DOI: /10.5513/JCEA01/21.2.2576

Possibility of increasing early crop potato yield with foliar application of seaweed extracts and humic acids

Możliwość zwiększenia plonu ziemniaków wczesnych przez stosowanie dolistne ekstraktów z wodorostów i kwasów huminowych

Tomasz DZIUGIEŁ[1], Wanda WADAS[2] (✉)

[1] Main Inspectorate of Plant Health and Seed Inspection, Voivodeship Plant Health and Seed Inspection Service, Żółkiewskiego 17, 05-075 Warszawa-Wesoła, Poland

[2] Siedlce University of Natural Sciences and Humanities, Institute of Agriculture and Horticulture, B. Prusa 14, 08-110 Siedlce, Poland

✉ Corresponding author: wanda.wadas@uph.edu.pl

Received: 13 July 2019; accepted: 10 January 2020

ABSTRACT

Under climate change conditions, biostimulants play an important role in plant adaptation to abiotic stress. This paper analyses the effect of the seaweed extracts Bio-algeen S90 (*Ascophyllum nodosum*) and Kelpak SL (*Ecklonia maxima*) and humic and fulvic acids HumiPlant (leonardite extract) on early crop potato yield and yield components. Three very early potato cultivars Denar, Lord and Miłek were tested. Biostimulants did not affect the number of tubers produced by potato plants but increased the tuber weight per plant and average tuber weight and, as a result, the tuber yield. The yield-increasing effect of biostimulants depended on the hydro- thermal conditions during potato growth. Bio-algeen S90 and Kelpak SL produced better results in a warm and very wet growing season, whereas HumiPlant produced better results in a year with lower air temperature and with drought periods during potato growth. The use of biostimulants in early crop potato culture assured higher yield under abiotic stress conditions, and also contributed to improving its marketable value by an increase in the productivity of the marketable-size tubers and, simultaneously, decreasing the share of large tubers with a diameter above 50 mm. The tested potato cultivars showed a similar response to the biostimulants applied.

Keywords: biostimulants, early potato, tuber number per plant, tuber weight, tuber yield

STRESZCZENIE

W warunkach zmian klimatu, biostymulatory odgrywają ważną rolę w adaptacji roślin do stresu abiotycznego. W pracy omówiono wpływ ekstraktów z wodorostów Bioalgeen S90 (*Ascophyllum nodosum*) i Kelpak SL (*Ecklonia maxima*) oraz kwasów huminowych i fulwowych HumiPlant (ekstrakt z leonardytu) na plon ziemniaków wczesnych i składowe plonu. Badano trzy bardzo wczesne odmiany ziemniaka Denar, Lord i Miłek. Biostymulanty nie miały wpływu na liczbę bulw z rośliny, ale powodowały zwiększenie masy bulw z rośliny i średniej masy bulwy, i w efekcie zwiększenie plonu. Działanie plonotwórcze biostymulantów zależało od warunków hydrotermicznych w okresie wzrostu ziemniaka. Bio-algeen S90 i Kelpak SL dały lepsze efekty w sezonie wegetacyjnym ciepłym i bardzo wilgotnym, a HumiPlant w roku o niższej temperaturze powietrza i z okresami suszy podczas wzrostu ziemniaka. Zastosowanie biostymulantów w uprawie ziemniaka na wczesny zbiór zapewniło większy plon w warunkach stresu abiotycznego i przyczyniło się do poprawy jego wartości handlowej, przez zwiększenie wydajności bulw o wielkości handlowej i zmniejszenie udziału bulw dużych, o średnicy powyżej 50 mm. Badane odmiany ziemniaka wykazały podobną reakcję na zastosowane biostymulatory.

Słowa kluczowe: biostymulatory, liczba bulw z rośliny, masa bulw, plon bulw, ziemniaki wczesne

INTRODUCTION

Potatoes play an important role in global food security (Devaux et al., 2014; Wijesinha-Bettoni and Mouillé, 2019). The actual potato yields are lower from 30% to 40% than the potential yields of many cultivars (Haverkort and Struik, 2015). Potato growth and tuber yield are influenced by many biotic and abiotic stresses, such as low or high temperatures, drought or high rainfall, pest and disease occurrence.

Climate change may impact biotic stress either positively or negatively, whereas abiotic stresses are likely to be greatly increased (George et al., 2017). The climate change impact simulations for potato production suggest a decline in global potato production of between 18% and 32% by 2055 (Hijmans, 2003). These ratios indicate the need to improve the potato yield. Periods of high temperature and drought are becoming more frequent in Central Europe. Under climate change conditions, plant growth stimulants have been gaining increasing importance. Biostimulants contain a wide range of bioactive compounds that have beneficial effects on plant growth and stress adaptation, which allows better use of the cultivar production potential under the environmental conditions of the crop area (Calvo et al., 2014; Brown and Saa, 2015; Van Oosten et al., 2017). In recent years, the use of seaweed extracts and humic substances as plant growth stimulants has been increasing (Verlinden et al., 2009; Sharma et al., 2014; Battacharyya et al., 2015; Canellas and Olivares, 2014).

