JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2021, 22(8), 54–63
https://doi.org/10.12911/22998993/140330
ISSN 2299-8993, License CC-BY 4.0

Received: 2021.06.16
Accepted: 2021.07.24
Published: 2021.08.06

The Leaf Greenness Index SPAD and Selected Features of Potato Following an Application of Herbicides and Biostimulants

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

[1] Siedlce University of Natural Sciences and Humanities, Faculty of Agrobioengineering and Animal Husbandry, ul. B. Prusa 14, 08-110 Siedlce, Poland

[2] Pope John Paul II State School of Higher Education in Biała Podlaska, Faculty of Health Sciences, ul. Sidorska 95/97, 21-500 Biala Podlaska, Poland

[3] The State Higher School of Vocational Education in Ciechanów, Faculty of Engineering Sciences, ul. Narutowicza 9, 06-400 Ciechanów, Poland

* Corresponding author's e-mail: kzarzecka@uph.edu.pl

ABSTRACT

The objective of the research was to determine the effect of herbicides and herbicides combined with biostimulants on the leaf greenness index SPAD and selected potato characteristics, i.e. plant height, yield of large tubers and the vitamin C content. A three-year experiment was conducted to examine the following factors: factor I – three potato cultivars: Bartek, Gawin, Honorata; factor II – five methods of an application of herbicides and biostimulants: 1. control unit without chemical control, 2. the Harrier 295 ZC herbicide (linuron + clomazone), 3. the Harrier 295 ZC herbicide (linuron + clomazone) and the Kelpak SL biostimulant (*Ecklonia maxima*), 4. the Sencor 70 WG herbicide (metribuzin), 5. the Sencor 70 WG herbicide (metribuzin) and the Asahi SL biostimulant (sodium para-nitrophenol, sodium ortho-nitrophenol, sodium 5-nitroguaiacol). The cultivars investigated in the experiment significantly affected the leaf greenness index SPAD, plant height, yield of large tubers and the vitamin C content. The herbicides and biostimulants enhanced the values of the examined potato characteristics. Linear correlation coefficients confirm a strong, significant, positive correlation between the SPAD index and plant height, yield of large tubers and vitamin C content.

Keywords: chlorophyll, *Solanum tuberosum* L., vitamin C, yield of tubers.

INTRODUCTION

Potato (*Solanum tuberosum* L.) belongs to one of three most important edible plants in the world, and is grown on all the continents [Birch et al. 2012]. Potato yields and quality are influenced by numerous agrotechnological, genetic and environmental factors [Escuredo et al. 2018, Trawczyński 2020, Wadas and Dziugieł 2020]. Appropriate tillage to control weeds is one of more important cultivation factors. Destruction of weeds by using a combination of mechanic and chemical practices contributes to increased tuber yields and improved tuber quality, as confirmed in the research by numerous authors [Ilić et al. 2016, Gugała et al. 2018, Barbaś and Sawicka 2020]. In recent years, there has been growing interest and application of various biostimulants in fields under crop plants, including potato, due to many sustainable agriculture-related benefits [Chehade et al. 2018, Nephali et al. 2020, Trawczyński 2020]. Biostimulants stimulate sprouting, development of the rooting system and plant growth [Ertani et al. 2018]. Moreover, they increase the efficiency of chlorophyll synthesis, root development, nutrient uptake from the soil and nutrient metabolism, particularly when the environmental conditions are unfavourable for plant growth and development [Calvo et al. 2014, Popko et al. 2018]. What is more, the products improve the plant resistance systems protecting them against abiotic stress and pathogens [Sharma et al. 2014].

In addition, they are safe for the environment and their application makes it possible to reduce the amount of chemicals utilised in agriculture and plant protection [Radkowski and Radkowska 2013, Du Jardin 2015].

The new regulation (EU) 2019/1009 defines plant biostimulants as follows: "EU fertilising product the function of which is to stimulate plant nutrition processes independently of the product's nutrient content with the sole aim of improving one or more of the following characteristics of the plant and/or the plant rhizosphere: (1) nutrient use efficiency, (2) tolerance resistance to (a) biotic stress, (3) quality characteristics, or (4) availability of confined nutrients in the soil or rhizosphere" [Regulation (EU) 2019]. The biostimulant product number and market are increasing year by year. In 2020, the list of growth stimulants in Poland included 64 products [Ministry of Agriculture and Rural Development 2021. Thus, the increasing range of biostimulants introduced into the market and their application in combination with other products prompt an assessment of a wide range of characteristics (physiological, morphological, chemical) of cultivated potato varieties. Potato is one of the most efficient plant species converting the solar energy into human food, both in qualitative and quantitative terms. The chlorophyll content in potato leaves is closely related to the potato content of nitrogen [Ramirez et al. 2014, Gaurav et al. 2019]. Vos and Bom [1993] demonstrated a very strong correlation (r = 0.97) between readings from the SPAD-502 measuring device manufactured by Minolta Camera as well as the nitrogen and chlorophyll concentrations in potato leaf laminae. Moreover, they found that the SPAD readings were closely correlated with the analytical measurements of chlorophyll contents, which ensures a good estimation of the leaf content of these components.

