JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(9), 96–110
https://doi.org/10.12911/22998993/204504
ISSN 2299–8993, License CC-BY 4.0

Received: 2025.04.17
Accepted: 2025.06.13
Published: 2025.06.23

Inoculation of seeds as a factor in increasing the productivity of soybean varieties of different maturity groups under irrigation conditions in southern Ukraine

Valentina Vasylivna Gamayunova[1], Olena Sydiakina[2*], Mykola Oleksandrovich Ivaniv[2], Viktor Viktorovich Vozniak[2]

[1] Mykolaiv National Agrarian University, Georgiy Gongadze Str., 9, Mykolaiv City, 54008, Ukraine
[2] Kherson State Agrarian and Economic University, Streetenska Str., 23, Kherson City, 73006, Ukraine
* Corresponding author's e-mail: sydiakina_o@ksaeu.kherson.ua

ABSTRACT

A two-factor study was conducted to investigate the impact of inoculants on the productivity of soybean varieties from different maturity groups under the soil and climatic conditions of the steppe zone of Ukraine, following generally accepted methodologies. Factor A consisted of early-maturing (Krynytsia, Rizdvyana, Zlatoslava) and early-ripening (Aurelina, Bettina, NS Maximus) soybean varieties. Factor B involved seed inoculation with bacterial preparations: control (water treatment), Bioboost Plus, Biomag-Soy, Ekovital, Humisol, Optimize 400, Rhizogumin. The bacterial preparations Rhizogumin and Humisol showed a relatively weak effect, while Ekovital and Optimize 400 contributed to a significant increase in yield – up to 25% compared to the control. The grain yield with the use of Ekovital and Optimize 400 was 3.17–3.25 t/ha, demonstrating their high effectiveness in the technology of growing early-maturing soybean varieties. These same inoculants also demonstrated maximum effectiveness in the cultivation of early-ripening soybean varieties, confirming their high biological activity and ability to improve plant growth and development. The yield increase in treatments using the Rhizogumin preparation for growing early-ripening varieties was within the experimental error (LSD_{05}), thus its impact on grain yield was determined to be insignificant. Early-ripening soybean varieties in the experiment formed a higher yield level compared to early-maturing varieties. The Zlatoslava variety stood out among early-maturing varieties for its yield, demonstrating a statistically significant advantage. Among early-ripening varieties, the Aurelina variety produced a higher yield, although its indicators did not show significant differences from the NS Maximus variety, indicating their equal potential. Seed inoculation with bacterial preparations had a positive effect on grain quality: Optimize 400 and Ekovital increased protein content, while Rhizogumin enhanced oil content. The conditional yield of protein per hectare of soybean crops increased by 4.63–27.78% due to seed bacterization, and oil yield increased by 7.27–23.64%, with the best results observed when using Ekovital and Optimize 400. This supports the rationale for their application to improve the quality characteristics of the harvest.

Keywords: early-maturing varieties, early-ripening varieties, seed inoculation, bacterial preparations, protein, oil.

INTRODUCTION

Soybean is one of the most important leguminous crops, which according to the FAO classification also belongs to the oilseed group [Hughes et al., 2022]. Its history spans over three thousand years, and the earliest mentions of its cultivation were found in China [Guo et al., 2022]. Initially, soy was primarily used as a green manure in crop rotation due to its ability to fix atmospheric nitrogen; it also served as a raw material for fermented food products. For a long time, its cultivation was limited to the territory of Asia, and only in the early 20th century did it begin to gain popularity in North and South America, and later in Europe [Dong et al., 2021; Nair et al., 2023].

Today, only in a few countries around the world is soy processed directly at the local level for the production of food products intended for human consumption. However, the majority of the soy grown is used on an industrial scale, primarily for the production of soybean meal and soybean oil. In particular, about two-thirds of the total processing volume is accounted for by meal production, while the share of soybean oil is approximately one-third. Today, this product is indispensable in cooking, and soybean meal is an important component of the feed base in animal husbandry [Singh and Krishnaswamy, 2022; Siamabele, 2020].

In recent years, there has been a rapid increase in the use of soybean oil for the production of biodiesel fuel, making this crop even more in demand in the field of renewable energy [Peng et al., 2024]. At the same time, the production of genetically modified soybean varieties is actively expanding, which allows for increased yields and plant resilience to adverse conditions [Rahman et al., 2023].

The global soybean market is characterized by a high concentration of production. Approximately 80% of the total volume of the cultivated crop comes from three countries: the United States, Brazil, and Argentina. Moreover, over 95% of global production is provided by countries that are part of the AMIS (Agricultural Market Information System). Soybeans play a significant role in global agricultural trade, with more than 90% of its exports originating from AMIS countries [Soybeans. Agricultural Market Information System, 2025].

The future of soybeans looks promising as global demand for this crop continues to grow. According to the forecasts of the Food and Agriculture Organization of the United Nations (FAO), by 2029, global soybean production may reach 480 million tons. Ukraine holds one of the leading positions in soybean production in Europe. According to the Food and Agriculture Organization of the United Nations, in 2023, 1.834 million hectares of soybeans were sown, yielding 4.743 million tons of grain with a productivity of 2.59 tons per hectare [Official site of Food and Agriculture Organization of the United Nations, 2025].

Ukraine exports soybeans to countries in the European Union, Asia, and Africa and has significant potential for expanding its sown areas and increasing the yield of this crop [Bogonos and Chmil, 2023]. Thanks to the application of modern agricultural technologies, the introduction of high-yielding adapted varieties, optimization of nutrient backgrounds, and methods of plant protection, substantial increases in production volumes can be achieved [Ivaniv et al., 2023; Yu et al., 2022]. An important factor for success is also the development of quality infrastructure for the storage and logistics of soybean grain, which will minimize losses during transportation and storage [Filassi and de Oliveira, 2021].

Given the changing climatic conditions, economic factors, and the need to optimize cultivation technologies, the introduction of early-maturing and early-ripening soybean varieties into production is becoming particularly relevant. These varieties, due to their short growing season, are characterized by the ability to produce consistently high yields earlier in the season. This allows for the sale of grain at higher prices at the beginning of the season when market supply is still limited. As a result, agricultural producers can achieve additional profits [Vogel et al., 2021; Luo et al., 2021].

The use of early-maturing and early-ripening soybean varieties allows for the implementation of more flexible crop rotation systems. In particular, after their harvest, there is sufficient time for proper soil preparation for winter crops, which contributes to increased soil fertility and optimization of land resource use [Kulig and Klimek-Kopyra, 2022].

In the context of climate change, increasing aridity, and uneven precipitation distribution, early-maturing and early-ripening soybean varieties are less vulnerable to stressful environmental conditions. Due to their shorter growing season, they are less exposed to pathogens and pests, which allows for a reduction in plant protection costs and improves the sustainability of cultivation [Song et al., 2023; Staniak et al., 2023].

