productivity (Rouphael and Colla 2020), mitigate negative results of the influence of abiotic stresses and diseases (Głosek-Sobieraj et al. 2019), increase yields and improve qualitative characteristics of potato tubers (Wierzbowska et al. 2015, Nazranov et al. 2020, Trawczyński 2018, 2020).

The objective of the study reported here was to determine the effect of a herbicide and a herbicide + a biostimulant on the vitamin C content and total protein content in table potato tubers.

MATERIAL AND METHODS

Field experiment

The research material consisted of potato tubers produced in a three-year field experiment which was carried out in the fields owned by the Siedlce University of Natural Sciences and Humanities in Siedlce, Poland. Soil type was sandy clay loam with acid soil reaction and 20.9-22.3 g kg^{-1} organic matter content (Table 1). The experiment was established in a split-

Table 1

Soil properties at 30 cm depth in the field experiment

Properties	Description		
	2018	2019	2020
pH (in 1 M KCl)	5.25	5.42	5.32
Organic matter (g kg^{-1})	20.9	22.3	21.1
Phosphorus – available (mg kg^{-1})	35.2	61.0	60.0
Potassium – available (mg kg^{-1})	102.1	149.0	140.0
Magnesium – available (mg kg^{-1})	36.6	61.0	51.0
Texture class	sandy clay loam	sandy clay loam	sandy clay loam

Table 2

Characteristics of cultivars grown in the field experiment (Nowacki 2019)

Cultivar	Registration year	Breeder	Maturity	Yield (t ha^{-1})	Vitamin C (mg kg^{-1})	Starch (mg kg^{-1})
Malaga	2013	Potato Breeding Zamarte, Poland	medium-early	56.7	188.0	150.0
Oberon	2012	Potato Breeding Zamarte, Poland	medium-early	53.1	235.0	135.0

plot arrangement with three replicates. The first factor included two table potato cultivars: Malaga and Oberon (Table 2), and the second factor was composed of five methods of weed control using the herbicide Avatar 293 ZC (the herbicide contained clomazone and metribuzin) and biostimulants: 1) control − without chemical protection, 2) the herbicide clomazone + metribuzin (Avatar 293 ZC) – 1.5 l ha^{-1} before potato emergence, 3) the herbicide clomazone + metribuzin (Avatar 293 ZC) – 1.5 l ha^{-1} before potato emergence and the biostimulant PlonoStart 2 l ha^{-1} after potato emergence, 4) the herbicide clomazone + metribuzin (Avatar 293 ZC) – 1.5 l ha^{-1} before potato emergence and the biostimulant Aminoplant 1.5 l ha^{-1} after emergence, 5) the herbicide clomazone + metribuzin (Avatar 293 ZC) – 1.5 l ha^{-1} before potato emergence and the biostimulant Agro-Sorb Folium 4 l ha^{-1} after emergence. The preceding crop was winter triticale. Every year, in autumn, applications were made of manure (25 t ha^{-1}) and mineral phosphorus + potassium fertiliser (44.0 kg P ha^{-1} and 124.5 kg K ha^{-1}), which were incorporated by ploughing in. Nitrogen fertilisers were used in spring at a dose of 100 kg N ha^{-1}. The tubers were planted manually in late April at a spacing of 40 × 67.5 cm. The potato crop was protected against pests and diseases as recommended by the Institute of Plant Protection-National Research Institute Poznań, Poland (Plant Protection Recommendations for 2018/2019, 2018). The potatoes were harvested at full physiological maturity of tubers, in early September.

Determination of vitamin C and total protein

Tubers from 10 plants were collected from each plot for chemical composition determination. The vitamin C content in fresh tubers was determined using the Tilman's method modified by Pijanowski (Ostrowska et al. 1991). This method is based on the extraction of a sample of potato tubers with oxalic acid, and titration of the obtained filtrate with 2,6-dichlorophenolo--indophenol. The vitamin C content was expressed as the ascorbic acid content in mg kg fresh weight. The protein content was determined in dry matter. The dry matter content was determined by a two-step drying method, i.e. drying at 60°C for 10-12 h and then at 105°C until the sample achieves constant weight. The total protein content was calculated from the nitrogen content, which – after mineralisation of a sample in concentrated sulfuric acid – was assayed with the Kjeldahl method on a 2300 Kjeltec Analyser Unit apparatus and then multiplied by 6.25 (Ostrowska et al. 1991).