The measurement of chlorophyll SPAD with a measuring device is predominantly used to determine the nitrogen status in crop plants. Many workers have pointed out that, at certain SPAD readings, potato plants are adequately supplied with nitrogen, and yields reach maximum levels. Giletto et al. [2010] and Trawczyński [2019] harvested the maximum tuber yields when the SPAD values ranged from 35 to 40 and from 43.7 to 43.9 units, respectively. Dvořák and Král [2019], who applied black textile mulch while growing potatoes, found a strong correlation (r = 0.6572) between the SPAD values and tuber yield. The authors suggest that, based on the SPAD values, it is possible to predict the potato tuber yield levels as well as yields of its components. Good development of plants is indicative of their good nutrition, normal course of their life processes and, thus, optimum yielding and nutrient accumulation. The purpose of the work was to assess the effect of herbicides and herbicides combined with biostimulants on the leaf greenness index SPAD, tuber yield and the vitamin C content in tubers.

MATERIAL AND METHODS

Field experiment and agrotechnological treatments

The field experiment was carried out for three years, from 2012 to 2014, on a farm of the multi-branch company Soleks located in the District of Siedlce, east-central Poland. It was established in a complete block design with a split-plot arrangement, with three replicates. Two factors were examined in the experiment:

- factor I – three medium-early table potato cultivars: Bartek (stem-type cultivar), Gawin (stem-type cultivar) and Honorata (leaf-like cultivar);
- factor II – five methods of herbicide and biostimulant application: 1. control unit without chemical control, 2. Harrier 295 ZC (linuron + clomazone) at a rate of 2.0 dm^3 ha^{-1}, 3. Harrier 295 ZC (linuron + clomazone) at a rate of 2.0 dm^3 ha and the Kelpak SL growth regulator (*Ecklonia maxima*) at a rate of 2.0 dm^3 ha^{-1}, 4. Sencor 70 WG (metribuzin) at a rate of 1.0 kg ha^{-1}, 5. Sencor 70 WG (metribuzin) at a rate of 1.0 kg ha^{-1} and the Asahi SL growth regulator (sodium para-nitrophenol, sodium ortho-nitrophenol, sodium 5-nitroguaiacol) at a rate of 1.0 dm^3 ha^{-1}.

Herbicides and biostimulants were used in accordance with the recommendations of the Institute of Plant Protection of Poland [Plant Protection Recommendations for 2014/15, 2014]. The dates of major agricultural treatments in the experiment are presented in Table 1.

The work of Gugała et al. [2018] presents a detailed description of the treatments applied to units with herbicides and biostimulants. There were 45 plots in the experiment and the area of each plot was 18.75 m^2 (that is, 15 plants spaced every 37 cm in five rows, each 67.5 cm apart). Each year, the previous crop was winter wheat. The potato plants were protected against diseases

Table 1. Dates of major agricultural treatments in the experiment

Parameters	2012	2013	2014
Fertilization with phosphorus (44 kg ha^{-1} P) and potassium (125 kg ha^{-1} K) and farmyard manure (25 t ha^{-1}) – autumn	10.11.2011	14.11.2012	15.11.2013
Nitrogen fertilization 100 kg ha^{-1} N – spring	27.04.2012	06.05.2013	21.04.2014
Planting potato tubers	30.04.2012	08.05.2013	23.04.2014
Application Harrier 295 ZC (linuron+clomazone)	10.05.2012	18.05.2013	02.05.2014
Application Kelpak SL (*Ecklonia maxima*)	06.06. and 20.06.2012	12.06. and 24.06.2013	31.05. and 20.06.2014
Application Sencor 70 WG (metribuzin)	22.05.2012	29.05.2013	18.05.2014
Application Asahi SL (sodium para-nitrophenol, sodium ortho-nitrophenol, sodium 5-nitroguaiacol)	06.06. and 20.06.2012	12.06. and 24.06.2013	31.05. and 20.06.2014
Date of harvest	04.09.2012	04.09.2013	02.09.2014

and insects following recommendations of the Institute of Plant Protection of Poland [Plant Protection Recommendations for 2014/15, 2014]. During the growing season, the Colorado potato beetle was controlled with the following insecticides: Apacz 50 WG (clothianidin) and Fastac 100 EC (alpha, cypermethrin); the fungicides used against potato blight were as follows: Ridomil Gold MZ 68 WG (metalaxyl-M+mancozeb) and Altima 500 SC (fluazinam).