Despite numerous advantages, the adoption of early-maturing and early-ripening soybean varieties requires scientific validation and comprehensive research. It is particularly important to identify the most suitable varieties for specific agro-ecological zones, taking into account the soil and climatic characteristics of the regions [Dayoub et al., 2021; Staniak et al., 2023].

Another important element of modern soybean cultivation technologies is seed inoculation with bacterial preparations. The use of inoculants promotes the active assimilation of atmospheric nitrogen and its conversion into forms available for plant uptake, ensuring optimal growth and development. Inoculation enhances the efficiency of soybean nitrogen nutrition, significantly reducing the need for mineral fertilizers, lowering costs for agrochemical products, and positively affecting soil conditions by increasing their fertility [Mazur et al., 2023; Szpunar-Krok et al., 2023].

Given the importance of the aforementioned factors, the application of inoculants in combination with the cultivation of modern early-maturing and early-ripening soybean varieties is particularly relevant. This combination will contribute to increased yields, improved quality indicators of the grain, and a reduction in negative environmental impacts due to decreased use of mineral fertilizers. Research on the effect of seed inoculation with modern biopreparations on the productivity of early-maturing and early-ripening soybean varieties is a pertinent direction for the development of agricultural science and practice in Ukraine. This will enhance production efficiency, ensure sustainable development of the agricultural sector, and improve the competitiveness of Ukrainian soybeans in the global market.

The aim of this scientific research was to refine certain elements of soybean cultivation technology, specifically to study the impact of seed inoculation with bacterial preparations on the productivity of early-maturing and early-ripening varieties of this crop under irrigation conditions in southern Ukraine.

RESEARCH METHODOLOGY

Field studies, in accordance with the set objective, were conducted in 2021–2022 at the Educational, Scientific, and Practical Center of Mykolaiv National Agrarian University (46°58′31″ N latitude, 31°59′37″ E longitude), located in the southern steppe zone of Ukraine.

The climate of the research area is moderately continental, characterized by sharp fluctuations in temperature and relative humidity during the summer and winter seasons. Another distinctive feature is the relatively low amount of precipitation.

The year 2021 proved favorable for soybean crops, as most precipitation fell during the critical growth phases (June–July) (Figure 1). In 2022, a moisture deficit was observed from May to August, which could have led to weakened plant growth processes, uneven flowering, and a reduced number of formed pods. However, the soybean in the experiment was grown under irrigation, which ensured a sufficiently high grain yield, although slightly lower than in 2021.

The temperature regime plays a crucial role in the growth, development, and yield formation of soybeans. The optimal average daily temperature for soybean germination under the soil and climatic conditions of Ukraine is 15–20 °C, while during the vegetative growth period, it is 18–22 °C. Deviations from these values may negatively affect seedling uniformity, plant development, and yield formation [Mazur et al., 2022].

The average annual temperature in 2021 was 9.91 °C, while in 2022, it was 10.88 °C, which is 0.97 °C higher (Figure 2). The most significant differences between the research years were observed in February (3.66 °C), April (1.74 °C), June (1.49 °C), and October (1.53 °C). The year 2022 was warmer during May and June, which contributed to rapid initial soybean growth and better nutrient uptake by plants. However, in July, the temperature was 1.38 °C lower than in 2021, which slowed down the flowering phase and reduced the number of fertilized flowers. The increased temperature in August 2022, combined with a moisture deficit, accelerated grain filling, which negatively affected both yield and quality parameters.

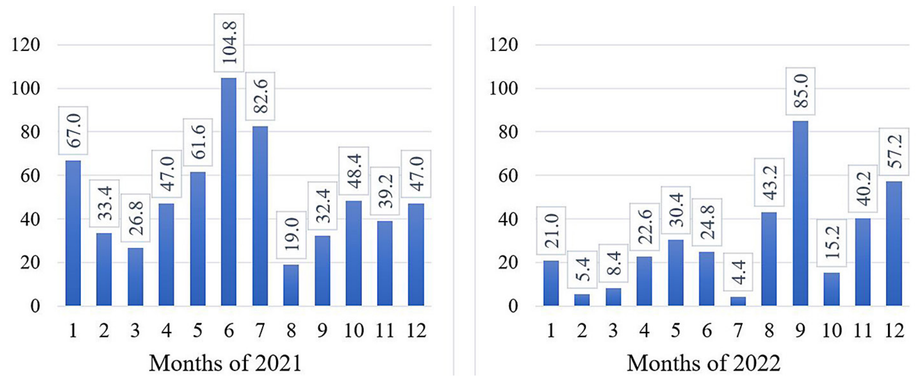

Figure 1. Precipitation levels (mm) during the research years (according to the meteorological station of Mykolaiv National Agrarian University)

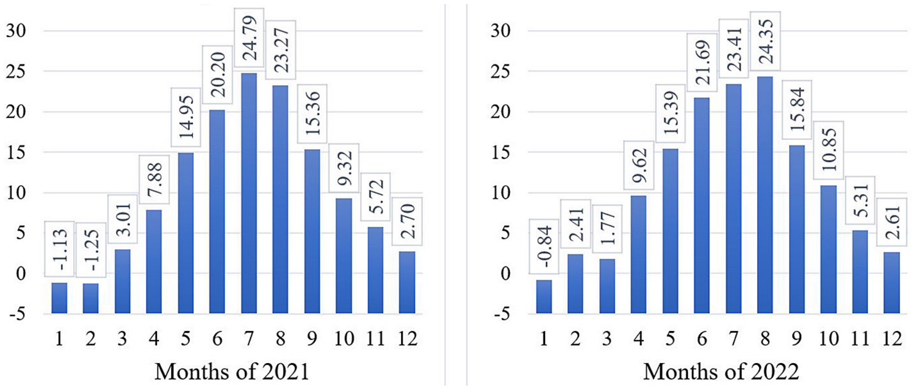

Figure 2. Air temperature (°C) during the research years (according to the meteorological station of Mykolaiv National Agrarian University)

Overall, the weather conditions during the research years were favorable for achieving a relatively high grain yield in the early-maturing and early-ripening soybean varieties studied in the experiment.

The soil of the experimental field is represented by southern low-humus black soil with the following sequence of genetic horizons:
- Hn – humus-accumulative horizon;
- Hp(i) – humus-transition horizon;
- Phi(k) – horizon of humus accumulations;
- Ph – transition horizon;
- PK – carbonate horizon;
- Pk – parent soil-forming rock – carbonate loess.

The granulometric composition of the soil in the experimental field is heavy clay, with no differentiation by genetic horizons (Figure 3).