Most commercial seaweed products are manufactured from brown microalgae (*Ascophyllum nodosum*, *Ecklonia maxima*, *Sargassum* spp. or *Durvillaea* spp.). Many plant growth-stimulating compounds (auxins, cytokinins, gibberellins, betaines, polyamines, abscisic acid, brassinosteroids, minerals) are extracted from seaweed.

These compounds affect plant metabolism, leading to increased tolerance to abiotic stresses, improved plant growth and influenced fruit or tuber initiation. Foliar application of seaweed extracts in low concentrations produced a measurable response in a range of crops in the form of higher yield (Khan et al., 2009; Sharma et al., 2014; Battacharyya et al., 2015; Begum et al., 2018). A positive response of potato growth and yield to the foliar application of the extracts from *Ascophyllum nodosum* (Primo, Bio-algeen S90) and *Ecklonia maxima* (Kelpak SL) was shown in studies carried out in China, Pakistan and Poland (Yanbo, 2008; Haider et al., 2012; Wierzbowska et al., 2015). In Poland, with low air temperature and precipitation shortage during the potato growth period, Bio-algeen S90 increased the tuber yield by 16.3% and Keplak SL by 24.7% (Wierzbowska et al., 2015).

Natural plant growth stimulants are humic and fulvic acids extracted from naturally humified organic matter (peat) or from composts and from mineral deposition (leonardite). They can induce changes in plant primary and secondary metabolism related to abiotic stress tolerance (Nardi et al., 2002; Fachramand et al., 2014; Canellas et al., 2015). The effect of humic acids on plant growth depends on their source and concentration and on the plant species and environment conditions (Calvo et al., 2014; Canellas and Olivares, 2014). Leonardite is the most common commercial source of humic substances. In some studies, a lower crop response was observed to humic substances extracted from leonardite than to humic substances extracted from peat or composts (Canellas et al., 2015). A high potato response to humic substances originating from leonardite formations in Canada (Humifirst) has been reported. Potato yield increased by 13% if Humifirst was applied as a liquid solution to the soil and by 17% if Humifirst was applied as a solid incorporated in mineral fertilizers (Verlinden et al., 2009). Later studies carried out in Poland, Iraq, Saudi Arabia, Pakistan and China confirmed the positive potato response to foliar or soil application of humic and fulvic acids. Following the application of humic acids the tuber yield was higher by more than 20% (Matysiak and Adamczewski, 2010; Sarhan, 2011; Alenazi et al., 2016; Zhang et al., 2017). A study carried out in Korea showed that foliar or soil application of humic and fulvic acids had no clear effect on the potato yield (Suh et al., 2014).

In most experiments, the effect of seaweed extract and humic acids on the growth and yield of later-maturing potato cultivars was studied. To date, few studies have focused on the effects of seaweed extract and humic acid application in early crop potato culture. The aim of the study was to determine the effect of seaweed extracts and humic acid application on early crop potato yield and yield components. It was hypothesised that the stimulation of potato growth by seaweed extracts and humic acid application would contribute to increasing early crop potato yields and improving its marketable value by an increase share of marketable-size tubers. The assumption was also made that potato response to foliar application of seaweed extracts and humic acids depends on the cultivar and environmental conditions.

MATERIALS AND METHODS

Experimental site and season

The field experiment was carried out in central-eastern Poland (52°03'N, 22°33'E) during three growing seasons 2012-2014 on Luvisol with an acidic-to-slightly-acid reaction (pH_{KCl} 4.7 to 6.3), with a high content of available phosphorus (118 to 144 mg P·kg^{-1} of soil), a medium-to-high content of potassium (124 to 208 mg K·kg^{-1} of soil) and a low-to-medium content of magnesium (22 to 51 mg Mg·kg^{-1} of soil). In each year of the study, spring triticale was grown as a potato forecrop.

