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RESULTS OF SOYBEAN SEED TREATMENT WITH INOCULANTS IN COMBINATION WITH A NITROGEN-FIXING AGENT BEFORE SOWING

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Annotation. The article presents the results of research dedicated to evaluating the effectiveness of soybean seed treatment with inoculants in combination with a nitrogen-fixing agent before sowing. The studies revealed that such treatment enhances seed germination, accelerates plant growth, and increases their resistance to unfavorable conditions. The effects of inoculants and nitrogen-fixing agents on nitrogen metabolism in soybean plants, as well as on final yield indicators, were studied across various agro-climatic zones. The findings confirm that integrated seed treatment significantly increases soybean productivity by improving nitrogen nutrition and stimulating the active function of symbiotic bacteria. The conclusions can serve as a foundation for developing recommendations to optimize soybean cultivation technologies in agriculture. Additionally, the research demonstrated that treated plants showed improved chlorophyll content and root development, contributing to overall plant vigor. These results highlight the potential for sustainable yield enhancement without increasing chemical fertilizer use. This makes the technology particularly relevant in the context of modern agriculture, which is focused on environmental sustainability and resource efficiency.

Keywords: seed treatment, soybean, inoculants, nitrogen-fixing agent, pre-sowing treatment, symbiotic bacteria, yield, nitrogen metabolism, agro-technology.

Introduction. The genetic potential of soybean productivity can be realized by improving the availability of essential growth factors, primarily through optimizing nutrition. In addition to macronutrients (nitrogen, phosphorus, potassium), soybeans actively absorb micronutrients, which play a crucial role in the physiological and biochemical processes of plants (boron, cobalt, molybdenum, copper). Cobalt enhances photosynthetic activity, nitrogen fixation, and the protective functions of plants against diseases. Molybdenum strengthens nitrogen fixation, nitrogen metabolism, and the absorption of mineral nutrients (P, K, Mn), while also increasing plant resistance to climatic stresses [1]. Specific doses of molybdenum and cobalt positively influence the physiological qualities of soybean seeds when applied as foliar treatments [2].

Modern agriculture is inseparable from the active use of mineral fertilizers, as they are essential for increasing crop yields and, consequently, reducing the cost of agricultural production. Organic fertilizers are also used because they cause less soil acidification, positively affect humus accumulation, enrich the soil with plant nutrients, and improve its physical and chemical properties. Organic fertilizers enhance the phytosanitary condition of the soil, boost its biological activity, improve the water regime and nutrient availability, and increase the buffering capacity of the soil solution [3].

In addition, the use of mineral fertilizers is one of the main techniques in intensive farming. With high levels of agro-technology and fertilizer application, yields can be managed and significantly increased [4]. During the growing season, the normal development of crops is impossible without micronutrients. These elements are involved in metabolism and participate in complex processes such as the synthesis and breakdown of proteins, fats, carbohydrates, enzymes, and vitamins. Thus, optimal micronutrient levels in the soil positively affect yield, crop quality, seed development, and their sowing characteristics. Over the past 25 years, the use of micronutrients has gained widespread adoption in global agricultural practices [5].

To optimize soybean growth, excessive doses of chemical fertilizers are often applied to this crop. However, the constant use of chemical fertilizers without adding organic fertilizers may lead to rapid depletion of nutrients in the soil [6].

Today, fertilizer application is firmly integrated into advanced technologies for growing agricultural crops as a critical component for achieving high and stable yields. The nutritional regime of plants cannot be optimized solely through macronutrients and mesonutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and others. Plants also require micronutrients that increase their resistance to unfavorable growing conditions, diseases, and pests. Numerous studies have convincingly demonstrated that micronutrients play a significant role in plant development, their adaptation to changing climate conditions, and the quantity and quality of yields. Consequently, modern agricultural technologies place significant emphasis on foliar feeding. Applying fertilizers by spraying nutrient solutions on the leaf surface overcomes negative soil factors such as leaching of nutrients, the formation of insoluble residues, ion antagonism, and soil heterogeneity, which prevent the effective application of small doses of fertilizers and the formation of inaccessible phosphorus and potassium forms.

The advantage of foliar feeding over a single soil application is that nutrients can be applied at the peak of plant demand, quickly addressing deficiencies, and significantly reducing fertilizer use, aligning with both economic and environmental requirements [7]. The objective of the study is to investigate methods for optimizing soybean nutrition to realize its genetic productivity potential, including evaluating the effects of various agrological factors and agrochemical treatments on plant growth and development.