Statistical analysis

The research results were statistically analysed with an analysis of variance. The significance between means was checked with the Tukey's test at the significance level of $p \leq 0.05$ (Trętowski, Wójcik 1991).

Meteorological conditions during the growing season

Weather conditions in the study period were quite varied (Table 3). The year 2018 was warm with precipitation similar to the long-term sum. The year 2019 was by 2°C colder and it was characterised by precipitation shortages. The precipitation and thermal conditions the most conducive to potato growing were recorded in 2020, which was mild and had an optimal precipitation level.

Table 3

Mean air temperature and rainfall during potato vegetation (Zawady Meteorological Station)

Months	Mean temperature (°C)				Rainfall (mm)			
	2018	2019	2020	30-year mean 1980-2009	2018	2019	2020	30-year mean 1980-2009
April	13,1	9.8	8.6	7.9	34.5	5.9	6.0	49.6
May	17.0	13.3	11.7	11.2	27.3	59.8	63.5	48.2
June	18.3	17.9	19.3	16.7	31.5	35.9	118.5	60.7
July	20.4	18.5	19.0	19.3	67.1	29.7	67.7	45.7
August	20.6	19.9	20.2	18.0	54.7	43.9	17.9	53.0
September	15.9	14.2	15.5	13.0	80.6	17.4	38.8	50.7
Mean Sum	17.6	15.6	15.7	14.4	295.7	192.6	312.4	307.9

RESULTS AND DISCUSSION

The vitamin C content in table potato tubers registered in the National Register in 2019 ranged from 115 to 267 mg kg^{-1} fresh matter (NOWACKI 2019). In the study reported here, the concentration of this component in tubers fell within the range of 183.8 to 209.5 mg kg^{-1} and was significantly affected by weed control methods using the herbicide and biostimulants, and by the research years (Tables 4, 5). The herbicide used to control weeds, whether applied alone or with the biostimulants PlonoStart, Aminoplant or Agro-Sorb Folium, contributed to an increase in the concentration of vitamin C compared with the control. The highest vitamin C content was recorded after clomazone + metribuzin was applied in combination with the bio-

Table 4

The content of vitamin C and total protein in potato tubers

Treatment	Cultivars		Mean
	Malaga	Oberon	
Vitamin C (mg kg^{-1})			
1) control object – without herbicide and biostimulants	183.8*A*	196.4*A*	190.1*b*
2) clomazone + metribuzin (Avatar 293 ZC)	200.1*A*	198.2*A*	199.1*a*
3) clomazone + metribuzin + PlonoStart	202.7*A*	202.6*A*	202.7*a*
4) clomazone + metribuzin + Aminoplant	206.6*A*	204.3*A*	205.4*a*
5) clomazone + metribuzin + Agro-Sorb-Folium	204.4*A*	202.6*A*	203.5*a*
Mean	199.5*a*	200.8*a*	200.2
Total protein (g kg^{-1})			
1) control object - without herbicide and biostimulants	113.6*A*	146.3*A*	130.0*c*
2) clomazone + metribuzin (Avatar 293 ZC)	122.4*A*	150.5*A*	136.5*bc*
3) clomazone + metribuzin + PlonoStart*	127.0*A*	167.6*A*	147.3*a*
4) clomazone + metribuzin + Aminoplant**	125.1*A*	158.5*A*	141.8*ab*
5) clomazone + metribuzin + Agro-Sorb-Folium***	125.4*A*	164.0*A*	144.7a
Mean	122.7*b*	157.4*a*	140.1