The soil of the experimental field is low-humus, containing 3.2% humus in the arable layer. The pH of the soil is neutral, ranging from 7.0 to 7.1. The cation exchange capacity is 45 meq per 100 g of soil, including calcium – 23.5, magnesium – 8.2, sodium – 0.5, and potassium – 0.6 meq/100 g of soil. Thus, the primary composition of the soil absorption complex is represented by calcium and magnesium cations.

The physical properties of the experimental field soil are characterized by the following indicators: bulk density – 1.22 g/cm^3, particle density – 2.68 g/cm^3, and total porosity – 54.5%.

The water retention properties of the soil at the beginning of the experiment were as follows: maximum adsorption moisture capacity – 5.9%, wilting point – 11.8%, minimum moisture-holding capacity – 29.5%, and capillary moisture capacity – 34.5%.

In the arable soil layer, the content of key nutrients was: 35 mg/kg of soil for nitrates (NO_3^-), 45 mg/kg of soil for available phosphorus (P_2O_5), and 358 mg/kg of soil for exchangeable potassium (K_2O).

The scientific research involved the study of two factors. Factor A – soybean varieties of different maturity groups: early-maturing Krynytsia, Rizdvyana, Zlatoslava; early-ripening Aurelina, Bettina, NS Maximus. Factor B – seed inoculation with bacterial preparations: control (water treatment); Bioboost Plus (1.6 l/t); Biomag-Soy (4 l/t); Ekovital (2 l/t); Humisol (8 l/t); Optimize 400 (1.8 l/t); Rhizogumin (2 l/t).

Originators of the soybean varieties selected for the study:
- Krynytsia – Yuriev Plant Production Institute of the National Academy of Agrarian Sciences of Ukraine;
- Rizdvyana – Yuriev Plant Production Institute of the National Academy of Agrarian Sciences of Ukraine;
- Zlatoslava – National Academy of Agrarian Sciences of Ukraine;
- Aurelina – Austrian company Saatzucht Donau Ges.m.b.H. & CoKG;
- Bettina – University of Guelph (Canada);
- NS Maximus – Institute of Field and Vegetable Crops, Novi Sad (Serbia).

The main characteristics of the studied soybean varieties are presented in Table 1. All selected varieties for the experiment are resistant to drought, lodging, and shattering. Bioboost Plus – a liquid sterile inoculant containing two highly active strains of *Delftia acidovorans* and *Bradyrhizobium japonicum*. The product is manufactured by Lallemand SAS (Canada).

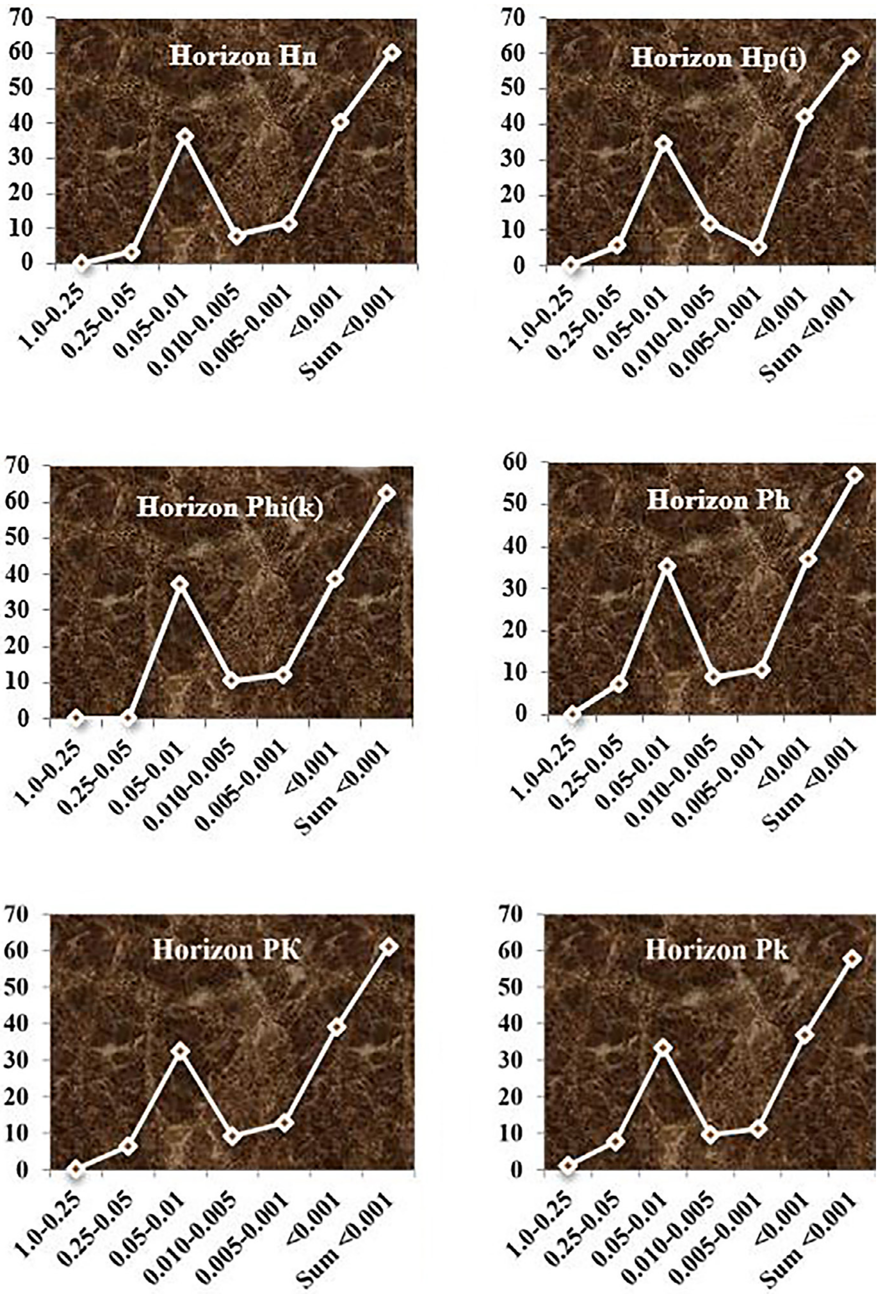

Figure 3. Fractions of granulometric composition by genetic horizons of southern black soil research plots, % based on absolutely dry non-carbonate weight

Table 1. Main characteristics of the soybean varieties grown in the experiment

Indicators	Early-maturing varieties			Early-ripening varieties		
	Krynytsia	Rizdvyana	Zlatoslava	Aurelina	Bettina	NS Maximus
Year of entry of the variety into the State Register of Ukraine	2017	2017	2018	2019	2019	2019
Vegetation period, days	100–110	90–100	90–100	110–115	107–113	110–115
Plant height, cm	65–68	70–80	80–100	65–95	65–95	68–90
Height of the lower pod attachment, cm	11–13	12–14	17–20	9–16	8–15	15–20
Crude protein content, %	39–40	39–40	39–40	40–42	36–38	35–36
Oil content, %	19–20	21–22	22–23	22–23	22–24	20–22
Weight of 1000 seeds, g	144–168	147–159	140–160	180–200	150–180	150–170

Biomag-Soy – a liquid concentrated mixture containing *Bradyrhizobium japonicum* rhizobia and their metabolic products. The producer is PJSC "Enzyme Company" (Ukraine).