Materials and Methods. The material for the study consisted of soybean varieties developed by the Kazakh Research Institute of Agriculture and Crop Production, approved for cultivation in the southern and southeastern regions of Kazakhstan. The varieties belong to the medium-late and late-maturing groups, with a growing season of 125–130 and 140–145 days (Table 1).

Table 1 – Average Yield and Quality Indicators of Soybean Varieties at the Time of Submission for State Variety Trials

Variety	Yield, c/ha	Growing period, days	Protein, %	Oil, %	Year approved	Region approved
Lastochka	32-42	140-145	36,8-38,8	20,1-22,7	2011	Southeast Kazakhstan
Zhansaya	35-51	127-135	40,2-41,2	20,5-21,1	2012	Southeast Kazakhstan
Birlik KV	34-44	133-138	33,8-36,7	22,6-24,1	2017	Southeast Kazakhstan
Ivushka	34-45	140-145	35,5-37,8	20,0-21,8	2020	Southeast Kazakhstan

Results. The study analyzed the effects of pre-sowing soybean seed treatment with inoculants combined with a nitrogen-fixing agent on various agronomic parameters. The results showed that the combined treatment had a variable impact on plant growth, development, and yield depending on the variety and agro-climatic conditions.

In the experiments, soybean seeds were treated one day before sowing with an ammonium molybdate solution (40 g per 100 kg of seeds) and cobalt sulfate (4 g per 100 kg of seeds). On the day of sowing, the seeds were treated with the nitrogen-fixing bacterial preparation "Histick" at a rate of 400 g per 100 kg of seeds. The experimental scheme included the following variants:

Control – no treatment.

Histick treatment – seed inoculation with Histick.

Mo + Co treatment – seed treatment with molybdenum and cobalt.

Histick + Mo + Co – combined seed treatment with Histick and microelements.

Sowing was carried out in the third decade of April. Each plot measured 25 m², with a seeding rate of 500,000 seeds per hectare, row spacing of 30 cm, and a sowing depth of 4 cm. The randomized trial was conducted in four replicates. Agricultural practices were performed according to standard methodologies and regional recommendations for the study zone [8]. The experiments, harvest, and yield analysis were conducted following the field experiment methodology of Dospekhov B.A. [9]. Phenological observations were made for key development stages: sowing, emergence (VE), trifoliate leaf appearance (V1), beginning of flowering (R1), pod formation (R4), pod filling (R6), and full maturity (R8) [10].

Structural analysis followed VIR methods [11]. Irrigation was applied three times during the growth phases (flowering, pod formation, and pod filling) – June 15–20, July 10–15, and August 10–15, with an irrigation rate of 1200 m³/ha. Phenological Observations. The study of plant phenological phases showed slight variations between years within the same variety, but the different treatments did not significantly affect the duration of individual development phases. All varieties, both in the control and treated groups, matured within their respective maturity groups. The growing period for Ivushka was 97–101 days, Birlik KV was 108–117 days, Zhansaya was 130–139 days, and Lastochka was 140–150 days.

The length of the growing period, measured in days from emergence to maturity, was influenced by the number of days from sowing to emergence.

Productivity Analysis. Productivity indicators reflect yield characteristics, which correlate positively with individual productivity traits. Key productivity traits in soybeans include plant height, the number of lateral branches, the number of productive nodes, the number of pods per plant, seed mass per plant, and the mass of 1,000 seeds.

The analysis of productivity showed that pre-sowing treatments with microelements significantly influenced soybean productivity elements. In general, the architecture of the plant remained consistent across different treatments. Plant height, the height of attachment of the lowest pods, and branching were not significantly affected by treatment type and remained within the varietal specificity, environmental conditions, and applied agricultural practices. Pre-sowing treatments notably increased flower set, resulting in more pods and seeds per plant, ultimately increasing yield. Varietal Results. For the medium-late varieties Zhansaya and Lastochka, the highest increase in the number of pods per plant and seed mass per plant was observed with the combined treatment of Histick + Mo + Co (Figures 1, 2).