Means followed by different letters were significantly different at $P \leq 0.05$. Means in columns marked with capital letters refer to interactions between the factors. Means in the last column and means in the last row (followed by lowercase letters) are for treatments and cultivars

* PlonoStart – contains: min.: N_{total} – 16.4,%, K_2O – 0.75%, CaO – 0.07%, MgO – 0.02%, S – 941 mg kg^{-1}, lactic acid bacteria, actinomycetes; Producer – Przedsiębiorstwo-Wdrożeniowo--Innowacyjne Andrzej Bogdanowicz, Skarszewy Poland; (www.ipm.iung.pulawy.pl.fert wyszukiwarka-nawozów-wyszukiwanie-IUNG; www.gov.pl_web_rolnictwo_wykaz_nawozow Rejestr_NAWOZY_22_06_2021);

** Aminoplant – contains: N_{total} – 9.48%, $N_{organic}$ – 9.2%, N-NH4 – 0.88%, $C_{organic}$ – 25%, free amino acids – 11.57%, organic matter – 87.7%; Producer – ISAGRO Sp.A., Milano Italy; (www.ipm.iung.pulawy.pl.fert wyszukiwarka-nawozów-wyszukiwanie-IUNG; www.gov.pl_web_rolnictwo_wykaz_nawozow Rejestr_NAWOZY_22_06_2021);

*** Agro-Sorb-Folium – contains: N_{total} – 2.2%, B – 0.02%, Mn – 0.05%, Zn – 0.09%, total amino acids – 13.11%, free amino acids – 10.66%; Producer – Biopharmacotech Sp. z o.o., Częstochowa Poland (www.ipm.iung.pulawy.pl.fert wyszukiwarka-nawozów-wyszukiwanie-IUNG; www.iung.pl_Wykaz_ekologia Wykaz nawozów i środków poprawiających…IUNG)

Table 5

The content of vitamin C and total protein in potato tubers in the research years

Years	Cultivars		Mean
	Malaga	Oberon	
Vitamin C (mg kg^{-1})			
2018	193.9*A*	197.9*A*	195.9*b*
2019	195.2*A*	202.2*A*	198.7*a*
2020	209.5*A*	202.4*A*	206.0*a*
Mean	199.5*a*	200.8*a*	202.0
Total protein (g kg^{-1})			
2018	121.1*A*	168.5*A*	144.8*a*
2019	121.7*A*	141.6*B*	131.7*b*
2020	125.3*A*	162.1*A*	143.7*a*
Mean	122.7*b*	157.4*a*	140.1

Means followed by different letters were significantly different at $P \leq 0.05$. Means in columns marked with capital letters refer to interactions between the factors. Means in the last column and means in the last row (followed by lowercase letters) are for years and cultivars.

stimulant Aminoplant. The main reason for increasing the content of vitamin C in the object sprayed with the herbicide and the Aminoplant biostimulant was the addition of the Aminoplant preparation, containing as many as 18 free amino acids, which increase the activity of many enzymes, have a positive effect on the yield and improve its quality (www.ipm.iung.pulawy.pl.fert; www.gov.pl_web_rolnictwo_wykaz_nawozow). An increase in the content of this vitamin was reported by Gugała et al. (2019), who applied the herbicides clomazone (Command 480 EC) and pendimethalin (Stomp 400 SC) and their mixtures with linuron (Dispersion Afalon 450 SC), as well as by Barbaś and Sawicka (2015), who combined mechanical and chemical weed control in a potato crop. An increase in the vitamin C content following an application of biostimulants was recorded by Al-Juthery et al. (2018) and Trawczyński (2020), whereas Wadas and Dziugieł (2020) only pointed to an upward tendency following an application of biostimulants. The beneficial effect of Aminoplant on the chemical composition of carrot roots was reported by Grabowska et al. (2012).