Ekovital – a multi-component bacterial suspension whose main active ingredients are highly active strains of *Bradyrhizobium japonicum* and *Bacillus megaterium*. The inoculant is produced by the D.K. Zabolotny Institute of Microbiology and Virology of the National Academy of Sciences of Ukraine.

Humisol – a liquid concentrate based on biohumus that retains all the beneficial properties of vermicompost due to specialized production technologies. It contains humic substances, macro- and microelements, fulvic acids, vitamins, amino acids, phytohormones, and beneficial soil microflora. The product is manufactured by LLC "Agrofirma Hermes" (Ukraine).

Optimize 400 – a soluble concentrate from the German company Bayer CropScience AG. Active ingredients: *Bradyrhizobium japonicum* and lipochitooligosaccharide.

Rhizogumin – a bacterial suspension of *Bradyrhizobium japonicum* rhizobia, containing a complex of biologically active substances, including auxins, amino acids, humic acids, cytokinins, chelated microelements, and initial doses of macronutrients. The producer of Rhizogumin is the Institute of Agricultural Microbiology and Agro-Industrial Production of the National Academy of Agrarian Sciences of Ukraine.

The experiment was conducted in four replications, with an experimental plot area of 200 m^2 (10 × 20 m) and an accounting plot area of 107 m^2 (5.35 × 20 m).

Grain yield was measured for each experimental plot using the weight method. In the collected grain samples, the protein content was determined by measuring total nitrogen according to the Kjeldahl method (State Standard of Ukraine 7169:2010 – Feeds, compound feeds, feed raw materials. Methods for determining nitrogen and crude protein content). The oil content was measured by extraction in a Soxhlet apparatus using the method of S.V. Rushkovsky (State Standard of Ukraine 13496.15–97 – Feeds, compound feeds, feed raw materials. Methods for determining crude fat content).

The statistical analysis of the field experiment results was performed using variance analysis according to V.O. Ushkarenko's methodology, utilizing the "Agrostat" computer program [Ushkarenko et al., 2008].

Soybean was preceded by corn for grain. After harvesting, the field was disked twice to a depth of 6–8 cm and 10–12 cm. Two weeks later, plowing was carried out to a depth of 28–30 cm. In spring, harrowing was performed at a depth of 5–6 cm, followed by pre-sowing cultivation at the same depth. Nitrogen and phosphorus fertilizers (ammonium nitrate and double granulated superphosphate) were applied during pre-sowing cultivation at a rate of $N_{60}P_{30}$. Before sowing, the seeds were treated with bacterial preparations according to the experimental design. The sowing method was wide-row with 70 cm row spacing. After sowing, the field was rolled. During the growing season, inter-row cultivation, irrigation, and treatment against diseases and pests were performed. Soybeans were harvested using a New Holland combine with a Cressoni SF2 soybean header at a seed moisture content of 13–14%.

RESULTS AND DISCUSSION

The minimum yield was observed in all early-maturing soybean varieties in the control variant of the experiment. Seed inoculation with bacterial preparations significantly increased yield, as confirmed by the results of variance analysis, which validated the reliability of the obtained yield increments. The differences between variants exceeded the statistical significance threshold (Table 2).

The least impact on the yield of early-maturing soybean varieties was observed with Rhizogumin and Humisol, which increased yield by 0.08–0.17 t/ha and 0.12–0.16 t/ha, respectively. This corresponds to a 3.05–6.75% and 4.76–6.11% increase compared to the control variant with water-treated seeds.

The highest yield increase was achieved with the inoculants Ekovital and Optimize 400: 0.60–0.63 t/ha (23.81–25.00%) for the Krynytsia variety; 0.55–0.66 t/ha (20.99–25.19%) for the Rizdvyana variety; 0.54–0.65 t/ha (20.15–24.25%) for the Zlatoslava variety.

On average, across early-maturing soybean varieties, pre-sowing inoculation with Ekovital and Optimize 400 resulted in a yield of 3.17–3.25 t/ha (Figure 4a), which exceeded the control variant (water-treated seeds) by 21.46–24.52% (Figure 4b). All studied inoculants contributed to an

Table 2. Effect of seed Inoculation on the yield of early-maturing soybean varieties (average for 2021–2022)

Inoculants (factor B)	Early-maturing varieties (factor A)								
	Krynytsia			Rizdvyana			Zlatoslava		
	Yield, t/ha	Increase over control		Yield, t/ha	Increase over control		Yield, t/ha	Increase over control	
		t/ha	%		t/ha	%		t/ha	%
Control (water treatment)	2.52	–	–	2.62	–	–	2.68	–	–
Bioboost Plus	3.10	0.58	23.02	3.07	0.45	17.18	3.18	0.50	18.66
Biomag-Soy	2.88	0.36	14.29	2.97	0.35	13.36	3.05	0.37	13.81
Ekovital	3.12	0.60	23.81	3.17	0.55	20.99	3.22	0.54	20.15
Humisol	2.64	0.12	4.76	2.78	0.16	6.11	2.82	0.14	5.22
Optimize 400	3.15	0.63	25.00	3.28	0.66	25.19	3.33	0.65	24.25
Rhizogumin	2.69	0.17	6.75	2.70	0.08	3.05	2.78	0.10	3.73
LSD_{05}, t/ha	2021 – 0.11 2022 – 0.10			2021 – 0.15 2022 – 0.12			2021 – 0.13 2022 – 0.11		

increase in the yield of early-ripening soybean varieties compared to the control variant (water treatment). The yield increase for the Aurelina variety ranged from 0.07 to 0.65 t/ha or 2.15–20.00% (Table 3). The NS Maximus variety responded to pre-sowing seed inoculation with a yield increase of 0.07–0.62 t/ha or 2.19–19.44%. A slightly lower efficiency was observed for the Bettina variety, with a yield increase of 0.06–0.59 t/ha or 1.94–19.09%.

The highest yield increase in all soybean varieties was achieved using Optimize 400 and Ekovital, confirming their high efficiency in stimulating plant growth and development. The Rhizogumin inoculant resulted in the smallest yield increase compared to other bacterial preparations. Its effect fell within the experimental error range (LSD_{05}), making the yield increase statistically insignificant. A statistically significant but lowest yield increase for early-ripening soybean varieties was observed with Humisol. On average, its use resulted in a yield of 3.31 t/ha (Figure 5a), which was only 4.09% higher than the control variant (Figure 5b).