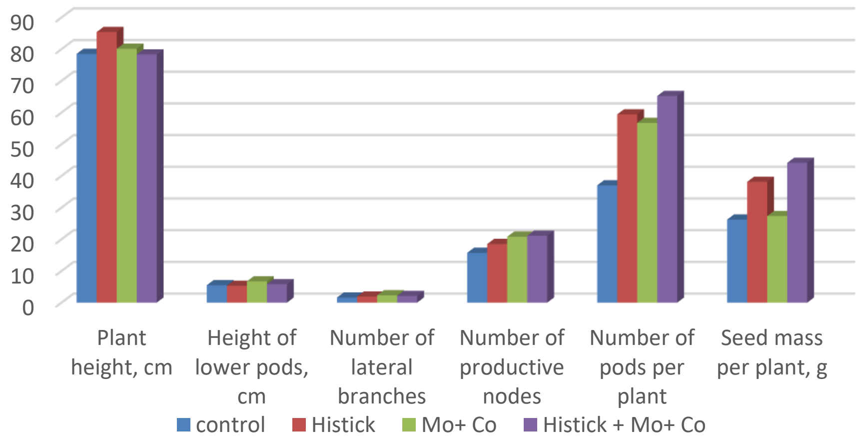

Figure 1 – Average Productivity Traits of Soybean Variety Zhansaya Depending on Pre-Sowing Seed Treatment

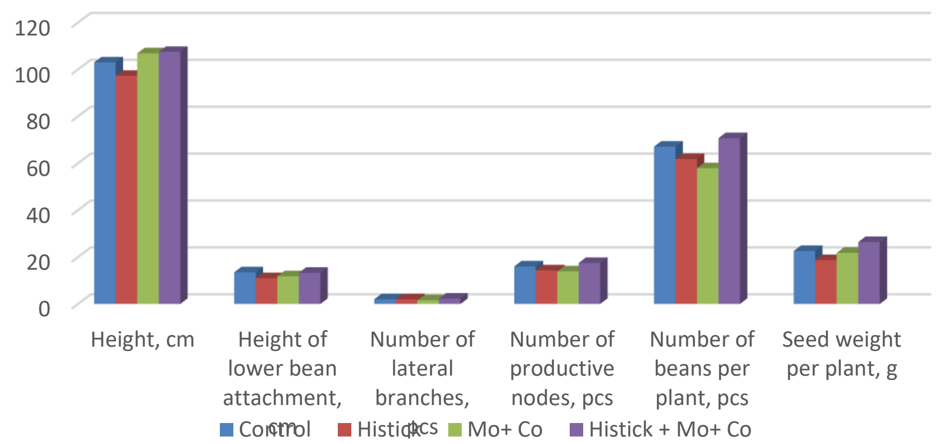

Figure 2 – Average productivity characteristics of the Lastochka soybean variety depending on pre-sowing seed treatment

For the medium-early variety Birlik KV, the productivity traits responded equally well to Histick alone and the combined treatment with microelements (Histick + Mo + Co) (Figure 3).

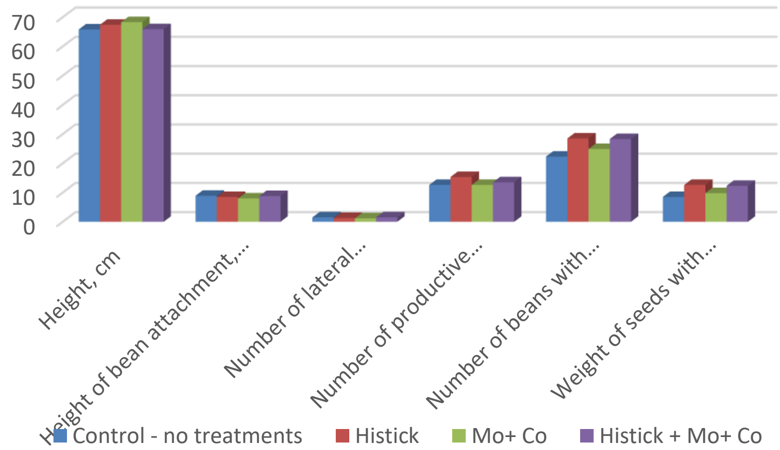

Figure 3 – Average Productivity Traits of Soybean Variety Birlik KV Depending on Pre-Sowing Seed Treatment

For the early-maturing variety Ivushka, the best results were obtained with seed treatment using only microelements (Figure 4). The yield of soybean varieties has a positive correlation with the maturity group r = 0.87. It is interesting to note that weather conditions had an ambiguous effect on the formation of the yield of varieties of different maturity groups.