Experimental design

The field experiment was established in a split plot design with three replications. The potato (*Solanum tuberosum* L.) plants were treated with two seaweed extracts (Bioalgeen S90 and Keplak SL) and humic and fulvic acids (HumiPlant). Bio-algeen S90 is an extract from *Ascophyllum nodosum* which contains amino acids, vitamins, alginic acids and other active components of seaweeds, as well as macro- (N, P, K, Ca, Mg) and micronutrients (B, Fe, Cu, Mn, Zn, Se, Co). Kelpak SL is an extract from *Ecklonia maxima* containing auxin (11 mg·L^{-1}) and cytokinin (0.031 mg·L^{-1}) with a mean auxin:cytokinin ratio of 350/1. HumiPlant is an extract from leonardite which contains humic acid (12%) and fulvic acid (6%) as well as macro- (K, Ca, Mg, S) and micronutrients (Fe, Mn, B, Mo, Zn, Cu). The biostimulants were applied in doses recommended by the manufacturers: Bio-algeen S90 – 2 L·ha^{-1} at the beginning of leaf development stage (BBCH 10-11) and 2 L·ha^{-1} two weeks after the first treatment, Kelpak SL – 2 L·ha^{-1} at the leaf development stage (BBCH 14-16) and 2 L·ha^{-1} two weeks after the first treatment, HumiPlant – 2 L·ha^{-1} at the leaf development stage (BBCH 14-16) and 2 L·ha^{-1} one week after the first treatment. Potato plants sprayed with water were used as a control object without a biostimulant.

Three very early potato cultivars listed in the Common Catalogue of Varieties of Agricultural Plant Species (CCV) Denar, Lord and Miłek were grown. In successive years, 6-weeks pre-sprouted seed potatoes were planted on April 12, 18 and 7 with a row spacing of 25 cm and 67.5 cm between rows. The plot area was 16.2 m^2 (96 plants per plot). Potato cultivation was carried out according to common agronomical practice. Farmyard manure was applied in autumn, at rate of 25 t·ha^{-1}, and mineral fertilizers were applied in rates 80 kg N (ammonium nitrate), 35 kg P (superphosphate) and 100 kg K (potassium sulphate) per hectare in spring. Colorado potato beetle (*Leptinotarsa decemlineata*) was controlled using Actara 25 WC (thiametoksam) and Apacz 50 WG (chlotianidine). Potatoes were harvested 75 days after planting (the end of June).

The tuber number and tuber weight per plant, average tuber weight, total and marketable tuber yield (diameter above 30 mm) were determined. The tuber size in a potato yield, i.e. the percentage weight of very small tubers (diameter below 30 mm), small tubers (31-40 mm), medium-sized tubers (4150 mm), large tubers (51-60 mm) and very large tubers (above 61 mm) was also determined. The tuber number and weight per plant, and the tuber size in the yield were determined on ten successive plants per plot.

Statistical analysis

The results of the study were analysed statistically with an analysis of variance (ANOVA) for the split pot design. The significance of differences was verified using Tukey's test at P<0.05.

Weather conditions

Good conditions for early potato growth occur when the soil is heated up to 5-6°C at the beginning of April, and when the average air temperature in May amounts to approximately 14°C and to 17°C in June or higher if in the earlier period there were cooler days. The optimum precipitation sum for early potato harvested 75 days after planting is about 210 mm (Chotkowski et al., 1995; Szutkowska, 2008). The most favourable thermal and moisture conditions for early crop potato culture were in the warm and moderately wet growing season of 2012 (Table 1). 2013 was warm and with a heavy rainfall, whereas 2014 was cool with a heavy rainfall after plant emergence and a drought in the period of tuber growth.

RESULTS

Tuber number and tuber weight per plant

The biostimulants used in the experiment had no effect on the tuber number per plant, but caused an increase in the tuber weight, on average, by 37 g to 55 g (Table 2). The effect of biostimulants on tuber weight per plant depended on the weather conditions during potato growth (Table 3). Bio-algeen S90 and Keplak SL caused the highest increase in the tuber weight per plant in the warm and very wet growing season of 2013. In that year, with the application of those biostimulants, the tuber weight per plant was higher by 89 g (16.8%), on average, in comparison with the cultivation without biostimulant. HumiPlant caused a higher increase in tuber weight per plant in 2012 and 2014 with a low air temperature and with a drought periods during tuber growth, although the differences were not statistically confirmed. The tested potato cultivars showed a similar response to the biostimulants applied.

Regardless of the treatment (with or without biostimulant), the tuber number per plant was higher for Denar than for Lord and Miłek, although the tuber weight per plant was not significantly different (Table 4).

The tuber number and tuber weight per plant depended on the weather conditions during potato growth (Table 5). Regardless of the experimental factors, the tuber number per plant was the lowest in 2012 with a water shortage at tuber formation stage, although the tuber weight per plant was highest in this year.

Average tuber weight

The type of biostimulant had a significant effect on the average tuber weight (Table 2). The average tuber weight was the highest with the use of Bio-algeen S90.

Following the application of this biostimulant, the average tuber weight was higher by 6.19 g (13.6%), compared with the cultivation without biostimulant. Following the application of Kelpak SL and HumiPlant, the differences were smaller and not statistically confirmed.

The average tuber weight depended to a great extent on the cultivar and weather conditions during potato growth (Tables 4 and 5). The average tuber weight was higher for Lord and Miłek than for Denar and was highest in 2012, with the most favourable thermal and moisture conditions for early crop potato culture.