Analyzing the yield of different soybean varieties, it was noted that early-ripening varieties produced a higher yield compared to early-maturing varieties (Figure 6). This is attributed to their longer growing season and more efficient utilization of moisture and nutrients.

Among the early-maturing varieties, the lowest grain yield was recorded for the Krynytsia variety (2.87 t/ha), while the highest yield was observed for the Zlatoslava variety (3.01 t/ha) (Figure 6a). The yield increase of Zlatoslava compared to other studied early-maturing varieties

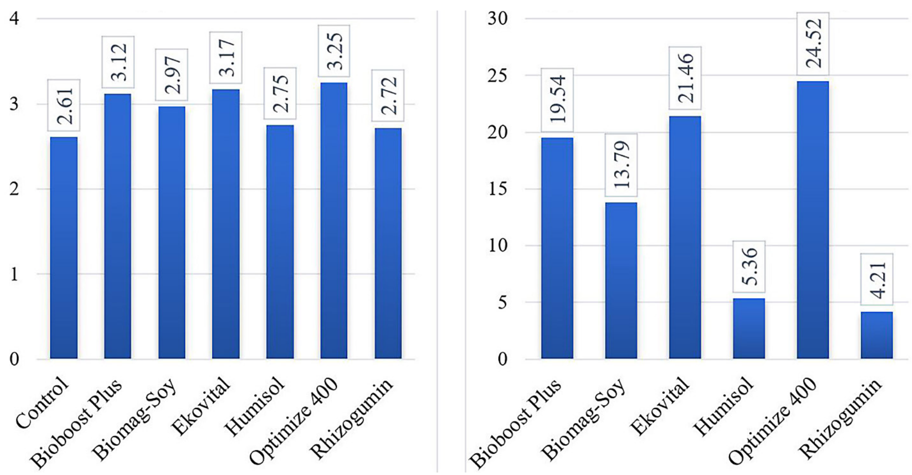

Figure 4. Average yield (t/ha) indicators of early-maturing soybean varieties (a) and their increase (%) compared to the control (b) under the influence of seed inoculation (average for 2021–2022)

Table 3. Effect of seed inoculation on the yield of early-ripening soybean varieties (average for 2021–2022)

Inoculants (factor B)	Early-ripening varieties (factor A)								
	Aurelina			Bettina			NS Maximus		
	Yield, t/ha	Increase over control		Yield, t/ha	Increase over control		Yield, t/ha	Increase over control	
		t/ha	%		t/ha	%		t/ha	%
Control (water treatment)	3.25	–	–	3.09	–	–	3.19	–	–
Bioboost Plus	3.75	0.50	15.38	3.58	0.49	15.86	3.66	0.47	14.73
Biomag-Soy	3.61	0.36	11.08	3.46	0.37	11.97	3.57	0.38	11.91
Ekovital	3.77	0.52	16.00	3.67	0.58	18.77	3.72	0.53	16.61
Humisol	3.39	0.14	4.31	3.22	0.13	4.21	3.33	0.14	4.39
Optimize 400	3.90	0.65	20.00	3.68	0.59	19.09	3.81	0.62	19.44
Rhizogumin	3.32	0.07	2.15	3.15	0.06	1.94	3.26	0.07	2.19
LSD_{05}, t/ha	2021 – 0.13 2022 – 0.10			2021 – 0.12 2022 – 0.11			2021 – 0.12 2022 – 0.10		

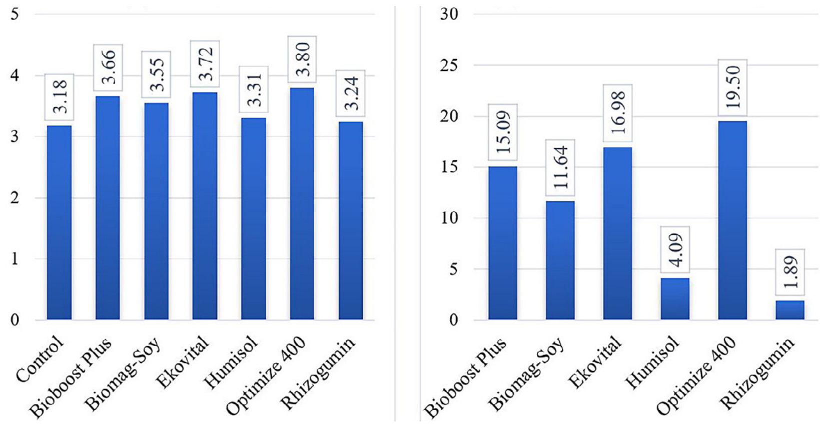

Figure 5. Average yield indicators (t/ha) of early-ripening soybean varieties (a) and their increase (%) compared to the control (b) under the influence of seed inoculation (average for 2021–2022)

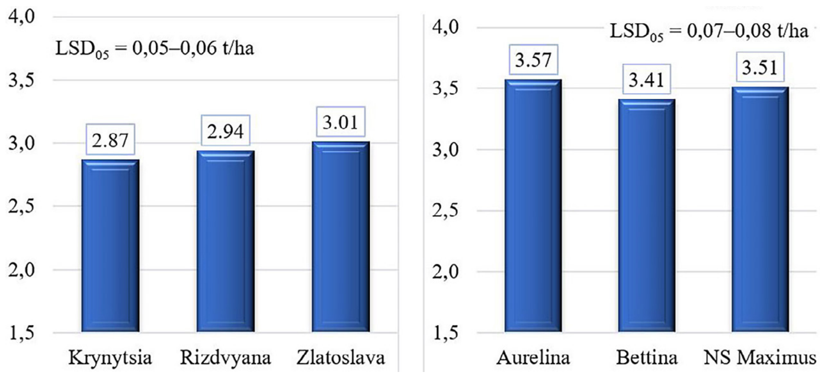

Figure 6. Average yield levels of early-maturing (a) and early-ripening (b) soybean varieties across bacterial treatments (average for 2021–2022), t/ha

exceeded the calculated critical deviation (LSD_{05} = 0.05–0.06 t/ha), indicating high potential for this variety under the soil and climatic conditions of the study area. Among the early-ripening varieties, the Bettina variety (3.41 t/ha) had a lower yield compared to Aurelina (3.57 t/ha) and NS Maximus (3.51 t/ha) (Figure 6b). The calculated critical deviation (LSD_{05}) for the yield of varieties in this maturity group was 0.07–0.08 t/ha, indicating no statistically significant differences between Aurelina and NS Maximus.