Pre-sowing seed treatment showed varietal specificity to the types of treatment. Thus, the average yield for three years of research of the early ripening variety Ivushka was the lowest, and depending on the treatment was in the range from 17.7 ± 4.4 c / ha to 19.4 ± 4.1 c / ha.The highest yield for this variety was shown when treating seeds only with microelements. It is characteristic to note that this coincides with the data on productivity traits. The second in terms of yield was the mid-early variety Birlik KV with indicators from 28.6 ± 4.8 c / ha to 32.2 ± 3.4 c / ha. Soybean varieties of maturity groups II and III were the most productive. The yield of the Zhansaya variety over the years of research averaged 44.9±11.8 - 49.0±12.8 c/ha, and for the latest ripening variety Lastochka 50.4±3.8 - 54.6±3.8 c/ha. The yield of the ultra-early ripening variety Ivushka and the late ripening variety Lastochka was most affected by pre-sowing treatment with Mo, Co microelements without the use of a nitrogen-fixing preparation.

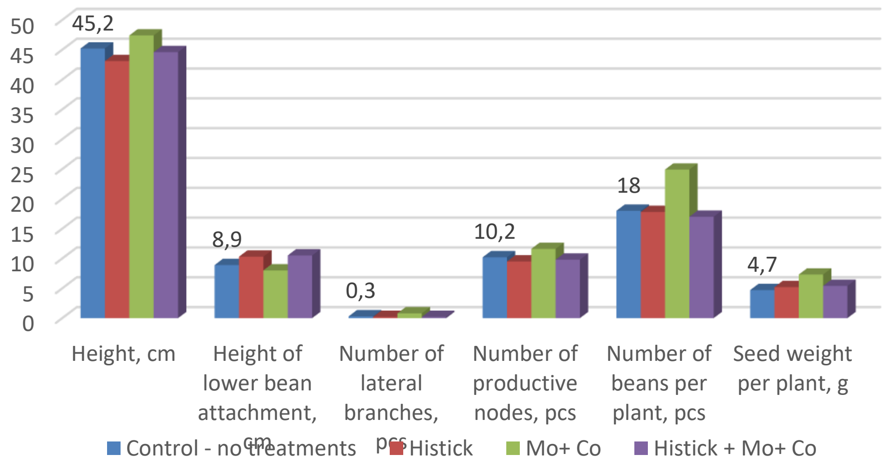

Figure 4 – Average productivity characteristics of the Ivushka soybean variety depending on pre-sowing seed treatment

The yield increase compared to the control for these varieties was 1.4 and 4.2 c/ha, respectively. The yield of the early ripening variety Birlik KV and the mid-season variety Zhansaya significantly increased by 3.6 and 1.8 c/ha with a combined seed treatment with the nitrogen-fixing preparation Histick and Mo, Co microelements (Table 2).

Table 2 – Yield of soybeans of four maturity groups with different types of pre-sowing seed treatment, c/ha

Types of treatments	2021 year	2022 year	2023 year	Average	Deviations from control
Ivushka (OO)					
Control	22,9±1,9	16,5±2,5	14,5±2,9	18,0±4,2	0,0
Histik	23,4±1,8	14,6±1,7	15,0±1,0	17,7±4,4	-0,3
Mo,Co	24,5±2,4	16,3±4,4	17,4±5,9	19,4±4,1	1,4
Histik+ Mo,Co	24,1±2,8	16,7±3,1	16,7±0,4	19,2±3,7	1,2
LSD	*1,81*	*1,77*	*1,25*		
Birlik KB (O)					
Control	27,1±1,2	34,1±3,3	24,6±7,7	28,6±4,8	0,0
Histik	28,1±2,3	32,5±3,5	25,0±7,1	28,5±3,8	-0,1
Mo,Co	30,2±3,1	30,0±4,8	27,7±1,7	29,3±1,3	0,7
Histik+ Mo,Co	33,1±2,4	35,1±4,2	28,3±6,1	32,2±3,4	3,6
LSD	*2,11*	*2,12*	*1,88*		
Zhansaya (II)					
Control	41,6±4,3	59,2±9,2	40,7±4,4	47,2±9,3	0,0
Histik	41,1±3,8	61,4±9,6	40,6±2,9	47,7±10,4	0,5
Mo,Co	40,4±4,1	58,9±5,2	35,3±8,5	44,9±11,8	-2,3
Histik+ Mo,Co	43,3±3,9	64,6±7,1	39,0±4,0	49,0±12,8	1,8
LSD	*1,8*	*1,55*	*2,14*		
Lastochka (III)					
Control	54,4±3,2	46,9±4,2	50,0±4,2	50,4±3,8	0,0
Histik	55,1±2,7	46,4±2,7	56,9±6,3	52,8±5,3	2,4
Mo,Co	57,2±4,1	49,7±6,9	56,9±6,3	54,6±3,8	4,2
Histik+ Mo,Co	56,4±2,1	49,9±1,9	56,9±2,1	54,4±3,5	4,0
LSD	*2,21*	*1,99*	*1,85*		

