

Evaluation of the prospects for the use of growth-stimulating complexes of endometabolites of cyanobacteria *Arthrospira platensis* in soybean cultivation

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Abstract. For the first time, data were obtained on the use of the cyanobacteria *Arthrospira platensis* endometabolite complex and its modifications, fortified (additionally enriched) with nutrients B, Se, and P in soybean cultivation technology, which acted not only as growth regulators, but also as adaptogens to external abiotic stress factors during the growing season of the studied crop. It was found that the use of complexes fortified with phosphorus and selenium in pre-sowing seed treatment (0.6 l/t) and foliar top dressing of vegetative soybean plants in the phase of 1-3 triple leaves provides the greatest increase in grain yield by 0.23 and 0.2 t/ha, or by 10.1 and 8.8% in the indeterminate Mezenka variety, and protein collection at the same time is 1022.5 and 1012.7 kg/ha, respectively.

1 Introduction

The prospects for the use of biological products as biologized elements in new modern technologies of crop cultivation, considering the requirements of organic farming, are beyond doubt. Biopreparations are able to trigger important physiological and biochemical mechanisms of the plant organism involved in the formation of yield and quality of products, including against the background of external biological and abiotic stress factors [1-3].

Scientific research indicates the effectiveness of the use of biostimulants of various natures in the cultivation of a wide range of crops [4]. At the same time, the question about the influence of the biological product nature on the intensity of the response of a particular culture to its use remains open. Difficulties in establishing such relationships are due to the presence of a number of reasons, among which the following can be distinguished: the fragmentation of research, insufficient information on the chemical composition of biological products, the use of a limited number of varieties of one crop in research, the

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variety of soil and climatic conditions of testing. In this regard, the accumulation of data characterizing the prospects of using growth-stimulating complexes in the cultivation of specific crops in specific soil and climatic conditions remains relevant. Obtaining such data in the development of new biological products is of particular importance.

Cyanobacteria *Arthrospira platensis*, due to the ability to carry out targeted regulated cultivation of this type of microorganisms and a wide range of biologically active substances in their composition, are a promising base for creating effective environmentally friendly products [5].

The purpose of the work was to study the effect of growth-stimulating complexes of cyanobacteria *Arthrospira platensis* endometabolites when used in pre-sowing seed treatment and foliar (leaf) top dressing of vegetative plants on the yield of soybean grain, a valuable crop that plays an important role in human and animal nutrition.

2 Materials and methods

Field research was carried out on the basis of the laboratory of vegetation management and production process of agricultural crops of the Federal State Budgetary Scientific Institution "Federal Scientific Center for Legumes and Cereals".

The work used biostimulant endometabolite complex of cyanobacteria *Arthrospira platensis* (Spirustim Fer) and its modifications, fortified (additionally enriched) with nutrients: boron (Spirustim Fer+B), selenium (Spirustim Fer+Se) and phosphorus (Spirustim Fer+P), considered as prototypes for the development of a new plant, prepared on the basis of KSU Ecomonitoring Research Laboratory.

Before the field research, a number of laboratory experiments were conducted using a wide range of different doses of these complexes in the pre-sowing treatment of seeds of nitrogen-fixing crops of different varieties to identify maximum efficiency by determining germination energy, laboratory germination according to State Standard 12038-84, seedling growth energy with simultaneous fixation of biometric indicators [6]. The best options were selected for subsequent research in field experiments.

Field studies were carried out on a new promising soybean variety Mezenka of an indeterminate type of growth and development of breeding of the Federal Scientific Centre for Pulses and Cereals (in the State Register of the Russian Federation since 2016) [7].

The Mezenka variety was selected for the study taking into account its phenotypic and functional features. Its growing season averages 107 days, and the height of the plants reaches 386-138 sm. Its yield potential exceeds 3 t/ha, and the seeds are characterized by a high content of protein (41.8%) and lipids (21.5%). The average weight of 1000 seeds is 147 g.

The effect of the use of growth-stimulating complexes in field experiments was studied on gray forest medium loamy medium cultivated soil in 2023. The registered area of the plot is 10.0 m², the repetition is three-fold, the placement is systematic. The sowing method is wide-row (0.45 m) with a SCS-6-10 breeding seeder, the seeding rate is 600 thousand germinating seeds per 1 hectare.

The average temperature and precipitation during the growing season of soybeans are shown in Table 1.

Scheme of the experiment: 1. control (untreated seeds and plants), 2. basic complex of cyanobacteria *Arthrospira platensis* endometabolites (Spirustim Fer), 3. selenium fortified complex (Spirustim Fer+Se), 4. phosphorus fortified complex (Spirustim Fer+P), 5. boron fortified complex (Spirustim Fer+C). The consumption of the studied preparations in pre-sowing seed treatment was 0.6 l/t, and in leaf dressing 0.3 l/ha.

Table 1. Meteorological conditions of the experiment (field season 2023), data from CHEM, city of Oryol.