Leaf greenness index SPAD

The assessment of leaf greenness SPAD (Soil Plant Analysis Development) was conducted using a SPAD-502Plus measuring device (Konica Minolta, INC, Japan). The SPAD-502Plus chlorophyll meter is a small, handy, non-destructive device the readings of which are expressed in nonmetric SPAD units ranging from 0 to 200 [Chlorophyll meter SPAD 502Plus/502DL Plus]. It measures the light absorption by leaves at the wavelengths of 650 and 940 nm. The measurements were taken twice at 10-day intervals, beginning at the stage of full flowering (BBCH 67-68) and after chemical control treatments with herbicides and biostimulants Adamczewski and Matysiak [2011] (Table 2).

Ten individual readings were taken in the second row of each plot starting with the third plant (on a second leaf from the top of the plant). The SPAD readings were taken in the morning between ten and noon on the same plants. Next, the values were recorded and averaged.

Plant height, tuber yield and determination of the vitamin C content

When the potato plants were fully developed, that is at the flowering stage (BBCH 67-68), 10 plants in each plot were analysed at three replicates. Each year, prior to harvest, tubers of randomly selected ten plants were dug out in each unit to determine the yield structure based on the following size fractions: 35 or less, 36–50, 51–60 and 60 mm or more. Total tuber yield comprised the weight of tubers manually harvested from each plot and the weight

Table 2. Occurrence of the main development phases of potato cultivars

Development phases		Years								
BBCH scale		2012			2013			2014		
		Bartek	Gawin	Honorata	Bartek	Gawin	Honorata	Bartek	Gawin	Honorata
Emergence	beginning 10	29.05.	26.05.	29.05.	05.06.	02.06.	07.06.	24.05.	21.05.	25.05.
	full 12-13	04.06.	30.05.	04.06.	12.06.	07.06.	12.06.	31.05.	29.05.	31.05.
	end 15	09.06.	06.06.	09.06.	17.06.	12.06.	16.06.	04.06.	03.06.	04.06.
Flower buds 51		25.06.	20.06.	20.06.	26.06.	28.06.	24.06.	20.06.	16.06.	17.06.
Flowering	beginning 60	25.06.	22.06.	23.06.	30.06.	02.07.	29.06.	22.06.	18.06.	21.06.
	full 67-68	29.06.	27.06.	27.06.	09.07.	13.07.	09.07.	30.06.	29.06.	02.07.
	end 69	10.07.	07.07.	07.07.	13.07.	18.07.	14.07.	10.07.	08.07.	10.07.
Yellowing	beginning 81	20.08.	17.08.	17.08.	18.08.	16.08.	18.08.	09.08.	09.08.	14.08.
	full 95	24.08.	26.08.	21.08.	23.08.	20.08.	22.08.	14.08.	14.08.	22.08.
	end 99	30.08.	28.08.	28.08.	01.09.	30.08.	01.09.	22.08	22.08.	26.08.

of samples taken earlier (expressed as t ha^{-1}). The yield of large tubers consisted of tubers the diameter of which exceeded 50 cm and which were without any external or internal defects [Roztropowicz 1999]. Determination of the vitamin C content was carried out in fresh tubers 4–5 days after potato harvest. The vitamin C content was expressed in mg per 1 kg fresh matter. The vitamin C content was determined by means of Tilman's method as modified by Pijanowski [Rutkowska 1981].

Soil and meteorological conditions

The soil samples were taken each year before the experiment was set up from the topsoil at a depth of 0–30 cm. The soil was classified as Haplic Luvisol [IUSS Working Group WRB, 2015]. The soil was characterised by slightly acidic to neutral pH (pH in 1 M KCl from 5.60 to 6.35), organic matter content 15.0–18.7 g kg^{-1}, from high to very high content of available phosphorus (68.6–110 mg kg^{-1} P), medium to very high potassium content (99.6–149.4 mg kg^{-1} K), and high magnesium content (50.0–56.0 mg kg^{-1} Mg).

The weather data are presented in Table 3. On the basis of Sielianinov's hydrothermal coefficient, the year 2012 was dry, 2013 was optimum and 2014 was relatively dry [Skowera et al. 2014].

In 2012, the average air temperature in April-September was 15.4 °C and was by 0.7 °C higher than the long-term mean for these months. In contrast, precipitation was lower than the long-term value, rendering the growing season unfavourable for potato growth and development. In 2013, the temperature was higher than the long-term mean and precipitation was by higher than the long-term value as much as 166.1 mm.

