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Exogenous regulation of the potatoes' adaptive potential when using bio stimulants

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Abstract: Potato from the Solanaceae family is one of the most important crops in the world and its cultivation is common in many places. The average yield of this crop is 20 $Mg \cdot ha^{-1}$ and it is compatible with climatic conditions in many parts of the world. The experiment studied the possibility of exogenous regulation of the adaptive potential available for four potato cultivars through the use of growth stimulants with different action mechanisms: 24-epibrassinolide (EBL) and chitosan biopolymer (CHT). The results allowed us to establish significant differences in growth parameters, plant height, leaf index, vegetation index, chlorophyll content, and yield structure. Monitoring growth and predicting yields well before harvest are essential to effectively managing potato productivity. Studies have confirmed the empirical relationship between the normalised difference vegetation index (*NDVI*) and N-tester vegetation index data at various stages of potato growth with yield data. Statistical linear regression models were used to develop an empirical relationship between the *NDVI* and N-tester data and yield at different stages of crop growth. The equations have a maximum determination coefficient (R^2) of 0.63 for the N-tester and 0.74 for the *NDVI* during the flowering phase (BBCH[1] 65). *NDVI* and N-tester vegetation index positively correlated with yield data at all growth stages.

Keywords: abiotic stress, antioxidant, biopolymer chitosan, growth regulators, potato, N-tester, near infrared, normalised difference vegetation index (*NDVI*)

INTRODUCTION

Potatoes (*Solanum tuberosum* L.) are the fourth most cultivated crop in the world after rice, wheat, and maize. The world volume of potato production worldwide reached 371 mln Mg, showing a steady growth of 2% over the last year [Ahmadi *et al.* 2010; Koch *et al.* 2020]. The largest potato producers in the world are currently China (93 mln Mg) and India (51 mln Mg). The global average potato yield has increased by 46.2% over the past 50 years. In the short term, in connection with the spread of organic farming, research on the purposeful management of the potato production process through the use of growth biostimulants is especially significant [Wilkinson *et al.* 2020; Yagiz *et al.* 2020]. The main problems of large-scale potato production during its growth period and development are biotic and abiotic stresses. The use of systemic induced resistance is considered as one of the strategies for solving the assigned tasks [Murashev *et al.* 2020].

The characteristics of photosynthesis, such as the leaf surface development of plants, the photosynthesis productivity, stomatal conductance, the transpiration rate, and the intercellular concentration of CO_2, play a key role in the productivity of

[1] The BBCH-scale is used to identify the phenological development stages of plants. The first digit of the scale refers to the principal growth stage. The second digit refers to the secondary growth stage which corresponds to an ordinal number or percentage value. Post-harvest or storage treatment is coded as 99. Seed treatment before planting is coded as 00. The abbreviation BBCH derives from the names of the originally participating stakeholders: "Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie".

agricultural crops and are closely related to yield [ABDOU *et al.* 2018; MAN-HONG *et al.* 2020; SHAHEEN *et al.* 2019]. Nevertheless, these photosynthesis parameters are sensitive to unfavourable environmental conditions, and the plant photosynthesis activity shows a tendency to decrease with increasing water stress [ARAUJO *et al.* 2019; MAN-HONG *et al.* 2020].

Plant growth regulators (PGRs) play an important role in tuberisation, accelerated maturation, and also physical and chemical processes during storage. Various growth promoters are widely used in agriculture to increase crop yields. The PGRs activity in stimulating plant growth has been extensively studied. Both direct (secretion of substances that stimulate plant growth), and indirect (antimicrobial substances such as antibiotics, enzymes that can inhibit pathogenic microorganisms) growth regulators' influence can be noted. Their additive characteristics are the mobilisation of nutrients, nitrogen fixation, etc. The results obtained on the foliar application of preparations with different action mechanisms were most effective for vegetative growth of plants, tuber yield, and quality indicators of yield.

Chitosan biopolymer (CHT) is environmentally non-toxic and biocompatible, and is a promising resource for sustainable agriculture as a growth stimulant and antimicrobial agent [CHAKRABORTY *et al.* 2020; STALLKNECHT 2018; UTAMI *et al.* 2018]. Influencing the physiological processes of plants, it induces growth, absorption of nutrients, enhances enzymatic activation and protein synthesis, which ultimately can lead to an increase in yield. Studies on the effectiveness of its use on potatoes show its potential for reducing the abiotic and biotic stress effect in the context of the ever-growing need to modify the technology of potato cultivation, and sustainably to overcome environmental changes [LIU *et al.* 2019; WANG *et al.* 2020]. Brassinosteroids are capable of exerting a wide physiological effect at low concentrations and greater activity compared to other phytohormones due to their positive effect on photosynthesis and respiration. The brassinosteroids' ability to change the photosynthetic pigments content and to increase the total chlorophyll content was noted [ALI 2019; KHAN *et al.* 2018]. Stressful growing conditions affect photosynthetic activity, which is closely related to yield. There are variables associated with monitoring the agrocenosis state being a frequently used variable of the chlorophyll content in leaves, which has a high correlation with yield [ABROUGUI *et al.* 2019; GÓMEZ *et al.* 2019].