Table 1. Mean air temperature and precipitation sums in the potato growing season

Month	Ten-day period	Temperature (°C)			Rainfall (mm)		
		2012	2013	2014	2012	2013	2014
April	I	3	0.6	6.9	4.6	24.8	4.3
	II	8.9	9.3	8.4	21.1	7.4	15.2
	III	14.9	12.2	14	4.2	3.8	25.5
	mean/sum	8.9	7.4	9.8	29.9	36	45
May	I	15.1	15.3	10.2	17.3	14.2	18.2
	II	12.2	17.3	13.1	33	2.8	47.9
	III	16.4	13.3	17.2	3.1	88.9	26.6
	mean/sum	14.6	15.3	13.5	53.4	105.9	92.7
June	I	13.9	17.2	16.6	26.4	52.6	11.1
	II	17.6	18.7	15	37.7	6.4	14.7
	III	17.5	18.1	14.4	12.1	39.8	29.6
	mean/sum	16.3	18	15.4	76.2	98.8	55.4

Table 2. Effect of biostimulants on the tuber yield and yield components

Type of biostimulants	Tuber number per plant	Tuber weight per plant (g)	Average tuber weight (g)	Total tuber yield ($t \cdot ha^{-1}$)	Marketable tuber yield ($t \cdot ha^{-1}$)
Without biostimulant	12.8[a]	576[b]	45.58[b]	34.37[b]	32.86[b]
Bio-algeen S90	12.3[a]	613[ab]	51.77[a]	36.84[a]	34.74[ab]
Kelpak SL	12.8[a]	620[a]	49.45[ab]	37.04[a]	34.99[a]
HumiPlant	13.1[a]	631[a]	48.61[ab]	37.14[a]	35.29[a]

Means within columns followed by the same letter do not differ significantly at P<0.05 according to Tukey's test

Table 3. Tuber number and tuber weight per plant in relation to the type of biostimulant and year

Type of biostimulant	Tuber number			Tuber weight (g)		
	2012	2013	2014	2012	2013	2014
Without biostimulant	11.8[a]	13.4[a]	13.3[a]	661[a]	529[b]	538[a]
Bio-algeen S90	10.5[a]	13.6[a]	12.7[a]	666[a]	622[a]	551[a]
Kelpak SL	11.5[a]	13.7[a]	13.2[a]	674[a]	615[a]	571[a]
HumiPlant	12.3[a]	13.5[a]	13.6[a]	727[a]	573[ab]	592[a]

Means within columns followed by the same letter do not differ significantly at P<0.05 according to Tukey's test

Table 4. Tuber yield and yield components in relation to cultivar

Cultivar	Tuber number per plant	Tuber weight per plant (g)	Average tuber weight (g)	Total tuber yield ($t·ha^{-1}$)	Marketable tuber yield ($t·ha^{-1}$)
Denar	13.4[a]	597[a]	45.44[b]	35.73[a]	33.69[a]
Lord	12.7[a]	613[a]	49.8[a]	36.95[a]	35.06[a]
Miłek	12.2[b]	619[a]	51.33[a]	36.37[a]	34.65[a]

Means within columns followed by the same letter do not differ significantly at P<0.05 according to Tukey's test

Table 5. Tuber yield and yield components in relation to year

Year	Tuber number per plant	Tuber weight per plant (g)	Average tuber weight (g)	Total tuber yield ($t·ha^{-1}$)	Marketable tuber yield ($t·ha^{-1}$)
2012	11.5[b]	682[a]	60.17[a]	41.1[a]	40.02[a]
2013	13.6[a]	585[b]	43.44[b]	34.62[b]	32.53[b]
2014	13.2[a]	563[b]	42.96[b]	33.31[c]	30.86[c]

Means within columns followed by the same letter do not differ significantly at P<0.05 according to Tukey's test

Tuber yield

The biostimulants used in the experiment caused an increase in the total tuber yield, on average, by 2.47 $t·ha^{-1}$ to 2.77 $t·ha^{-1}$ and marketable tuber yield by 1.88 $t·ha^{-1}$ to 2.43 $t·ha^{-1}$ (Table 2). The productive effect of biostimulants depended on weather conditions during potato growth (Table 6). Bio-algeen S90 and Keplak SL caused the highest increase in tuber yield in the warm and very wet growing season of 2013.

With the use of Bio-algeen S90, the total tuber yield was higher, on average, by 5.42 $t·ha^{-1}$ (17.2%) and marketable tuber yield by 4.89 $t·ha^{-1}$ (16.4%) in comparison with the cultivation without biostimulant, whereas with the use of Kelpak SL, the yield increase was 4.84 $t·ha^{-1}$ (15.4%) and 4.37 $t·ha^{-1}$ (14.7%), respectively. HumiPlant caused the highest increase in tuber yield in 2014 with a low air temperature and with a periodical water shortage during potato growth. With the use of HumiPlant, the total tuber yield was higher, on average, by 3.89 $t·ha^{-1}$ (12.4%) and marketable tuber yield was higher by 3.49 $t·ha^{-1}$ (11.8%). The type of biostimulant and cultivar interaction effect on the tuber yield was not statistically confirmed.