Table 3. Rainfall, air temperature and the hydrothermal of coefficient Sielianinov during the potato growing season according to the meteorological station in Zawady

Year	Month	Rainfall (mm)	Air temperature (°C)	Hydrothermal coefficient k*	Evaluation of the month*
2012	April	29.9	8.9	1.10	relatively dry
	May	53.4	14.6	1.20	relatively dry
	June	76.2	16.3	1.60	optimal
	July	43.0	20.7	0.69	very dry
	August	51.0	18.0	0.94	dry
	September	11.4	14.1	0.27	extremely dry
	Sum/Average	264.9	15.4	0.95	dry
2013	April	36.0	7.4	1.60	optimal
	May	105.9	15.3	2.30	humid
	June	98.8	18.0	1.80	relatively humid
	July	91.3	19.0	1.60	optimal
	August	15.0	18.8	0.30	extremely dry
	September	94.3	11.7	2.70	very humid
	Sum/Average	441.3	15.0	1.60	optimal
2014	April	45.0	9.8	1.50	optimal
	May	92.7	13.5	2.30	humid
	June	55.4	15.4	1.20	relatively dry
	July	10.0	20.8	0.16	extremely dry
	August	105.7	18.1	1.90	relatively dry
	September	26.3	14.1	0.62	very dry
	Sum/Average	335.1	15.3	1.20	relatively dry
Multiyear 1987-2000		275.2	14.7		

* hydrothermal of coefficient Sielianinov was calculated according to the formula: $k = 10\ P/\ \Sigma t$, Skowera et al. [2014], where: P - the sum of the monthly rainfalls in mm, Σt - monthly total air temperature > 0 °C. Ranges of values of this coefficient were classified as follows: up to 0.4- extremely dry; 0.41–0.7 - very dry; 0.71–1.0 - dry; 1.01–1.3- relatively dry; 1.31–1.6 - optimal; 1.61–2.0 - relatively humid; 2.01–2.5 - humid; 2.51–3.0 - very humid; over 3.0- extremely humid

The meteorological conditions in the growing season 2014 were the most favourable as the air temperature averaged 15.3 °C and precipitation sum reached 335.1 mm. According to Kalbarczyk and Kalbarczyk [2009], the weather conditions which are optimum for plant yielding in Poland consist of the average air temperature from May to September of 15.2 °C and precipitation sum 335 mm and from the stage of flowering to maturing (July and August), potato plant water demand is at its highest. In the study reported here, in 2012, 2013 and 2014, precipitation from July to August was, 94.0, 106.3 and 115.7 mm, respectively.

Statistical analysis

The data obtained in the experiment were analysed statistically using ANOVA. The significance of the sources of variation was tested with the F Fisher-Snedecor test, and the significance of differences between means was checked at the significance level p≤ 0.05 using Tukey's multiple intervals. All calculations were performed in MS Excel using the authors' own algorithms based on the split-plot mathematical model. The above-mentioned statistical procedures are presented in the work by Trętowski and Wójcik [1991]. The relationships between potato plant height, yield of large tubers, vitamin C content and the leaf greenness index SPAD were also determined by computing linear correlation coefficients.

RESULTS AND DISCUSSION

Leaf greenness index SPAD

The SPAD leaf greenness index determined at the first date averaged 39.71 units and ranged from 34.87 to 43.70 (Tables 4, 5) according to cultivars, methods of herbicide and biostimulant application and atmospheric conditions in the study years. At the second date, SPAD was higher as it averaged 40.64 units and, depending on the experimental factors, ranged from 36.53 to 44.09 units. The values were close to readings reported by Mauromicale et al. [2006], Li et al. [2015], Zarzyńska and Pietraszko [2017] and Trawczyński [2019].

The cultivars grown in the experiment differed significantly in terms of the leaf greenness index. The highest value of the discussed parameter was recorded for cv. Honorata, being significantly lower for cv. Bartek and the lowest for cv. Gawin. The SPAD values which varied according to cultivars have been reported by other authors [Giletto et al. 2010, Zarzyńska and Pietraszko 2017].

In the study reported here, the leaf greenness index values were affected by the methods of herbicide and biostimulant application. These products increased the SPAD parameters compared with control, the highest readings resulting from a combined application of herbicides and biostimulants. A similar response was observed by Dvořák et al. [2016], whereas Wadas and Dziugieł [2020] found no influence of the following biostimulants: Bio-algeen S90,

Table 4. Leaf greenness index SPAD depending on cultivar

Methods of herbicides and biostimulants application	Cultivars			Mean value
	Bartek	Gawin	Honorata	
Leaf greenness index – SPAD I term				
1. Control object	37.66C	34.87D	41.20B	37.91d
2. Harrier 295 ZC	38.73B	36.07C	42.66A	39.15c
3. Harrier 295 ZC + Kelpak SL	39.48A	37.43B	43.09A	40.00b
4. Sencor 70 WG	39.62A	38.08B	42.83A	40.18b
5. Sencor 70 WG + Asahi SL	41.03A	39.31A	43.70A	41.35a
Mean	39.30b	37.15c	42.70a	39.71
Leaf greenness index – SPAD II term				
1. Control object	39.68A	36.53A	41.40A	39.20d
2. Harrier 295 ZC	40.52A	37.32A	42.46A	40.10c
3. Harrier 295 ZC + Kelpak SL	41.13A	39.06A	43.34A	41.18b
4. Sencor 70 WG	41.13A	38.28A	43.10A	40.84bc
5. Sencor 70 WG + Asahi SL	42.17A	39.55A	44.09A	41.93a
Mean	40.93b	38.15c	42.88a	40.64

Means followed by the same letters do not differ significantly at P≤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) are for methods and cultivars.