The analysis of the impact of inoculants on the protein content in soybean grain showed that all studied bacterial preparations contributed to its increase compared to the control, which provided a protein content of 37.3% (Figure 7a). The smallest increase in protein content was provided by the variants using Rhizogumin (0.5%) and Humisol (0.6%), while the highest increase was observed with Optimize 400 (1.8%) and Ekovital (1.5%) (Figure 7b). The maximum amount of protein was accumulated in the soybean grain of the variants with pre-sowing seed inoculation using Optimize 400 (39.1%) and Ekovital (38.8%), indicating the high effectiveness of these inoculants in optimizing nitrogen nutrition for soybean plants.

The minimum oil content was determined in the soybean grain of the control variant of the experiment with water-treated seeds – 19.1% (Figure 8a). Inoculation with bacterial preparations contributed to an increase in this indicator by 0.3–0.7% (Figure 8b). The lowest effectiveness regarding oil content was provided by the inoculants Ekovital and Optimize 400. With their use, the oil content increased by only 0.3% compared to the control. The maximum increase in this indicator was achieved through the inoculation of seeds with the bacterial preparation Rhizogumin – 19.8%, which exceeded the control by 0.7%.

All studied inoculants contributed to an increase in the conditional yield of protein per hectare of soybean crops compared to the control variant, where this indicator was determined at a minimum level of 1.08 t/ha (Table 4). The seed inoculation allowed for an increase in the conditional yield of protein by 0.05–0.30 t/ha or 4.63–27.78% compared to the control. The smallest increases in conditional protein yield were provided by seed inoculation with Rhizogumin (+0.05 t/ha) and Humisol (+0.07 t/ha). The highest conditional yield of protein per hectare of soybean crops was achieved with the use of Optimize 400 (1.38 t/ha,

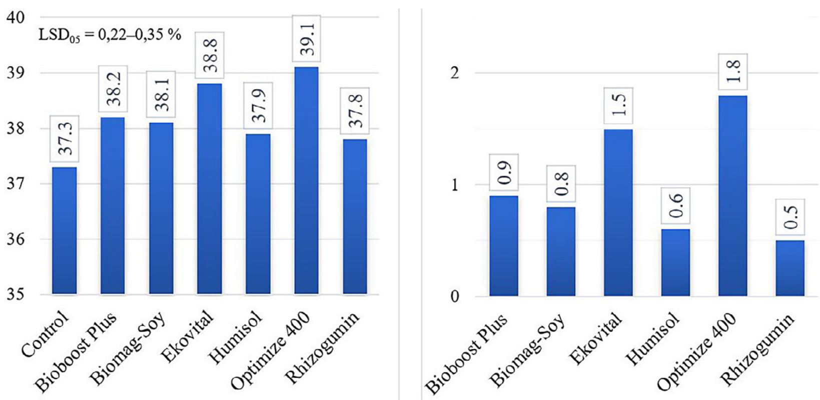

Figure 7. Protein content in soybean grain (%) under the influence of pre-sowing seed inoculation (a) and its increase compared to the control (b) (averaged data across studied varieties) (mean for 2021–2022), %

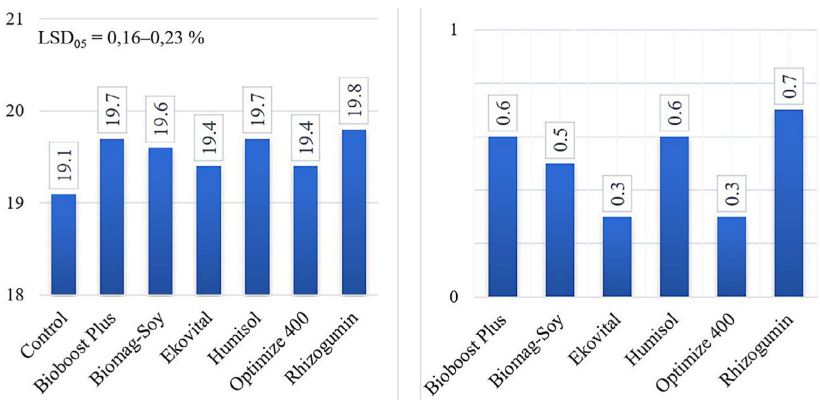

Figure 8. Oil content in soybean grain under the influence of pre-sowing seed inoculation (a) and its increase compared to the control (b) (averaged data across studied varieties) (mean for 2021–2022), %

Table 4. Conditional yield of protein and oil per hectare of soybean crops (average for 2021–2022)

Inoculants	Conditional yield of protein per hectare of crops			Conditional yield of oil per hectare of crops		
	t/ha	± compared to control		t/ha	± compared to control	
		t/ha	%		t/ha	%
Control (water treatment)	1.08	0.00	0.00	0.55	0.00	0.00
Bioboost Plus	1.29	+0.21	+19.44	0.67	+0.12	+21.82
Biomag-Soy	1.24	+0.16	+14.81	0.64	+0.09	+16.36
Ekovital	1.34	+0.26	+24.07	0.67	+0.12	+21.82
Humisol	1.15	+0.07	+6.48	0.60	+0.05	+9.09
Optimize 400	1.38	+0.30	+27.78	0.68	+0.13	+23.64
Rhizogumin	1.13	+0.05	+4.63	0.59	+0.04	+7.27

which is 0.30 t/ha more than the control) and Ekovital (1.34 t/ha, which is 0.26 t/ha more than the control), demonstrating the high effectiveness of these bacterial preparations in enhancing soybean crop productivity through improved nitrogen nutrition and protein synthesis.

Based on the research results, a positive effect of seed inoculation with bacterial preparations on the oil productivity of soybean has been established. In the control variant of the experiment, where seeds were treated with water, the conditional yield of oil was 0.55 t/ha. Bacterial inoculation increased this yield by 0.04–0.13 t/ha or 7.27–23.64%. The smallest increase in this indicator, due to a lower level of formed yield, was found in the experimental variants using Rhizogumin (0.04 t/ha or 7.27%) and Humisol (0.05 t/ha or 9.09%). The maximum values of conditional oil yield were achieved with the use of Optimize 400, Bioboost Plus, and Ekovital – 0.67–0.68 t/ha, which is 0.12–0.13 t/ha or 21.82–23.64% more compared to the control.

Our research substantiates that the application of biological approaches in the cultivation of soybean varieties, specifically the pre-sowing inoculation of seeds with various strains of nitrogen-fixing bacteria, can significantly increase yield and improve grain quality. This improvement occurs due to enhanced plant resilience to adverse conditions and stress factors. The results obtained are of great importance for developing strategies aimed at environmental conservation, increasing the productivity of this valuable leguminous crop, and supporting the sustainable development of the agricultural sector.