The accumulation of protein and oil in soybean seeds has a strong negative correlation that cannot be broken. It has been established that the negative correlation between traits can vary from r = -0.25 to r = -0.93 [12] and has a high heritability coefficient of 0.89-0.93 [13].

Overall plant productivity often negatively correlates with protein content, although this relationship is weaker than between protein and oil content.

The research revealed that various types of pre-sowing seed treatment did not affect the protein and oil content in seeds. More visible fluctuations in the qualitative composition were observed across the years of research, which may be due to weather conditions. Thus, in 2021, there was an obvious decrease in protein content and an increase in oil levels in the seeds of all studied varieties (Table 3).

More indicative characteristics for assessing the impact of pre-sowing treatment are the protein and oil yield per hectare, since the yield increased without changing the quality characteristics. In the new generation soybean varieties of KazNIIZIR LLC, the protein yield per hectare is in the range of 944.7 -1705.3 kg, oil - 415.9-974.6 kg. The yield of varieties is in the range of 20.9 - 43.9 c / ha depending on the maturity group [14].

Table 3 – Quality indicators of soybean seeds with different types of treatments

Experimental variant	Protein content, %				Fat content, %			
	2021	2022	2023	average	2021	2022	2023	average
Ivushka								
Control - no treatments	43,4	47,4	47,0	45,9	20,7	19,0	19,4	19,7
Histick	44,2	47,0	47,6	46,3	20,5	19,1	19,2	19,6
Mo+ Co	43,8	47,2	47,2	46,1	20,1	19,1	19,4	19,5
Histick + Mo+ Co	43,5	44,7	47,5	45,2	20,7	20,2	19,5	20,1
Birlik KB								
Control - no treatments	40,1	43,3	43,4	42,3	22,7	21,2	20,8	21,6
Histick	40,2	43,4	43,2	42,3	22,5	21,1	20,5	21,4
Mo+ Co	40,5	43,0	43,7	42,4	22,7	21,1	20,9	21,6
Histick + Mo+ Co	40,1	43,1	43,9	42,4	22,8	21,2	20,8	21,6
Zhansaya								
Control - no treatments	39,1	40,7	41,5	40,4	22,7	22,0	23,0	22,6
Histick	39,7	40,1	40,6	40,1	22,0	22,0	22,6	22,2
Mo+ Co	38,7	40,8	39,8	39,8	22,6	21,9	22,8	22,4
Histick + Mo+ Co	39,8	40,5	42,0	40,8	22,2	21,9	22,6	22,2
Lastochka								
Control - no treatments	37,0	39,9	39,5	38,8	21,3	21,1	21,7	21,4
Histick	38,1	40,4	39,5	39,3	21,1	21,2	21,9	21,4
Mo+ Co	37,8	40,1	39,2	39,0	21,5	21,0	21,7	21,4
Histick + Mo+ Co	38,3	39,8	39,3	39,1	21,4	20,9	21,3	21,2

Studies show an increase in protein yield per hectare. In the early maturing soybean variety Ivushka from 826.2 kg / ha in the control to 894.3 kg / ha when treated with pure microelements. In the Birlik KV variety from 1209.8 kg / ha in the control to 1365.3 when using Histick + Mo + Co. For the Zhansaya variety, from 1906.9 kg/ha without treatment to 1999.2 with the use of Histick + Mo + Co. For the late-ripening Lastochka variety, from 1955.5 without treatment to 2127.0 with the use of Histick + Mo + Co (Figure 5).