Indicators/ Months, decades		The average temperature of the air, 32F / ± to the average temperature. normal	The amount of precipitation, mm / % of the average. normal	The coefficient of moisture by G.T. Selaninov 2023/ multi- year	Characteristics of period of coefficient of moisture 2023./multi- year
May	1	8.1/-4.5	8.2/54.7	0.29/1.34	dry/sufficient moisture
	2	15.1/+0.8	0/0		
	3	15.3/-0.5	8.6/50.6		
June	1	15.6/-1.4	1.7/11.3	1.10/1.18	low aridity/ low aridity
	2	18.3/+0.4	9.6/41.7		
	3	17.4/-1.4	44.6/165.2		
July	1	20.7/+1.2	13.5/50.0	1.3/1.42	low aridity/ adequate hydration
	2	17.8/-2.2	6.8/21.3		
	3	19.2/-0.9	57.0/203.6		
August	1	22.2/+2.5	14.6/97.3	0.7/1.26	severe aridity/low aridity
	2	21.0/+2.4	14.8/82.2		
	3	18.0/+0.9	14.5/84.8		
September	1	15.7/+0.6	0/0	0/1.50	dry/sufficient moisture
	2	14.5/+1.5	0/0		
	3	15.8/+5.0	0/0		

Pre-sowing seed treatment was carried out the day before sowing, the dose of the working solution was 20 l/t. Foliar (leaf) top dressing — in the phase of 1-3 triple leaves, the dose of the working solution is 300 l/ha. The harvesting method is direct harvesting with a Zürn 150 hand-picked combine driver in the macrophase of development — dying (code VVSN 909). The accounting of the harvest is by plots.

Biochemical assessment of soybean grain quality was carried out in the laboratory of Physiology and biochemistry. The protein and fat content in the samples was determined using the Infratec 1241 grain analyzer (SO 090711 program). The results of accounting for the yield and grain quality were processed by the method of dispersion analysis by B.A. Dospekhov [8].

During field tests, the activity of peroxidases in the tissues of various organs of soybean plants in different phases of their growth and development was additionally determined. The determination was carried out by the Boyarkin method based on the rate of oxidation of the substrate - benzidine with hydrogen peroxide [9]. At the same time, some modification of the process of plant material sample preparation was carried out with the establishment of the weight of the attachments (0.2 g and 0.5 g for stems and roots, respectively) and the amount of buffer solution (5 and 10 ml, respectively) for the subsequent preparation of the supernatant involved in the oxidation reaction.

Statistical processing of the obtained results was carried out by the method of one-factor analysis of variance of field experiment according to B.A. Dospekhov using the Variance 3.0 (Office XL) program.

3 Results and discussion

The results of studies of the effect of the cyanobacteria *Arthrospira platensis* endometabolite complex and its fortified modifications on the yield and quality of Mezenka soybean grain are presented in Table 2.

Table 2. The effect of preparations on the yield and quality of soybean grain of the Mezenka variety.

Option	Grain yield, t/ha	± to control		Grain content, %			
		t/ha	%	protein	± to control	fat	± to control
Control	2.27	-	-	40.9	-	21.2	-
Spirustim Fer	2.32	0.05	2.2	41.1	0.2	21.4	0.2
Spirustim Fer+Se	2.47	0.2	8.8	41.0	0.1	21.5	0.3
Spirustim Fer+P	2.5	0.23	10.1	40.9	-	21.7	0.5
Spirustim Fer+B	2.29	0.02	0.9	40.9	-	21.6	0.4
HCP ₀₅	0.21			0.32		0.22	

The analysis of the table showed that Mezenka soybeans reacted differently to the use of complexes of different composition. Only the use of a complex of endometabolites enriched with phosphorus (Spirustim Fer+P) for pre-sowing seed treatment at a dose of 0.6 l/t and one leaf dressing in the phase of 1-3 triple leaves at a dose of 0.3 l/ha led to a statistically significant increase in grain yield by 0.23 t/ha or 10.1% at the yield on the control variant 2.27 t/ha. The use of complexes did not have a statistically significant effect on yield, nevertheless, a positive trend was noted, which may be more pronounced in other soil and climatic conditions.

In addition, the experimental versions recorded differences in such a qualitative indicator of grain as fat content. They are fixed on variants with the use of "Spirustim Fer+P", "Spirustim Fer+B", and "Spirustim Fer+Se" in descending order, significant increases amounting to 0.5 ...0.3%, respectively, in comparison with the control.

The complexes used did not have a significant effect on the protein content in the grain. Nevertheless, with a combination of high values for the indicators "yield" and "amount of protein in grain", when there is a high degree of positive influence between them ($r=0.4891$), the maximum protein harvest was observed on the variant using "Spirustim Fer+P" and "Spirustim Fer+Se" and is 1022.5 and 1012.7 kg/ha, respectively, which is more than the control variant by 94.1 and 84.3 kg/ha or 11.0 and 9.2% (Figure 1).