Table 6. Tuber yield in relation to the type of biostimulant and year

Type of biostimulant	Total tuber yield ($t·ha^{-1}$)			Marketable tuber yield ($t·ha^{-1}$)		
	2012	2013	2014	2012	2013	2014
Without biostimulant	40.26[a]	31.46[b]	31.38[b]	39.48[a]	29.75[b]	29.34[a]
Bio-algeen S90	40.45[a]	36.88[a]	33.19[ab]	38.96[a]	34.64[a]	30.62[a]
Kelpak SL	41.43[a]	36.3[a]	33.4[ab]	40.22[a]	34.12[a]	30.62[a]
HumiPlant	42.29[a]	33.85[b]	35.27[a]	41.43[a]	31.61[ab]	32.83[a]

Means within columns followed by the same letter do not differ significantly at P<0.05 according to Tukey's test

The tuber yields of the tested potato cultivars were similar (Table 4). The potato yield depended to a greater extent on the weather conditions during potato growth (Table 5). Regardless of the experimental factors, the tuber yield was highest in the warm and moderately wet growing season of 2012.

Tuber size in potato yield

Regardless of the treatment (with or without biostimulant), the potato yield consisted of medium-sized tubers, with a diameter of 41-50 mm mainly (Table 7). Bio-algeen S90 and Kelpak SL application caused a decrease in the share of large tubers, with diameters above 51 mm, and an increase in the share of medium-sized tubers, on average, by 2.6% in comparison with the cultivation without those biostimulants.

HumiPlant caused a decrease in the share of large tubers and increase in the share of small tubers with diameters of 31-40 mm, on average, by 3.1%. Bio-algeen S90 and Keplak SL had a greater effect the tuber growth in 2014 with a low air temperature and with drought periods during potato growth, whereas HumiPlant had a greater effect in the warm and very wet growing season of 2013.

Bio-algeen S90 and Keplak SL had a greater effect on the tuber size in the yield of the Denar and Lord cultivars, whereas HumiPlant affected the yield of Miłek cultivar (Table 8), although the type of biostimulant and cultivar interaction effect on the tuber yield was not statistically confirmed.

Table 7. Tuber size in potato yield in relation to the type of biostimulant and year

Type of biostimulant	Year	Percentage weight of tubers with diameter				
		<30 mm	31-40 mm	41-50 mm	51-60 mm	>60 mm
Without biostimulant	2012	2.1	20.6	45.3	27.1	4.9
	2013	5.1	24.2	24.2	24.7	6.2
	2014	7.2	40.2	34	17.9	0.8
	mean	4.8	28.3	39.7	23.3	3.9
Bio-algeen S90	2012	2.8	19.6	46.5	24.6	6.5
	2013	6.1	25.6	41	21	6.3
	2014	7	36.4	40	15.6	1
	mean	5.3	27.2	42.5	20.4	4.6
Kelpak SL	2012	2.9	17.3	49	26.8	4
	2013	6.5	27.5	41.6	17.5	6.9
	2014	8.5	39.6	35.2	14.3	2.4
	mean	6	28.1	42	19.5	4.4
HumiPlant	2012	2.1	21.2	45.4	25.4	5.9
	2013	6.6	29.6	44.1	15.2	4.6
	2014	7.6	43.7	31.3	16.9	0.5
	mean	5.4	31.4	40.3	19.2	3.7

Table 8. Tuber size in potato yield in relation to the type of biostimulant and cultivar

Type of biostimulant	Cultivar	Percentage weight of tubers with diameter				
		<30 mm	31-40 mm	41-50 mm	51-60 mm	>60 mm
Without biostimulant	Denar	4.9	26.3	40.7	23.3	4.8
	Lord	5.2	32.2	38.8	21.5	2.2
	Miłek	4.3	26.5	39.7	24.9	4.7
Bio-algeen S90	Denar	6.2	30.1	41.5	19	3.2
	Lord	5	24.9	45.7	20.1	4.3
	Miłek	4.8	26.6	40.2	22.1	6.3
Kelpak SL	Denar	6.4	28.6	44.1	17.2	3.7
	Lord	6.1	26.8	41.6	22.5	3
	Miłek	5.4	29	40.1	18.9	6.6
HumiPlant	Denar	5.7	29.1	40.2	21.3	3.7
	Lord	5	32.3	39.8	18.4	4.5
	Miłek	5.6	33	40.8	17.8	2.8

DISCUSSION

In recent years, potato growth and tuber yield have been great influenced by abiotic stresses. Periods of high temperature and drought are becoming more frequent in Central Europe. Under climate change conditions, biostimulants have been gaining increasing importance in plant adaptation to environmental stresses (Brown and Saa, 2015; Van Oosten et al., 2017). In the present study, the application of seaweed extract *Ascophyllum nodosum* (Bio-algeen S90) and *Ecklonia maxima* (Keplak SL) or humic and fulvic acids (HumiPlant) had no effect on the tuber number produced per plant of very early potato cultivars, but they caused an increase in the tuber weight.