Kelpak SL and HumiPlant on the SPAD values in potato leaves although they noticed a significant impact of study years on this characteristic. In the research discussed here, there was no influence of weather conditions nor interaction between years and methods of product application on SPAD determined at both dates (Table 5).

Potato plant height, yield of large tubers and the vitamin C content in potato tubers

Potato plant height, yield of large tubers and the vitamin C content were significantly affected by methods of herbicide and biostimulant application as well as cultivars, weather conditions having an effect on plant height only (Tables 6, 7).

Table 5. Leaf greenness index SPAD depending on weather conditions during the study years

Methods of herbicides and biostimulants application	Years			Mean value
	2012	2013	2014	
Leaf greenness index – SPAD I				
1. Control object	36,99A	38.03A	38.70A	37.91d
2. Harrier 295 ZC	39.09A	38.57A	39.80A	39.15c
3. Harrier 295 ZC + Kelpak SL	40.16A	39.23A	40.61A	40.00b
4. Sencor 70 WG	39.79A	39.23A	41.51A	40.18b
5. Sencor 70 WG + Asahi SL	40.93A	40.81A	42.30A	41.35a
Mean	39.39a	39.17a	40.58a	39.71
Leaf greenness index – SPAD II				
1. Control object	37.31A	40.04A	40.26A	39.20d
2. Harrier 295 ZC	38.67A	40.60A	41.03A	40.10c
3. Harrier 295 ZC + Kelpak SL	40.44A	41.49A	41.60A	41.18b
4. Sencor 70 WG	39.53A	41.21A	41.77A	40.84bc
5. Sencor 70 WG + Asahi SL	41.53A	41.82A	42.45A	41.93a
Mean	39.50a	41.00a	41.42a	40.64

Means followed by the same letters do not differ significantly at P≤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) are for methods and years.

Table 6. Plant height, yield of tubers and vitamin C content in potato depending on cultivar

Methods of herbicides and biostimulants application	Cultivars			Mean value
	Bartek	Gawin	Honorata	
Potato plant height (cm)				
1. Control object	56.02A	63.04A	61.57A	60.21d
2. Harrier 295 ZC	58.44A	65.09A	65.02A	62.85c
3. Harrier 295 ZC + Kelpak SL	62.47A	71.76A	69.03A	67.76ab
4. Sencor 70 WG	60.32A	70.11A	66.50A	65.64bc
5. Sencor 70 WG + Asahi SL	65.89A	74.42A	70.69A	70.32a
Mean	60.63b	68.88a	66.56a	65.36
Yield of large tubers (diameter over 50 mm) (t ha^{-1})				
1. Control object	21.51E	16.31C	20.79D	19.54d
2. Harrier 295 ZC	25.78D	23.54B	25.68C	25.00c
3. Harrier 295 ZC + Kelpak SL	27.16C	24.03B	28.38B	26.52b
4. Sencor 70 WG	29.52B	26.09A	33.33A	29.65a
5. Sencor 70 WG + Asahi SL	32.33A	27.39A	32.47A	30.73a
Mean	27.26a	23.47b	28.13a	26.29
Vitamin C content of fresh matter (mg kg^{-1})				
1. Control object	199.5	193.7	200.7	197.9c
2. Harrier 295 ZC	203.4	195.8	202.6	200.6b
3. Harrier 295 ZC + Kelpak SL	205.0	197.0	203.9	202.0a
4. Sencor 70 WG	202.0	195.6	204.2	200.6b
5. Sencor 70 WG + Asahi SL	203.2	199.1	206.4	202.9a
Mean	202.7a	196.2b	203.5a	200.8

Means followed by the same letters do not differ significantly at P≤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) are for methods and cultivars.

Table 7. Plant height, yield of tubers and vitamin C content in potato tubers depending on weather conditions during the study years

Methods of herbicides and biostimulants application	Years			Mean value
	2012	2013	2014	
Potato plant height (cm)				
1. Control object	62.53A	56.80A	61.27A	60.21d
2. Harrier 295 ZC	64.09A	61.20A	63.27A	62.85c
3. Harrier 295 ZC + Kelpak SL	69.66A	65.30A	68.33A	67.76ab
4. Sencor 70 WG	67.33A	63.00A	66.60A	65.64bc
5. Sencor 70 WG + Asahi SL	74.06A	66.50A	70.40A	70.32a
Mean	67.53a	62.60b	65.96a	65.36
Yield of large tubers (diameter over 50 mm) (t ha^{-1})				
1. Control object	16.50C	20.01C	22.11C	19.54d
2. Harrier 295 ZC	24.59B	25.66B	24.75B	25.00c
3. Harrier 295 ZC + Kelpak SL	29.00A	26.51B	24.06B	26.52b
4. Sencor 70 WG	29.58A	27.96B	31.40A	29.65a
5. Sencor 70 WG + Asahi SL	30.94A	30.81A	30.43A	30.73a
Mean	26.12a	26.19a	26.55a	26.29
Vitamin C content of fresh matter (mg kg^{-1})				
1. Control object	195.3A	198.6A	199.9A	197.9c
2. Harrier 295 ZC	199.5A	201.3A	201.0A	200.6b
3. Harrier 295 ZC + Kelpak SL	200.8A	203.5A	201.7A	202.0a
4. Sencor 70 WG	197.7A	201.8A	202.3A	200.6b
5. Sencor 70 WG + Asahi SL	199.6A	204.0A	205.2A	202.9a
Mean	198.6a	201.8a	202.0a	200.8