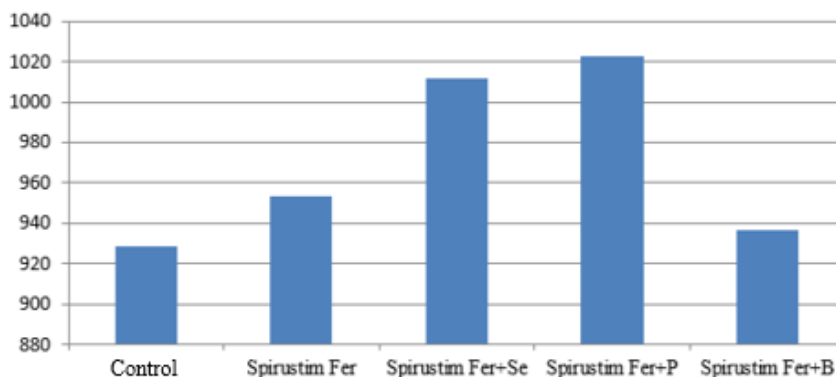


Fig. 1. Protein collection from 1 ha, depending on the use of microalgae complexes, kg.

The increase in productivity of agricultural plants under the action of biostimulants is stated by various authors. It is noted that the effect intensity depends on the type of biostimulator, its concentration and the number of applications [10-13]. The impact on crop quality indicators is also determined by various factors. Szparaga A., et al. studying the effect of synthetic stimulants on soybean culture, found that, leading to an increase in plant productivity, the preparations used by them led to a decrease in the protein and fat content in the grain, regardless of the number of treatments or concentrations of the tested preparations [13, 15].

Another study showed that the use of natural stimulants in soybean cultivation led to an increase in the total concentration of lipids in seeds with a slight decrease in protein content. In addition, the authors recorded changes in the amino acid profile and composition of the fat acids of the seeds [16].

The results of determining peroxidase activity in the tissues of various organs of soybean plants in different phases of their growth and development, obtained during the experiment are of great interest (Table 3).

Table 3. The effect of drugs on the activity of peroxidase (c.u./mg of crude weight) in soybean plants in the phase of 1-3 triple leaves before and after foliar fertilization.

Section	Stems		Roots	
	before	after	before	after
Control	0.0718	was not defined	0.0061	0.0076
Spirustim Fer)	0.1317		0.0088	0.0107
Spirustim Fer+Se	0.1237		0.0138	0.0177
Spirustim Fer+P	0.1197		0.0213	0.0190
Spirustim Fer+B	0.1133		0.0190	0.0297
HCP05	0.0496		0.0050	0.0041

It was shown that the peroxidase activity in soybean plant tissues in the phase of 1-3 triple leaves in the experimental variants after pre-sowing seed treatment was, on average, 23.2% higher in stems and 61.1% in plant roots than the peroxidase activity of tissues of the same parts of plants in the control variant. After leaf spraying, on average, the reaction rate in the roots increases by 60.4% compared to untreated plants. The obtained data are consistent with data obtained by a number of authors demonstrating the activation of the antioxidant system of agricultural plants under the influence of growth-stimulating preparations [14, 17-18].

At the same time, it is considered that root systems react more strongly to various stimuli as they are more sensitive to them, which is reflected in the results of the study.

The obtained results support the assumption put forward by a number of authors that the use of biostimulants is actually a controlled stress on plants. In a certain range of low concentrations, they cause "mild" stress, contributing to the intensification of physiological processes and the rapid onset of the adaptation stage with the restoration of balance between the formation and neutralization of reactive oxygen species in the plant.

In this regard, it is important to note that during the growth and development of soybean plants, external abiotic stress factors were observed within the part of the experiment, which were most pronounced in the first half. With the amount of precipitation in the first decade of June of 1.7 mm or 11.3% of the average annual norm in the previous months of April-May with a coefficient of moisture (hydrothermal coefficient) = 0.21-0.29, insufficient moisture is observed in the upper layers of the soil (soil drought!).

Thus, it can be concluded that the complexes used in this case acted as adaptogens, thereby contributing to increased productivity. The most important is the fact that biostimulants, unlike hormones, affect the metabolic processes of plants without changing their natural pathways [19-20].

4 Conclusion

Thus, the research results showed significant differences in the effect of different endometabolite complexes of cyanobacteria *Arthrospira platensis*, including fortified (enriched) nutrients, on soybean yield and the possibility of using the latter as preparations for pre-sowing treatment of seeds and foliar (leaf) top dressings.

The effectiveness of the use of complexes fortified with phosphorus or selenium during pre-sowing seed treatment and spraying of plants in the phase of 1-3 triple leaves at a dose of 0.6 l/t +0.3 l/ha on Mezenka soybean was revealed.

The use of these preparations helps in the activation of metabolic redox processes, thereby increasing stress resistance to adverse external influences and contribute to the maintenance of homeostasis.

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