Studies carried out in China and Pakistan showed that foliar application of *Ecklonia maxima* and *Ascophyllum nodosum* extracts caused an increase in tuber number per plant of medium-early potato cultivars (Yanbo, 2008; Haider et al., 2012), and a study carried out in Iraq showed that foliar application of humic acids caused an increase in tuber number per plant of medium-early potato cultivar (Sarhan, 2011), which was not confirmed in the present study with very early potato cultivars. Tuber number produced per plant to a greater extent depended on the cultivar and weather conditions at the tuber formation stage. A water deficit in the tuber formation stage causes a reduction in the number of tubers per plant (MacKerron and Jefferies, 1986; Haverkort et al., 1990), which was confirmed in the present study. The biostimulants used in the experiment caused an increase in tuber weight per plant, which was confirmed in studies carried out in Pakistan and Iraq with later-maturing potato cultivars (Sarhan, 2011; Haider et al., 2012). As the result, the total tuber yield 75 days after planting (the end of June) was higher by 2.47 $t \cdot ha^{-1}$ to 2.77 $t \cdot ha^{-1}$ and the marketable tuber yield (with diameter above 30 mm) increased by 1.88 $t \cdot ha^{-1}$ to 2.43 $t \cdot ha^{-1}$ compared to the cultivation without biostimulant. The yield-increasing effect of biostimulants depended on hydrothermal conditions during potato growth. The seaweed extracts Bio-algeen S90 and Kelpak SL produced better results in a warm and very wet growing season, whereas humic and fulvic acids from leonardite produced better results in a cool growing season and with a periodical water shortage during potato growth. A study carried out in Poland by other authors showed that Keplak SL did not have an effect on the tuber yield of very early potato cultivar Felka but caused an increase in the yield of Volumia cultivar. In a year with a lower air temperature and less rainfall, Bioalgeen S90 caused a higher increase in the tuber yield of the very early potato cultivar Volumia than Keplak SL (Erlichowski and Pawińska, 2003; Wierzbowska et al., 2015). Exogenous auxin and cytokinins play an important role in tuber formation and plant adaptation to environmental stresses, although potato response depends on the plant genotype and carbohydrate status (Ha et al., 2012; Kolachevskaya et al., 2019). In the present study, the type of biostimulant and cultivar interaction effect on early crop potato yield was not statistically confirmed. In a warm and very wet growing season, with the use of Bio- algeen S90, the total tuber yield was higher, on average, by 17.2% and marketable tuber yield (with diameter above 30 mm) was higher by 16.4% compared with the cultivation without biostimulant, whereas with the use of Kelpak SL the yield increase was 15.4% and 14.7%, respectively.

Little is known about the effect of humic and fulvic acids in early crop potato production. In the present study, in a year with low air temperature and with a drought periods during potato growth, HumiPlant increased the total tuber yield, on average, by 12.4% and marketable tuber yield by 11.8%. Under water stress, foliar application of humic acids can reduce the transpiration rate and thereby increase the plant drought resistance (Fahramand et al., 2014; Alenazi et al., 2016). Periods of high temperature and drought are becoming more frequent in Central Europe. A study carried out in China showed that foliar application of fulvic acid increased tuber number and tuber weight per plant, and marketable tuber yield of early maturing potato cultivar (Zhang et al., 2017). Positive response of medium-early potato cultivars to foliar application of humic and fulvic acids has been showed in the studies carried out in Poland, Iraq and Saudi Arabia (Matysiak and Adamczewski, 2010; Sarhan, 2011; Alenazi et al., 2016), while in a study carried out in Korea, humic and fulvic acids had no clear effect on the tuber yield (Suh et al., 2014). Plant response to humic substances is influenced by a number of environmental factors (Canellas and Olivares, 2014), which was confirmed in the present study. The effects of biostimulants are clearly visible under stress conditions. If the environmental conditions are more favourable for plant growth, the effects of biostimulants are smaller and may be unnoticed.

The marketable value of early crop potato yield depends on the tuber size. A lower yield of larger-sized tubers produces higher marketable value than the high yield of smaller tubers. Bio-algeen S90 and Kelpak SL caused an increase in the share of medium-sized tubers, with diameters of 41-50 mm, in early crop potato yield by 2.6%, whereas HumiPlant increased the share of small tubers, with diameters of 31-40 mm, by 3.1%. In studies carried out by other authors in Poland and China, Kelpak SL had no effect the tuber growth of a very-early potato cultivar (Felka), but caused an increase in the share of large tubers in the yield of later-maturing cultivars (Erlichowski and Pawińska, 2003; Yanbo, 2008). A study carried out in Korea showed an increase in the share of large-sized tubers in the yield of medium-early potato cultivar in response to the foliar application of fulvic acids, which resulted in an increase of the incidence of hollow heart (Suh et al., 2014).