Variance analysis confirmed the effect of moisture and thermal conditions during the study on the vitamin C content in potatoes (Table 5). Vitamin C accumulation was the highest in 2020, when precipitation was similar to the long-term average sum, and temperatures in the months of yield accumulation (July and August) were favourable. A significantly lower concentration of vitamin C was recorded in 2018, which was the warmest. No interaction between the experimental factors was confirmed. Also, Pszczółkowski et al. (2019) reported the highest vitamin C content associated with optimum moisture conditions (347.6 mm in April-September). Additionally, they confirmed an interaction between cultivation technology and study years.

An effect of weather conditions on the concentration of vitamin C has been reported by many authors (Hamouz et al. 2009, Wadas et al. 2012, Żołnowski 2013, Trawczyński 2020).

The examined weed control methods using the herbicide and biostimulants significantly affected the tuber content of protein (Table 4). The highest concentration of protein was determined in the tubers of potato treated with the herbicide clomazone + metribuzin (Avatar 293 ZC) combined with the biostimulant PlonoStart, which could be a consequence of the total nitrogen content in the amount of 16.4% in the biostimulant (www.ipm.iung.pulawy.pl.fert; www.gov.pl_web_rolnictwo_wykaz_nawozow). Compared with the control, significant differences were found for the treatments using the herbicide and the remaining biostimulants, that is Aminoplant and Agro-Sorb-Folium. A beneficial effect of herbicides and biostimulants was reported in earlier works by Zarzecka et al. (2020) and by Mystkowska (2018), who had examined biostimulants alone. In contrast, Wierzbowska et al. (2015) as well as Wadas and Dziugieł (2020) found no effect of biostimulants on the potato tuber content of protein.

Protein content was significantly higher in cv. Oberon than in cv. Malaga. The effect of cultivar-related characteristics on this traits has been reported by many researches (Wierzbowska et al. 2015, Leonel et al. 2017, Wadas, Dziugieł 2020).

Meteorological conditions in the study years determined the total protein content in potato tubers (Table 5). Protein accumulation in tubers was the highest in the warmest year 2018, when precipitation total was similar to the long-term value. In this study, an interaction between cultivars and the weather during the growing season was confirmed. Most protein was accumulated by cv. Oberon in the warm year 2018, while no year-related differences were found for cv. Malaga. A similar response associated with moisture and thermal conditions was reported by other authors (Lachman et al. 2005, Trawczyński 2016, Mystkowska 2018, Zarzecka et al. 2020). Research into the application of a herbicide and biostimulants suggests a new way of improving the qualitative characteristics of table potato tubers.

On average for the three years of research, the applied herbicide Avatar and biostimulants had a significant impact on the total yield of potato tubers (Table 6). The herbicide alone or applied with biostimulants increased the

Table 6

Treatment	Yield (t ha^{-1})
1) Control object - without herbicide and biostimulants	31.19c
2) clomazone + metribuzin (Avatar 293 ZC)	34.68b
3) clomazone + metribuzin + PlonoStart	37.79b
4) clomazone + metribuzin + Aminoplant	36.10b
5) clomazone + metribuzin + Agro-Sorb-Folium	40.68a
Mean	36.09

Means followed by different letters were significantly different at $P \leq 0.05$.

tuber yield by 3.49 up to 9.49 t ha^{-1} in comparison with the control object. The best results were obtained after the application of Avatar 293 ZC and the Agro-Sorb-Folium biostimulant. The increase in the yield from the objects sprayed with the herbicide and biostimulants resulted from reduced weed competition and the stimulating effect of Agro-Sorb-Folium, PlonoStart and Aminoplant preparations on the development of potato plants.

CONCLUSIONS

Methods of weed control involving application of a herbicide and biostimulants contributed to an increase in the vitamin C content and total protein content in table potato tubers. The highest vitamin C accumulation followed the application of the herbicide clomazone + metribuzin (Avatar 293 ZC) + the biostimulant Aminoplant, whereas the total protein content was the highest after spraying with the same herbicide + the biostimulant PlonoStart. The cultivar Oberon displayed higher potential than cv. Malaga for the accumulation of chemical components in tubers. The analyses conducted in the study demonstrated a significant effect of meteorological conditions throughout the study years on the concentration of the chemical components of potato tubers examined in the research.