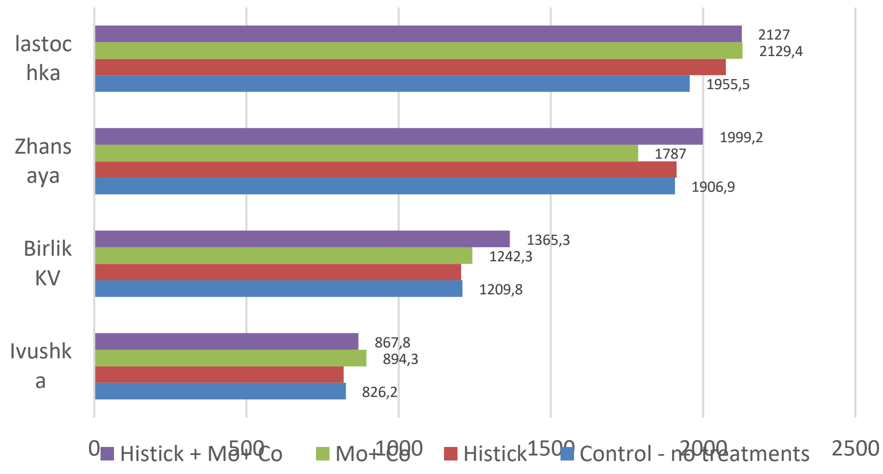

Figure 5 – Protein yield per hectare by different soybean varieties depending on the type of pre-sowing seed treatment (kg/ha)

A similar picture emerges with respect to the oil yield per hectare indicator (Figure 6). The lowest oil yield is provided by the early-ripening Ivushka variety, from 354.6 kg/ha without seed treatment to 385.9 kg/ha with complex treatment. The highest oil yield is shown by the late-ripening Lastochka variety, 1078.6 without pre-sowing treatment and 1153.3 with treatment with molybdenum and cobalt salts.

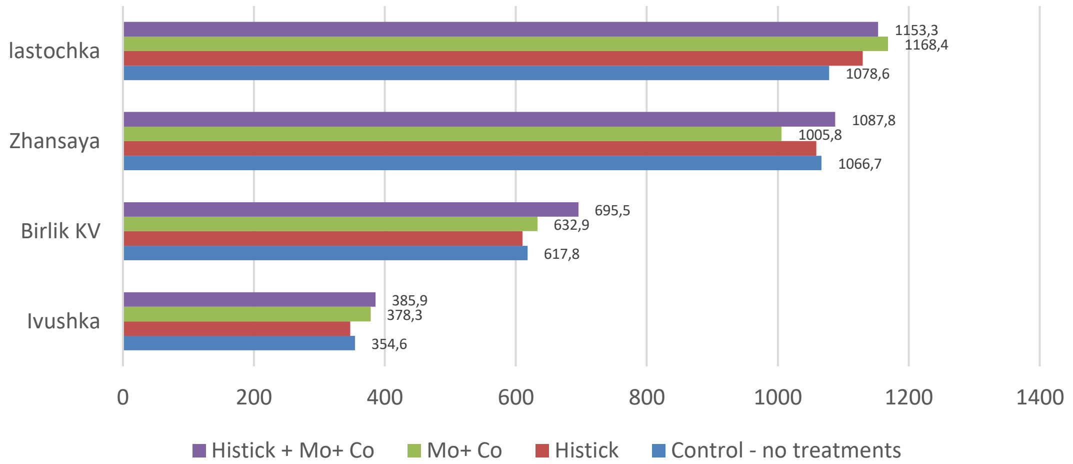

Figure 6 – Fat collection per hectare by different soybean varieties depending on the type of pre-sowing seed treatment (kg/ha)

Pre-sowing seed treatment revealed varietal responsiveness to the use of stimulants. No preparation had a positive effect on the yield of the ultra-early Ivushka variety. The yield of the early Birlik KV variety significantly increased by 2.1 c/ha with combined seed treatment with the nitrogen-fixing preparation Histick and microelements Mo, Co. In the mid-late Zhansaya variety and the late Lastochka variety, a significant increase in yield was noted only with seed treatment with the nitrogen-fixing preparation Histick by 1.6 and 2.1 c/ha, respectively. The studies did not reveal the effect of various treatments on the qualitative composition of seeds (protein and oil).