CONCLUSIONS

This study showed the possibility of increasing early crop potato yield with the foliar application of seaweed extracts Bio-algeen S90 (*Ascophyllum nodosum*) and Kelpak SL (*Ecklonia maxima*) or HumiPlant (leonardite extract) humic and fulvic acids.

These biostimulants did not affect the number of tubers produced by a potato plant but increased the tuber weight per plant and average tuber weight and the resulting tuber yield. The yield-increasing effect of biostimulants depended on the hydro- thermal conditions during potato growth. Bio-algeen S90 and Kelpak SL produced better results in a warm and very wet growing season, whereas HumiPlant produced better results in a year with lower air temperature and with drought periods during potato growth. The use of biostimulants in early crop potato culture assured higher tuber yield under abiotic stress conditions, and also contributed to improving its marketable value by an increase in the productivity of the marketable-size tubers and, simultaneously, a decreased share of large tubers with diameters above 50 mm. The tested very early potato cultivars showed a similar response to the applied biostimulants.

ACKNOWLEDGEMENTS

This study was supported by the Polish Ministry of Science and Higher Education under the statutory activities of the Siedlce University of Natural Sciences and Humanities [grant number 218/05/S]. The authors thanks for the technical assistance of K. Struk and K. Chromińska during the whole period of potato growing season.

REFERENCES

Alenazi, M., Wahb-Allah, M. A., Abdel-Razzak, H. S., Ibrahim, A. A., Alsadon, A. (2016) Water regimes and humic acid application influences potato growth, yield, tuber quality and water use efficiency. American Journal of Potato Research, 93 (5), 463-473. DOI: https://doi.org/10.1007/s12230-016-9523-7

Battacharyya, D., Babgohari, M. Z., Rathor, P., Prithiviraj, B. (2015) Seaweed extracts as biostimulants in horticulture. Scientia Horticulturae, 196, 39-48. DOI: https://doi.org/10.1016/j.scienta.2015.09.012

Begum, M., Bordoloi, B. C., Singha, D. D., Ojha, N. J. (2018) Role of seaweed extracts on growth, yield and quality of some agricultural crops: A review. Agricultural Reviews, 39 (4), 321-326. DOI: https://doi.org/10.18805/ag.r-1838

Brown, P., Saa, S. (2015) Biostimulants in agriculture. Frontiers in Plant Science, 6, Article 671. DOI: https://doi.org/10.3389/fpls.2015.00671

Calvo, P., Nelson, L., Kloepper, J. W. (2014) Agricultural uses of plant biostimulants. Plant and Soil, 383 (1-2), 3-41. DOI: https://doi.org/10.1007/s11104-014-2131-8

Canellas, L. P., Olivares, F. L. (2014) Physiological responses to humic substances as plant growth promoter. Chemical and Biological Technologies in Agriculture, 1 (1), 1-11. DOI: https://doi.org/10.1186/2196-5641-1-3

Canellas, L. P., Olivares, F. L., Aguiar, N. O., Jones, D. L., Nebbioso, A., Mazzei, P., Piccolo, A. (2015) Humic and fulvic acids as biostimulants in horticulture. Scientia Horticulturae, 196, 15-27. DOI: https://doi.org/10.1016/j.scienta.2015.09.013

Chotkowski, J., Gaziński, B., Rembeza, J. (1995) The estimation of natural conditions of potato cultivation in Poland. Postępy Nauk Rolniczych, 6, 47-57.

Devaux, A., Kromann, P., Ortiz, O. (2014) Potatoes for sustainable global food security. Potato Research, 57 (3-4), 185-199. DOI: https://doi.org/10.1007/s11540-014-9265-1

Erlichowski, T., Pawińska, M. (2003) Biological evaluation of product Kelpak on potato plants. Progress in Plant Protection, 43 (2), 606-609.

Fahramand, M., Moradi, H., Noori, M., Sobhkhizi, A., Adibian, M., Abdollahi, S., Rigi, K. (2014) Influence of humic acids on plants and soil properties. International Journal of Farming and Allied Science, 3 (3), 339-341.