An analysis of scientific sources indicates the relevance of these issues, which are examined by many authors from different perspectives across various natural and climatic zones. For instance, studies conducted in arid climate conditions with limited irrigation have identified the positive impact of fertilization with complex fertilizers containing iron and water-saving irrigation on soybean productivity [El Amine et al., 2024].

Cultivating soybeans under irrigation with full watering for 90 days during the growing season, followed by cessation of watering during the grain filling and ripening phases, in combination with seed inoculation, has shown that this technology significantly mitigates the drought-induced reduction in sugar, protein, and fat content in the grains compared to non-irrigated plots. The authors of these studies [Sheteiwy et al., 2021] explain the obtained results as a weakening of stress manifestations and activation of growth processes, especially under drought conditions, due to seed inoculation. Their conclusions closely align with the results of our research.

Similar research results have been reported by other authors [Jabborova et al., 2021], who studied the effect of inoculation in soybean cultivation under non-irrigated conditions. According to their data, droughts and the stress they cause limit the productivity of agricultural crops. However, inoculation with nitrogen-fixing bacteria and rhizobacteria stimulates growth processes and increases the drought resistance of plants when grown in arid and semi-arid regions. With the increase in drought resistance due to seed inoculation, the process of nodule formation is activated, and nutrient uptake by soybean plants under drought conditions is enhanced. This is particularly attributed to the strengthening of the root system's growth. Specifically, compared to the control group, root length increased by 56%, shoot length by 33%, dry weight of the root system by 47%, and shoot weight by 48%.

Chinese researchers [Gao et al., 2021] observed an increase in the efficiency of nutrient utilization due to improved microbial conditions during soybean cultivation, which contributed to increased yields of this crop. Other researchers [Didur et al., 2023; Zhang et al., 2023] also report a positive impact of microbial inoculants on the growth processes of soybean plants and their ability to enhance grain yield.

According to research conducted in the soil-climatic conditions of South Africa, it was established that inoculation and mycorrhization of seeds alleviate plant stress from drought, promote the accumulation of greater above-ground biomass, increase yield, and enhance the fat content in soybean grains. The authors [Igiehon et al., 2021] determined that the fat content in the grains increased by 8.4%, including a higher presence of fatty acids that are beneficial for human health. Additionally, seed inoculation significantly increased the yield of large grain fractions.

Similar results regarding the effectiveness of seed inoculation, especially in combination with foliar fertilization using biopreparations, have been obtained in the soil-climatic conditions of the Forest-Steppe zone in Ukraine. Researchers [Didur et al., 2023] found that this approach contributes to a significant increase in soybean yield, reaching a maximum of 3.31 t/ha. Such positive changes are explained by the ability of this crop not only to fix atmospheric nitrogen through symbiosis with nodule bacteria but also to partially assimilate it, which significantly reduces the need for mineral fertilizers. Through biological nitrogen fixation, plants receive sufficient nitrogen to form high-quality yields while simultaneously improving soil fertility. The additional use of biopreparations in foliar fertilization enhances the effectiveness of this agricultural practice by activating metabolic processes in plants, stimulating their growth and development, and increasing their resistance to stress factors, including drought and temperature fluctuations.

According to research on the impact of mineral fertilizers and manure on the main soil properties in the subtropical conditions of Central India, it was determined that the application of these agronomic practices contributes to increased soybean productivity by improving soil fertility. The nutrition of leguminous crops, particularly soybeans, plays an important role in cultivation technology since these plants can utilize both mineral nitrogen from the soil and nitrogen symbiotically fixed by nodule bacteria. An optimal combination of these nutrient sources allows for the optimization of nitrogen supply to plants, facilitating intensive growth, high-quality yield formation, and maintaining nitrogen balance in the soil [Bangre et al., 2024].

In experimental studies conducted in the southeastern region of Poland, the impact of mineral nitrogen nutrition and seed inoculation on soybean productivity was examined. Two varieties of this crop were selected for the experiments, to which nitrogen fertilizers were applied in different doses – N_0, N_{30}, and N_{60}. A crucial element of the cultivation technology scheme was pre-sowing inoculation of seeds with *Bradyrhizobium japonicum* (HiStick® Soy and Nitragina). The results obtained showed that the comprehensive application of these agronomic measures positively influenced the formation of the crop's generative organs. In particular, the authors observed an increase in the number of pods per plant, the number of seeds per pod, and an increase in their weight. This trend confirms the appropriateness of combining nitrogen nutrition with biological inoculation, which allows for optimizing the nitrogen balance in the soil, improving the morpho-physiological indicators of plants, and enhancing their productivity under appropriate soil-climatic conditions [Szpunar-Krok et al., 2023].

In the conditions of the Subcarpathian Voivodeship in Poland, the effectiveness of various soybean seed treatment methods was studied on the Mavka variety, specifically using a new coating (chitosan + alginate/PEG) and the inoculant HiStick® Soy, which contains *Bradyrhizobium japonicum* bacteria. The research results indicated that using only coated seeds did not ensure proper nodule formation, while the application of only the inoculant positively influenced plant development but did not provide the expected planting density. The most effective approach was found to be the combination of inoculation with seed coating, which resulted in maximum yield (4.32 t/ha), whereas exclusively inoculated seeds produced a slightly lower but very close productivity (4.23 t/ha) compared to the control yield of 3.64 t/ha. The study concluded that seed coating is an effective measure only when combined with inoculation, confirming the importance of biological seed treatment for increasing soybean yield [Jarecki, 2021].

In research conducted by scientists in Brazil [Bueno et al., 2022], it was established that soybean seed inoculation promotes active plant growth and significantly improves their physiological state. Specifically, it was determined that this process directly affects the formation of a robust root system, enhances nutrient uptake, and intensifies nitrogen fixation. Furthermore, researchers found a close relationship between inoculant concentration and the need for mineral fertilizer application: when there is a sufficient number of effective nitrogen-fixing bacteria, the need for additional nitrogen nutrition significantly decreases. This indicates the promising use of biological inoculation as an environmentally safe and economically viable method for optimizing soybean nutrition.

Chinese scientists [Ai et al., 2022] report significant positive effects of rhizobacteria on activating growth processes in soybeans, increasing crop productivity, and improving the quality characteristics of the harvest. They conducted comprehensive studies under both vegetative and field conditions and found that seed inoculation contributes to the formation of a greater number of pods per plant, with an average increase of 46.78%, ultimately impacting overall yield. Additionally, under the influence of nitrogen-fixing bacteria, the technological and quality properties of the grain significantly improve: oil content increases by 5.23%, and the weight of 1000 grains rises by 9.13%, indicating the formation of full-fledged and well-formed seeds. The results obtained are consistent with our findings regarding increased oil content in soybean grain and confirm the appropriateness of using inoculation as an effective agronomic measure to enhance soybean productivity and improve its commercial properties.