Means followed by the same letters do not differ significantly at P≤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) are for metthods and years.

The tallest plants were recorded for cv. Gawin, cv. Bartek being the lowest. The highest large tuber yield and vitamin C content were found for cv. Honorata. They were lower for cv. Bartek and significantly lowest for cv. Gawin. The cultivar-related differences for the discussed characteristics have been confirmed by other authors [Escuredo et al. 2018, Gugała et al. 2018, Ierna and Mauromicale 2019, Trawczyński 2019].

Herbicides applied alone or in combination with biostimulants contributed to an increase in plant height, yield of large tubers and the vitamin C concentration compared with control. The tallest potato plants and the highest vitamin C content in tubers were observed after a combined application of herbicides and biostimulants, the highest yield being harvested following spraying with Sencor and Sencor+Asahi SL. A positive effect of chemical control methods on tuber yield was reported by Barbaś and Sawicka [2020] and Gugała et al. [2018] whereas Ahmadi Lahijani et al. [2018], Trawczyński [2020] and Wadas and Dziugieł [2020] observed a positive influence of biostimulants on tuber yields, yield structure and elements of chemical composition, including vitamin C. Barbaś and Sawicka [2015] found increased vitamin C contents, compared with control tubers, following spraying of the crop with the herbicide Sencor 70 WG in combination with Titus 25 WG, Fusilade Forte 150 EC and Apyros 75 WG.

The weather conditions during the growing season significantly influenced plant height only (Table 7). The tallest plants grew in 2012 and the lowest in 2013. It was also observed that, in terms of yield and vitamin C accumulation, precipitation and thermal conditions which were the closest to optimum prevailed in 2014, which is consistent with the findings of long-term research by Kalbarczyk and Kalbarczyk [2009]. Linear correlation coefficients confirmed that the leaf greenness index SPAD at both determination dates was strongly associated with plant height and large tuber yield of all the cultivars (Table 8).

The vitamin C content was significantly correlated with SPAD I (the first date) for cv. Honorata, and SPAD II (the second date) for cv. Gawin and Honorata. Similar relationships were reported by other authors. Tang et al. [2018] found that SPAD was positively correlated with the *Solanum tuberosum* plant height under thermal stress conditions, Dvořák and Král [2019] observed a strong correlation of SPAD with tuber yield and weight

Table 8. Plant height, yield of tubers and vitamin C content in potato tubers depending on weather conditions during the study years

Index	Cultivars	Potato plant height (cm)	Yield of large tubers (t ha^{-1})	Vitamin C content in of fresh matter (mg kg^{-1})
Leaf greenness index – SPAD I term	Bartek	0.9678**	0.9803**	0.5826ns
	Gawin	0.9593**	0.9186**	0.8765ns
	Honorata	0.9617**	0.9526**	0.9492**
Leaf greenness index – SPAD II term	Bartek	0.9747**	0.9757**	0.6215ns
	Gawin	0.9916**	0.9413**	0.9244**
	Honorata	0.9852**	0.9844**	0.9838**

** Significant at P≤0.05; ns - non-significant

of tubers with the diameter 55–60 mm. Mauromicale et al. [2006] reported highly significant correlations of the chlorophyll content with tuber yield (r = 0.992) and plant dry matter yield (r = 0.969). Wadas and Kalinowski [2017] demonstrated that, in cv. Lord, the correlation between the leaf greenness index SPAD and tuber weight was stronger following an application of the Tytanit® biostimulant compared with non-treated control. The role of a chlorophyll meter and the possibility of its application are also stressed by other authors who point out strong correlations between readings obtained using a SPAD-502 chlorophyll meter and an N-tester in the examinations of various crop plant species [Pacewicz and Gregorczyk 2009, Zhu et al. 2012].

CONCLUSIONS

The findings of this study showed that herbicides and herbicides combined with biostimulants contributed to an increase in the leaf greenness index SPAD determined by a Konica Minolta SPAD-502Plus measuring device, plant height, yield of tubers and the vitamin C content in tubers. Strong correlation associations between SPAD and the determined characteristics (potato plant height, yield of large tubers and the vitamin C content) confirm a positive effect of the applied products and, simultaneously, they suggest SPAD may be a good indicator of normal plant development. Thus, the device measuring SPAD, as a non-invasive tool, may have a wider range of applications in integrated and precision agriculture.