Conclusion. It is important to note that the treatments did not have a significant effect on the qualitative characteristics of seeds, such as protein and oil content. These data confirm that the choice of preparations for pre-sowing treatment of soybean seeds should take into account the varietal characteristics of the crop, as well as the focus on optimizing the nutritional conditions and nitrogen metabolism in plants. The results of the study may be useful for further improvement of soybean cultivation technologies and increasing its productivity.

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РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЯ ОБРАБОТКИ СЕМЯН СОИ ИНОКУЛЯНТАМИ В КОМБИНАЦИИ С АЗОТФИКСИРУЮЩИМ ПРЕПАРАТОМ ПЕРЕД ПОСЕВОМ

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Аннотация. В статье представлены результаты исследования, посвящённые оценке эффективности обработки семян сои инокулянтами в сочетании с азотфиксирующим препаратом перед посевом. Исследования показали, что такая обработка способствует улучшению прорастания семян, ускорению роста растений и повышению их устойчивости к неблагоприятным условиям. Влияние инокулянтов и азотфиксирующих препаратов на азотный обмен в растениях сои, а также на конечные показатели урожайности, было изучено в различных агроклиматических зонах. Полученные данные подтверждают, что применение комплексной обработки семян позволяет значительно повысить продуктивность сои за счет улучшения её питания азотом и стимулирования активной работы симбиотических бактерий. Выводы исследования могут быть использованы для разработки рекомендаций по оптимизации технологий возделывания сои в сельском хозяйстве. Кроме того, исследование показало, что обработанные растения отличались повышенным содержанием хлорофилла и лучшим развитием корневой системы, что способствовало общей жизнеспособности растений. Полученные результаты подчеркивают потенциал устойчивого повышения урожайности без увеличения применения химических удобрений. Это делает технологию особенно актуальной в условиях современного сельского хозяйства, ориентированного на экологичность и ресурсосбережение.

Ключевые слова: обработка семян, соя, инокулянты, азотфиксирующий препарат, предпосевная обработка, симбиотические бактерии, урожайность, азотный обмен, агротехнология.

МАЙБҰРШАҚ ТҰҚЫМДАРЫН ИНОКУЛЯНТТАРМЕН ЖӘНЕ АЗОТ ФИКСАЦИЯЛАЙТЫН ПРЕПАРАТПЕН ДӘРІЛЕУДІҢ НӘТИЖЕЛЕРІ

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Аңдатпа. Мақалада майбұршақ тұқымдарды инокулянттармен және азотфиксаторлық препараттармен өңдеудің тиімділігін бағалауға арналған зерттеу нәтижелері ұсынылған. Зерттеулер көрсеткендей, осындай өңдеу тұқымдардың өнуін жақсартып, өсімдіктердің өсуін тездетеді және олардың қолайсыз жағдайларға төзімділігін арттырады. Инокулянттар мен азотфиксаторлық препараттардың майбұршақ өсімдіктерінің азот алмасуына, сондай-ақ өнімділік көрсеткіштеріне әсері әртүрлі агроклиматтық аймақтарда зерттелді. Алынған мәліметтер тұқымдарды кешенді өңдеудің майбұршақтың азотпен қамтамасыз етілуін жақсартып, симбиотикалық бактериялардың белсенді жұмысын ынталандыру арқылы өнімділігін айтарлықтай арттыратынын растайды. Зерттеу нәтижелері майбұршақ дақылының өндірісінде технологияларын оңтайландыру бойынша ұсыныстар әзірлеуде қолданылуы мүмкін. Сонымен қатар, зерттеу нәтижелері өңделген өсімдіктерде хлорофилл мөлшерінің жоғарылағанын және тамыр жүйесінің жақсы дамығанын көрсетті, бұл өсімдіктердің жалпы тіршілік қабілетін арттырды. Алынған нәтижелер химиялық тыңайтқыштарды көбейтпей-ақ, өнімділікті тұрақты арттыру мүмкіндігін көрсетеді. Бұл технологияны қазіргі экологиялық тұрақтылық пен ресурстарды үнемдеуге бағытталған ауыл шаруашылығы жағдайында аса өзекті етеді.

Тірек сөздер: тұқымдарды өңдеу, майбұршақ, инокулянттар, азотфиксаторлық препарат, себу алдындағы өңдеу, симбиотикалық бактериялар, өнімділік, азот алмасуы, агротехнология.