REFERENCES

Al-Juthery H.W., Ali N.S., Al-Taey D.K.A., Ali E.A.H. 2018. *The impact of foliar application of nanofertilizer, seaweed and hypertonic on yield of potato*. Plant Arch, 18(2): 2207-2212. DOI: 10.13140/RG.2.2.16557.33763

Barbaś P., Sawicka B. 2015. *The content of vitamin C in potato tubers depending on different methods of potato production*. Biul. IHAR, 278: 39-48 (in Polish). https://www.researchgate.net/publication/303297127

Beals K.A. 2019. *Potatoes, nutrition and health*. Am. J. Potato Res., 96: 102-110. DOI: 10.1007/s12230-018-09705-4

Djaman K., Sanogo S., Koudahe K., Allen S., Saibou A., Essah S. 2021. *Characteristics of organically grown compared to conventionally grown potato and the processed products*: *A Review*. Sustainability,13, 6289. DOI: 10.3390/su13116289

Dzwonkowski W. 2017. *Evolution of potato production in Poland and the EU*. Zesz. Nauk. SGGW, Probl. Rol. Świat., 17(32): 3: 71-80. (in Polish) DOI: 10.22630/PRS.2017.17.3.54

Dzwonkowski W. 2020. *Potato market. State and perspectives*. Ed. Institute of Agricultural and Food Economics-National Research Institute, Warsaw, Poland, 47: 1-37. (in Polish)

Głosek-Sobieraj M., Cwalina-Ambroziak B., Waśkiewicz A., Hamouz K., Perczak A. 2019. *The effect of biostimulants on the health status and content of chlorogenic acids in potato tubers (Solanum tuberosum* L.*) with colored flesh*. Gesunde Pflanzen. DOI: 10.1007/s10343-018-00441-7

Grabowska A., Kunicki E., Sękara A., Kalisz A., Wojciechowska R. 2012. *The effect of cultivar and biostimulant treatment on the carrot yield and its quality*. Veg Crops Res. Bul., 77: 37-48. DOI: 10.2478/v10032-012-0014-1

Grudzińska M., Czerko Z., Zarzyńska K., Borowska-Komenda M. 2016. *Bioactive compounds in*

potato tubers: Effects of farming system, cooking method, and flesh color. PLoS ONE, 3: 1-13. DOI: 10.1371/journal.pone.0153980

Gugała M., Zarzecka K., Sikorska A. 2019. *The effect of herbicides and their mixtures and weather conditions on the content of vitamin C in edible potato tubers*. Agronomy Sci., 74(4): 115-122. DOI: 10.24326/as.2019.4.8

Hamouz K., Lachman J., Dvořák P., Orsák M., Hejtmánková K., Čížek M. 2009. *Effect of selected factors on the content of ascorbic acid in potatoes with different tuber flesh colour*. Plant Soil Environ., 55(7): 281-287. https://doi.org/10.17221/82/2009-PSE

Lachman J., Hamouz K., Dvořák P., Orsák M. 2005. *The effect of selected factors on the content of protein and nitrates in potato tubers*. Plant Soil Environ., 51(10): 431-438. https://www.agriculturejournals.cz/publicFiles/50997.pdf

Leonel M., Carmo L., Fernandes A.M., Soratto R.P., Eburneo J.A.M., Garcia E.L., Santos T.P.R. 2017. *Chemical composition of potato tubers: the effect of cultivars and growth conditions*. J. Food Sci. Technol., 54(8): 2372-2378. DOI: 10.1007/s13197-017-2677-6

Leszczyński W. 2012. *Nutrition value of potato and potato products (Review of literature)*. Biul. IHAR, 266: 5-20. (in Polish) file:///C:/Users/Admin/Downloads/Wac%C5%82aw_ Leszczy%C5%84ski.pdf

Mystkowska I. 2018. *Content of total and true protein in potato tubers in changing weather conditions under the influence of biostimulators*. Acta Agroph., 25(4): 475-483. (in Polish) DOI: 10.31545/aagr/102470