Acknowledgments

The research was carried out under the research project No. 214/04/S financed from a science grant by the Ministry of Science and Higher Education of Poland.

REFERENCES

1. Adamczewski K, Matysiak K. 2011. Compendium of Growth Stage Identification Keys for Mono- and Dicotyledonous Plants Extended BBCH Scale. Institute of Plant Protection−National Research Institute Poznan, Poland. (in Polish)
2. Ahmadi Lahijani M.J., Kafi M., Nezami A., Nabati J., Erwin J. 2018. Effect of 6-Benzylaminopurine and Abscisic Acid on Gas Exchange, Biochemical Traits, and Minituber Production of Two Potato Cultivars (*Solanum tuberosum* L.). Journal of Agriculture, Science and Technology, 20, 129–139.
3. Barbaś P., Sawicka B. 2015. The content of vitamin C in potato tubers depending on different methods of potato production. Biuletyn Instytutu Hodowli i Aklimatyzacji Roślin, 278, 39−48. (in Polish)
4. Barbaś P., Sawicka B. 2020. Dependence of potato yield on weed infestation. Agronomy Research, 18(2), 346–359.
5. Birch P.R.I, Bryan G., Fenton B., Gilroy E.M., Hein I. 2012. Crops that feed the world 8: Potato: are the trends of increased global production sustainable? Food Security, 4, 477–508.
6. Calvo P., Nelson L., Kloeppe J.W. 2014. Agricultural uses of plant biostimulants. Plant and Soil, 383, 3–41.
7. Chehade A.L., Chami A.Z., De Pascali S.A., Cavoski I., Fanizzi F.P. 2018. Biostimulants from food processing by-products: Agronomic, quality and metabolic impacts on organic tomato (*Solanum lycopersicum* L.). Journal of the Science of Food and Agriculture, 98(4), 1426–1436.
8. Chlorophyll meter SPAD 502Plus/502DL Plus. Chlorophyll content meter. https://geomor.com.pl/produkt/chlorofilomierz-spad-502-plus-502dl-plus/ (accessed on 4 March 2021). (in Polish)
9. Du Jardin P. 2015. Plant biostimulants: Definition, concept, main categories and regulation. Scientia Horticulturae, 196, 3–14.
10. Dvořák P., Tomášek J., Hamouz K., Jedličková M. 2016. Potatoes (*Solanum tuberosum* L.). Organic Farming – A Promising Way of Food Production, pp. 147−166.