In the modern literature, we can find several methods for assessing the chlorophyll content based on the leaf reflectance; however, the chloroplast location in cells changes depending on light intensity and duration; this leads to a change in the values obtained using measuring devices [DINKA, DAWIT 2019; KHAN *et al.* 2020; LI *et al.* 2019; SALVADOR *et al.* 2020]. Recently, the variability, control and assessment monitoring of the dynamic parameters of photosynthetic activity in crop production is carried out using optical sensors, which make it possible to reliably determine these parameters in real time.

MATERIALS AND METHODS

The studies were carried out at the Russian State Agrarian University – Moscow Timiryazev Agricultural Academy in a field experiment condition; the soil was sod-podzolic and medium loamy with the following agrochemical indicators in the arable layer: humus content 2.6–2.7%; P_2O_5 – 145–160 mg·kg^{-1}; K_2O – 107–120 mg·kg^{-1}, pH_{KCl} – 4.8–5.0. The site is located in conditions typical of the Non-Black Earth Zone of the Russian Federation. Various plant growth bio stimulants were used to treat vegetative plants:

– PGR_0 = control (no application of plant growth regulator),
– PGR_1 = the chitosan biopolymer (CHT) – 30 g·dm^{-3},
– PGR_2 = 24-epibrassinolide (EBL) – 0.025 g·dm^{-3}).

Field experiments were carried out in grain-row crop rotation. Agricultural technology included milling the soil (John Deere 6920 + Amazone KE 303), planting in the first ten days of May, and ridge formation (John Deere 6920 + Grimme GF 75-4). The test plantings were kept weed-free. The experiment was carried out in a randomised block design, in four replicates. In the course of field trials, the shoots number, photosynthetic activity parameters, the aboveground biomass growth dynamics, and also yield and quality of potato tubers were determined.

During the budding phase, vegetative plants were treated with bio stimulants; the treatment was carried out in the early morning in order to avoid the rapid drying of the spray solution caused by transpiration. To assess the chlorophyll content in our experiment, we used an N-tester vegetation index (nitrogen-tester). An optical sensor was used to determine normalised difference vegetation index (*NDVI*).

Previous studies evaluated the varietal responses of potatoes to foliar treatments with growth bio stimulants to growth responses, the size of the assimilation apparatus, yield and its qualitative characteristics [AMAL *et al.* 2010; GŁOSEK-SOBIERAJ *et al.* 2018]. The objects of research were potato cultivars (*Solanum tuberosum* L.) selected in Russia and belonging to different ripeness groups:

– 'Zhukovskiy ranniy' (semi-spreading bush type), the cultivar's value is due to its resistance to nematodes, early tuberisation, tubers are resistant to mechanical damage;
– 'Snegir' (strongly leafy, leaf type) differs with its short-term flowering, resistance to potato cancer, early formation of marketable products;
– 'Krasavchik' (semi-erect stems, medium leafy plants) is medium early; it forms tubers with a high mass, and has a high starch content;
– 'Kumach' (bush of intermediate type, large-leaved) is resistant to potato cancer, scab, and also it has high uniformity of tubers.

RESULTS AND DISCUSSION

The research results made it possible to establish the effect of the preparations used on photosynthetic activity, tuberisation dynamics and intensity. In variants with plants having a powerfully developed leaf surface, induction of tuberisation occurred earlier, which led to a greater yield of tubers of a large (more than 80 g) fraction in the crop structure: the leaf area at the level of 35 thous. m^2·ha^{-1} made it possible to harvest more than 800 g per bush of large tubers. The biological productivity of potatoes was largely determined by the vegetation index value *NDVI*, which was changeable under the influence of the use of preparations and had a close correlation with the leaf surface area value (Tab. 1).

NDVI in the studies was subject to variability, and was determined to a greater extent by varietal characteristics and

Table 1. The applied bio stimulants for different cultivar "factor A"

Cultivar – factor A	PGR – factor B	BBCH 59	BBCH 65	BBCH 91
'Zhukovskiy ranniy'	PGR_0	0.84	0.86	0.75
	PGR_1	0.85	0.92	0.77
	PGR_2	0.90	0.94	0.88
	average	0.86	0.91	0.80
'Snegir'	PGR_0	0.85	0.88	0.71
	PGR_1	0.86	0.95	0.89
	PGR_2	0.89	0.92	0.70
	average	0.87	0.92	0.77
'Krasavchik'	PGR_0	0.84	0.85	0.76
	PGR_1	0.87	0.93	0.60
	PGR_2	0.81	0.94	0.87
	average	0.84	0.91	0.74
'Kumach'	PGR_0	0.85	0.86	0.72
	PGR_1	0.87	0.93	0.80
	PGR_2	0.88	0.93	0.86
	average	0.87	0.91	0.79

Explanations: PGR_0, PGR_1, PGR_2 as in p. 3, BBCH as in p. 234.
Source: own study.