George, T.S., Taylor, M. A., Dodd, I. C., White, P. J. (2017) Climate change and consequences for potato production: a review of tolerance to emerging abiotic stress. Potato Research, 60 (3-4), 239-268. DOI: https://doi.org/10.1007/s11540-018-9366-3

Ha, S., Vankova, R., Yamaguchi-Shinozaki, K., Shinozaki, K., Tran, L-S.P. (2012) Cytokinins: metabolism and function in plant adaptation to environmental stresses. Trends in Plant Science, 17 (3), 172-179. DOI: https://doi.org/10.1016/j.tplants.2011.12.005

Haider, M. W., Ayyub, C. M., Pervez, M. A., Asad, H. U., Manan, A., Raza, S.A., Ashraf, I. (2012) Impact of foliar application of seaweed extract on growth, yield and quality of potato (*Solanum tuberosum* L.). Soil and Environment, 31 (2), 157-162.

Haverkort, A. J., Struik, P. C. (2015) Yield levels of potato crops: Recent achievements and future prospects. Field Crops Research, 182, 76-85. DOI: https://doi.org/10.1016/j.fcr.2015.06.002

Haverkort, A. J., van de Waart, M., Bodlander, K. B. A. (1990) The effect of early drought on numbers of tubers and stolons of potato in controlled and field conditions. Potato Research, 33, 89-96.

Hijmans, R. J. (2003) The effect of climate change on global potato production. American Journal of Potato Research, 80 (4), 271-279. DOI: https://doi.org/10.1007/bf02855363

Khan, W., Rayirath, U.,P., Subramanian, S., Jithesh, M.,N., Rayorath, P., Hodges, D. M., Critchley, A. T., Craigie, J. S., Norrie, J., Prithiviraj, B. (2009) Seaweed extracts as biostimulants of plant growth and development. Journal of Plant Growth Regulation, 28 (4), 386-399. DOI: https://doi.org/10.1007/s00344- 009-9103-x

Kolachevskaya, O. O., Lomin, S. N., Arkhipov, D. V., Romanov, G. A. (2019) Auksin in potato: molecular aspects and emerging roles in tuber formation and stress resistance. Plant Cell Reports, 38 (6), 681-698. DOI: https://doi.org/10.1007/s00299-019-02395-0

MacKerron, D. K. L., Jefferies, R. A. (1986) The influence of early soil moisture stress on tuber numbers in potato. Potato Research, 29 (3), 299-312. DOI: https://doi.org/10.1007/bf02359959

Matysiak, K., Adamczewski, K. (2010) Effect of Moddus 250 EC, Kelpak SL, Algaminoplant, HumiPlant and Yield Plus on the size and structure of potato tuber yield. Ziemniak Polski, 1, 28-32.

Nardi, S., Pizzeghello, D., Muscolo, A., Vianello, A. (2002) Physiological effects of humic substances on higher plants. Soil Biology and Biochemistry, 34 (11), 1527-1536. DOI: https://doi.org/10.1016/s0038-0717(02)00174-8

Sarhan, T. Z. (2011) Effect of humic acid and seaweed extracts on growth and yield of potato plant (*Solanum tuberosum* L.) Desiree cv. Mesopotamia Journal of Agriculture, 39 (2), 19-27.

Sharma, H. S. 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. DOI: https://doi.org/10.1007/s10811-013-0101-9

Suh, H. Y., Yoo, K. S., Suh, S. G. (2014) Tuber growth and quality of potato (*Solanum tuberosum* L.) as affected by foliar or soil application of fulvic and humic acids. Horticulture Environment and Biotechnology, 55 (3), 183-189. DOI: https://doi.org/10.1007/s13580-014-0005-x

Szutkowska, M. (2008) Factors determining the success of potato cultivation for early crop. Ziemniak Polski, 1, 22-269.

Van Oosten, M. J., Pepe, O., De Pascale, S., Silletti, S., Maggio, A. (2017) The role of biostimulants and bioeffectors as alleviators of abiotic stress in crop plants. Chemical and Biological Technologies in Agriculture, 4 (1), Article 5, 1-12. DOI: https://doi.org/10.1186/s40538-017-0089-5

Verlinden, G., Pycke, J., Mertens, J., Debersaques, F., Verheyen, K., Baert, G., Bries, J., Haesaert, G. (2009) Application of humic substances results in consistent increase in crop yield and nutrient uptake. Journal of Plant Nutrition, 32 (9), 1407-1426. DOI: https://doi.org/10.1080/01904160903092630

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

Wijesinha-Bettoni, R., Mouillé, B. (2019) The contribution of potatoes to global food security, nutrition and healthy diets. American Journal of Potato Research, 96 (2), 139-149. DOI: https://doi.org/10.1007/s12230-018-09697-1

Yanbo, X. (2008) Effect of bio-stimulant Kelpak on potato yield. Chinese Potato Journal, 22 (3), 134-136.

Zhang, Y., Zhou, Q., Li, Y., Xu, C., He, S., Huang, Y., Yang, H., Wang, M., Liu, L., Tang, M. (2017) Effect of fulvic acids on agronomic traits and yield of autumn potato. Agricultural Science and Technology, 18 (8), 1448-1451.