Nazranov K., Didanova E., Shibzukhov Z.G., Orzalieva M., Nazranov B. 2020. *Influence of growth regulators on yield, quality and preservation of potato stubs in the mountain zone of the Kabardino-Balkaria Republic*. E3S Web of Conf 222, 02002. DOI: 10.1051/e3sconf/202022202002

Nowacki W. 2019. *Characteristic of native potato cultivars register*. Institute of Plant Breeding and Acclimatization-National Research Institute, Jadwisin Branch, pp. 43. (in Polish)

Ostrowska A., Gawliński S., Szczubiałkowa Z. 1991. *Methods of analysis and assessment of soil and plants*. Institute of Environment, Warszawa, pp. 334. (in Polish)

Plant protection recommendations for 2018/2019. 2018. Institute of Plant Protection-National Research Institute, Poznań, pp. 359. (in Polish)

Pszczółkowski P., Sawicka B., Danilčenko H. 2019. *Effect of biopreparations on the dry matter, starching and vitamin C in potato tubers*. Agronomy Sci., 74(3): 47-56. (in Polish) DOI: 0.24326/as.2019.3.4

Rouphael Y., Colla G. 2020. *Editorial: Biostimulants in Agriculture*. Front. Plant Sci. 11:40. DOI: 10.3389/fpls.2020.00040

Trawczyński C. 2016. *The influence of cultivars and weather conditions of vegetation period on the content of some nutritional and anti-nutritional components in potato tubers*. Acta Agroph., 23(1): 119-128. (in Polish) file:///C:/Users/Admin/Downloads/The%20influence %20of. pdf

Trawczyński C. 2018. *The effect of foliar preparation with silicon on the yield and quality of potato tubers in compared to selected biostimulators*. Fragm. Agron., 5(4): 113-122. DOI: 10.26374/fa.2018.35.47

Trawczyński C. 2020. *The effect of biostimulators on the yield and quality of potato tubers grown in drought and high temperature conditions*. Biul. IHAR, 289: 11-12. (in Polish) DOI: 10.37317/biul-2020-0017

Trętowski J., Wójcik R. 1991. *Methodology of agricultural experiments*. Wyższa Szkoła Rolniczo-Pedagogiczna, Siedlce, pp. 500. (in Polish)

Wadas W., Łęczycka T., Borysiak-Marciniak I. 2012. *Effect of fertilization with multinutrient complex fertilizers on tuber quality of very early potato cultivars*. Acta Sci. Pol., Hort. Cultus, 11(3): 27-41. http://www.hortorumcultus.actapol.net/pub/11_3_27.pdf

Wadas W., Dziugieł T. 2020. *Quality of new potatoes (Solanum tuberosum* L.*) in response to plant biostimulants application*. Agriculture, 10, 265. DOI: 10.3390/agriculture10070265

Wierzbowska J., Cwalina-Ambroziak B., Głosek-Sobieraj M., Sienkiewicz S. 2015. *Effect of biostimulators on yield and selected chemical properties of potato tubers*. J. Elem., 20(3): 757-768. DOI: 10.5601/jelem.2014.19.4.799

www.ipm.iung.pulawy.pl.fert wyszukiwarka-nawozów-wyszukiwanie-IUNG (accessed on 18 September 2021)

www.gov.pl_web_rolnictwo_wykaz_nawozow Rejestr_NAWOZY_22_06_2021(accessed on 18 September 2021)

www.iung.pl_Wykaz_ekologia Wykaz nawozów i środków poprawiających…IUNG (accessed on 18 September 2021)

Zarzecka K., Gugała M., Mystkowska I., Sikorska A. 2020. *Total and true protein content in potato tubers depending on herbicides and biostimulants*. Agronomy, 10, 1106; DOI: 10.3390/agronomy 10081106

Żołnowski A.C. 2013. *Studies on the variability of the yield and quality of table potato (Solanum tuberosum* L.*) grown under varied levels of mineral fertilization*. Diss. Monogr., 191, 259 p. (in Polish)