Table 2. Determination of chlorophyll using the nitrogen-tester

Cultivar –factor A	PGR – factor B	BBCH 59
'Zhukovskiy ranniy'	PGR_0	587
	PGR_1	594
	PGR_2	596
	average	592
'Snegir'	PGR_0	594
	PGR_1	598
	PGR_2	605
	average	599
'Krasavchik'	PGR_0	611
	PGR_1	655
	PGR_2	658
	average	641
'Kumach'	PGR_0	596
	PGR_1	594
	PGR_2	602
	average	597

Explanations as in Tab. 1.
Source: own study.

climatic conditions. The applied bio stimulants had a pronounced effect on this indicator changing it by 0.06–0.08 units for the 'Zhukovskiy ranniy' cultivar, by 0.03–0.05 units for the 'Snegir' cultivar, by 0.07 units for the 'Krasavchik' cultivar (Tab. 1). The action of bio stimulants used for processing plants made it possible to influence the change in morphometric indicators, led to the photosynthetic activity, and an intensive increase in the aboveground biomass, which subsequently had a positive effect on the yield and quality of tubers. The assimilation surface growth dynamics determined the overall photosynthesis productivity directly correlated with the yield. The leaf area size, as the basis for the high productivity formation of potato agrocenoses under optimal conditions for the development of potatoes, should have an area five times higher than the area occupied by plants; it is these dimensions that allow the most active and complete assimilation of active radiation for photosynthesis.

The bio stimulants used in the studies were analogues of physiological endogenous hormones due to the chlorophyll synthesis activation; growth and root formation processes had a noticeable effect on the hormonal status of plants. A change in the chlorophyll content in the potato organogenesis phases was noted; it increased by 0.2 units to the fruit formation phase, and then gradually decreased by 0.2–0.4 units to the wilting phase. The use of bio stimulants made it possible to somewhat increase the duration of pigment accumulation, up to wilting in some cases (Tab. 2).

Varietal specificity manifested itself in the reaction to treatment with bio stimulants: a high chlorophyll content under experimental conditions (phase BBCH 59) was noted in the 'Krasavchik' cultivar from 611 to 658 units; the plants of this cultivar were the most responsive to treatment with preparations: an increase of 44 units in the PGR_1 (CHT), 47 in the PGR_2 (EBL) variant. Plants of the 'Kumach' cultivar were weakly responsive to the use of bio stimulants; the chlorophyll concentration varied from 594 to 602 units.

The potential of bio stimulants in increasing the resistance to abiotic stress of agricultural crops is quite high. At present, the uncertainty of climatic conditions during the growing season of potato agrocenoses and abiotic stresses are the main threat to agricultural production worldwide. The yield of potatoes under the experimental conditions was determined by the moisture supply of agrocenoses, varietal adaptability, and the effect of the drugs used (see Tab. 3).

The most significant increase in yield was observed when chitosan (CHT) was used in the treatment with the chitosan biopolymer in the early-maturing eating cultivar 'Snegir' (increase

Table 3. Potato yield in the experiment

Cultivar –factor A	Yield ($Mg \cdot ha^{-1}$) for			
	PGR – factor B			average – factor A
	PGR_0	PGR_1	PGR_2	
'Zhukovskiy ranniy'	35.39	35.82	36.11	35.77
'Snegir'	32.35	34.31	33.92	33.53
'Krasavchik'	26.25	27.56	29.41	27.74
'Kumach'	38.31	36.27	39.46	38.01
Average – factor B	33.08	33.49	34.73	

Explanations: PGR_0, PGR_1, PGR_2 as in p. 235.
Source: own study.

in yield 1.96 Mg·ha^{-1}): the effect of the preparation made it possible to enhance photosynthetic activity and maintain the photosynthesis activity for a long time (*NDVI* 0.89 units, phase BBCH 91). The use of the preparation 24-epibrassinolide (EBL) made it possible to obtain an essential, statistically significant increase in the yield of the 'Krasavchik' cultivar 3.16 Mg·ha^{-1} with reference to the control samples (*NDVI* 0.87 units, phase BBCH 91).

CONCLUSIONS

As a result of studies on sod-podzolic soils, the use of growth biostimulants had a significant effect on the growth, physiological and tuber-forming processes in plants, their resistance to stress, at the same time, the intensity of the effect on plants depended on the type of preparation. Metabolic processes optimisation for potato plants, and reduction of photosynthesis depression under extreme environmental conditions ensured the ecological independence of the reproductive system and increased the regeneration potential of plants. The plants' response to the use of biostimulants confirmed that abiotic stress states were complex during the growing season, reflecting the stress effects level. The vegetation index *NDVI* was subject to variability, reflecting in the photosynthetic biomass amount and its change under the influence of the studied biostimulants. *NDVI* and N-tester vegetation index positively correlated with yield data at all growth stages.

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