11. Dvořák P., Král M. 2019. Effects of Organic Mulching on Soil Water Potential and SPAD Values as Factors on Yield of Potatoes (*Solanum tuberosum* L.). Journal of Agricultural Sciences, 25, 147−154.
12. Escuredo O,. Seijo-Rodríguez A., Rodríguez-Flores M.S., Míguez M., Seijo M.C. 2018. Influence of weather conditions on the physicochemical characteristics of potato tubers. Plant, Soil and Environment, 64, 317–323.
13. Ertani A., Francioso O., Tinti A., Schiavon M., Pizzeghello D., Nardi S. 2018. Evaluation of seaweed extracts from *Laminaria* and *Ascophyllum nodosum* spp. as biostimulants in *Zea mays* L. using a combination of chemical, biochemical and morphological approaches. Frontiers in Plant Science, 9, 428, 1−13.
14. Gaurav S., Babankumar B., Lini M., Jonali G., Burhan U.C., Raju P.L.N. 2019. Chlorophyll estimation using multi-spectral unmanned aerial system based on machine learning techniques. Remote Sensing Applications: Society and Environment, 15: 100235.
15. Gugała M., Zarzecka K., Dołęga H., Sikorska A. 2018. Weed infestation and yielding of potato under conditions of varied use of herbicides and bio-stimulants. Journal of Ecological Engineering, 19, 191–196.
16. Ierna A., Mauromicale G. 2019. Sustainable and Profitable Nitrogen Fertilization Management of Potato. Agronomy, 9(10), 582.
17. Ilić O., Nikolić L., Ilin Ž., Mišković A., Vujasinović V., Kukić B. 2016. Effect of cultural practices on weeds community in function of potato yield. Acta Scientiarum Polonorum, Hortorum Cultus, 15(5), 31–43.
18. IUSS Working Group WRB (2015). World Reference Base for Soil Resources 2014, Update 2015. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. World Soil Resources Reports No: 106, Rome.
19. Kalbarczyk R., Kalbarczyk E. 2009. The needs and deficiency in atmospheric precipitation in cultivated midlate and late potato in Poland. Infrastruktura i Ekologia Terenów Wiejskich, 3, 129–140. (in Polish)
20. Li L., Qin Y., Liu Y., Hu Y., Fan M. 2012. Leaf Positions of Potato Suitable for Determination of Nitrogen Content with a SPAD Meter. Plant Production Science, 15(4), 317−322.
21. Mauromicale G., Ierna A., Marchese M. 2006. Chlorophyll fluorescence and chlorophyll content in field-grown potato as affected by nitrogen supply, genotype, and plant age. Photosynthetica, 44, 76−82.
22. Ministry of Agriculture and Rural Development. 2021. List of plant conditioners. List of growth stimulants – November 2020. http://www.minrol.gov.pl/dataset/1013.wykaz-srodkow-wspomagajacych (accessed on 14 March 2021).
23. Pacewicz K., Gregorczyk A. 2009. Comparison values of chlorophyll content by chlorophyll meter SPAD-502 and N-tester. Folia Pomeranae Universitatis Technologiae Stetinensis, Agricultura, Alimentaria, Piscaria et Zootechnica, 269(9), 41–46. (in Polish)
24. Nephali L., Piater L.A., Dubery I.A., Patterson V., Huyser J. 2020. Biostimulants for Plant Growth and Mitigation of Abiotic Stresses: A Metabolomics Perspective. Metabolites, 10(12), 505.
25. Plant Protection Recommendations for 2014/15 (2014). Institute of Plant Protection−National Research Institute Poznań, Poland. (in Polish)
26. Popko M., Michalak I., Wilk R., Gramza M., Chojnacka K., Górecki H. 2018. Effect of the new plant growth biostimulants based on amino acids on yield and grain quality of winter wheat. Molecules, 23(2), 470.
27. Radkowski A., Radkowska I. 2013. Effect of foliar application of growth biostimulant on quality and nutritive value of meadow sward. Ecological Chemistry and Engineering A, 20, 1205–1211.
28. Ramirez D.A., Yactayo W., Gutierrez R., Mares F., De Mendiburu F. 2014. Chlorophyll concentration in leaves is an indicator of potato tuber yield in water – shortage conditions. Scientia Horticulturae, 168, 202–209.
29. Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L:2019:170:TOC (accessed on 14 March 2021).
30. Roztropowicz S. 1999. Methodology of observation, measurements and sampling in agricultural experiments with potato. Ed. Plant Breeding and Acclimatization Institute, Division at Jadwisin, Poland. (in Polish)
31. Rutkowska U. 1981. Selected methods of study composition and nutritive value of food product. Division at PZWL, Warszawa, Poland. (in Polish)
32. Sharma H.S., Fleming C., Selby C., Rao J.R., Martin T. 2014. Plant biostimulants: a review on the processing of macroalgae and use of extracts for crop management to reduce abiotic and biotic stresses. Journal of Applied Phycology, 26(1), 465−490.
33. Skowera B., Jedrszczyk E.S., Kopcinska J., Ambroszczyk A.M., Kołton A. 2014. The Effects of Hydrothermal Conditions during Vegetation Period on Fruit Quality of Processing Tomatoes. Polish Journal Environmental Studies, 23,195–202.
34. Tang R., Niu S., Zhang G., Chen G., Haron M. 2018. Physiological and growth responses of potato cultivars to heat stress. Botany, 96(12).
35. Trawczyński C. 2019. Assessment of the nutrition of potato plants with nitrogen according to the nni

test and spad indicator. Journal of Elementology, 24(2), 687−700.

36. Trawczyński C. 2020. The effect of biostimulators on the yield and quality of potato tubers grown in drought and high temperature conditions. Biuletyn Instytutu Hodowli i Aklimatyzacji Roślin, 289/2020, 11–19. (in Polish)
37. Trętowski J., Wójcik R. 1991. Methodology of agricultural experiments. Division at WSRP Siedlce, Poland. (in Polish)
38. Vos J., Bom M. 1993. Hand-held chlorophyll meter: A promising tool to assess the nitrogen status of potato foliage. Potato Research, 36, 301–308.
39. Wadas W., Kalinowski K. 2017. Effect of titanium on assimilation leaf area and chlorophyll content of very earlymaturing potato cultivars. Acta Scientiarum Polonorum, Agricultura, 16(2), 87–98.
40. Wadas W., Dziugieł T. 2020. Changes in Assimilation Area and Chlorophyll Content of Very Early Potato (*Solanum tuberosum* L.) Cultivars as Influenced by Biostimulants. Agronomy, 10(3), 387.
41. Zarzyńska K., Pietraszko M. 2017. Possibility to predict the yield of potatoes grown under two crop production systems on the basis of selected morphological and physiological plant indicators. Plant, Soil and Environment, 63(4), 165–170.
42. Zhu J., Tremblay N., Liang Y. 2012. Comparing SPAD and at LEAF values for chlorophyll assessment in crop species. Canadian Journal of Soil Science, 92, 645–648.