Considering the value of consuming vegetable oils, research was conducted at the Variety Evaluation Research Station in Przecław (Poland) with two soybean varieties, under which different doses of nitrogen fertilizers were applied and seed inoculation was performed. The authors concluded that the quality of the grain depended on the weather conditions of the growing year, fertilizers, seed inoculation, and significantly on varietal characteristics [Szpunar-Krok and Wondołowska-Grabowska, 2022].

Studies conducted in the Right Bank Forest-Steppe of Ukraine also confirm that the variety is a determining factor in achieving high soybean grain yields. Thus, with the pre-sowing treatment of seeds using a bacterial preparation and a growth regulator, the studied varieties accumulated varying amounts of protein, fat, carbohydrates, enzymes, vitamins, and minerals in their grains based on their chemical composition. The amino acids produced by the plants differed in solubility and nutritional value. Consequently, the obtained grain yield levels varied among the varieties in the authors' studies under the same technological elements of their cultivation [Mazur et al., 2023].

Polish researchers [Szpunar-Krok and Wondołowska-Grabowska, 2022] indicate that different soybean varieties respond differently to both technological cultivation measures and changes in weather conditions, confirming the importance of selection and adaptation of varieties to specific agro-climatic zones. The results of the studies demonstrate significant variability in soybean yield levels depending on varietal characteristics, moisture conditions, and temperature regime throughout the growing season. Particular attention was paid to changes in yield quality indicators, specifically the fat content in the grains, which varied significantly depending on the weather conditions of a given year. This further confirms that the effectiveness of soybean cultivation largely depends on the combination of optimal agronomic practices, weather factors, and the genetic potential of the variety.

In studies conducted in southeastern Poland, the response of two soybean varieties (Aldana and Annushka) to the application of mineral fertilizers at doses of N_{30} and N_{60} was examined, as well as to pre-sowing inoculation of seeds with different strains of nitrogen-fixing bacteria. The authors [Szpunar-Krok et al., 2021] established that the studied varieties exhibited differentiated responses to nitrogen nutrition levels, as well as significant variability in indicators depending on the weather conditions during the years of cultivation and the type of inoculant used. Specifically, it was determined that these factors significantly influenced primarily the fat content in the grains and its fatty acid composition, which are fundamental to soybean yield quality. Based on the conducted research, Polish scientists concluded that the selection of varieties for cultivation should consider not only their adaptive potential and yield level but also the dynamics of changes in the chemical composition of grains depending on agronomic and climatic factors. Similar trends are also observed in our research conducted in the context of soil-climatic conditions in the Southern Steppe of Ukraine, further confirming the relevance of our findings.

CONCLUSIONS

Seed inoculation with bacterial preparations significantly increases the yield of early-ripening soybean varieties. The minimum yield level was formed in the control variant with water-treated seeds. The lowest effectiveness was determined with the use of Rhizogumin and Humisol. The maximum yield increase was provided by Ekovital and Optimize 400 – up to 25% compared to the control. The average yield when using these inoculants reached 3.17–3.25 t/ha, which justifies their use for increasing the productivity of early-ripening soybean varieties.

All studied inoculants increased the yield of early-ripening soybean varieties; however, their effectiveness varied. The highest yield increase was achieved with the inoculants Optimize 400 and Ekovital, confirming their ability to stimulate plant growth and development significantly. The smallest effect was observed with Rhizogumin, where the yield increase was statistically insignificant. The inoculant Humisol also demonstrated low effectiveness, providing only a 4% increase in yield.

Analysis of the research results revealed a higher yield of early-ripening soybean varieties compared to early-maturing varieties, which can be explained by their longer growing period and prolonged utilization of water and nutrients. Among the early-maturing varieties, Zlatoslava was identified as the most productive, exceeding the critical deviation (LSD_{05}) and demonstrating high potential in the study area. Among early-ripening varieties, Aurelina provided the highest yield, although there were no statistically significant differences between it and the NS Maximus variety. This indicates similar levels of productivity for these varieties and their prospects for cultivation in the research region.

Seed inoculation confirmed the effectiveness of bacterial preparations in increasing protein and oil content in soybean grain. The most effective inoculants for increasing protein content were Optimize 400 and Ekovital, while Rhizogumin was most effective for oil content. All studied bacterial preparations contributed to an increase in the conditional yield of protein and oil per hectare of crops. Seed bacterization provided an increase in conditional protein yield by 4.63–27.78% and oil yield by 7.27–23.64% compared to the control (water treatment). The lowest indicators of conditional protein and oil yields were found in variants using Rhizogumin and Humisol, while the highest were achieved with Optimize 400 and Ekovital.

REFERENCES

1. Ai W., Guo T., Lay K.D., Ou K., Cai K., Ding Y., Liu J., Cao Y. (2022). Isolation of soybean-specific plant growth-promoting rhizobacteria using soybean agglutin and evaluation of their effects to improve soybean growth, yield, and soil nutritional status. *Microbiological Research, 261*, 127076. https://doi.org/10.1016/j.micres.2022.127076
2. Bangre J., Sinha N.K., Mohanty M., Jayaraman S., Sahoo R.N., Dwivedi A.K., Singh D., Mishra A., Kumar S., Wanjari R., Jha P., Kumar D., Mishra R., Mandloi S., Singh U.K., Chaudhary R., Reddy K.S., Prabhakar M., Singh V.K., Rao C.S. (2024). Long-term impact of inorganic fertilizers and farmyard manure on soil quality and productivity in subtropical Vertisols under a soybean-wheat cropping system. *Land Degradation & Development, 35*(14), 4257–4270. https://doi.org/10.1002/ldr.5220
3. Bogonos M., Chmil A. (2023). Development of agricultural trade between Ukraine and EU. German-Ukrainian Agricultural Policy Dialogue (APD), 71.
4. Bueno C.B., Dos Santos R.M., de Souza Buzo F., de Andrade da Silva M.S.R., Rigobelo E.C. (2022). Effects of chemical fertilization and microbial inoculum on Bacillus subtilis colonization in soybean and maize plants. *Frontiers in Microbiology, 13*, 901157. https://doi.org/10.3389/fmicb.2022.901157
5. Dayoub E., Lamichhane J.R., Schoving C., Debaeke P., Maury P. (2021). Early-stage phenotyping of root traits provides insights into the drought tolerance level of soybean cultivars. *Agronomy, 11*(1), 188. https://doi.org/10.3390/agronomy11010188
6. Didur I., Tsyhanskyi V., Tsyhanska O. (2023). Influence of biologisation of the nutrition system on the transformation of biological nitrogen and formation of soybean productivity. *Plant & Soil Science, 14*(4). https://doi.org/10.31548/plant4.2023.86
7. Dong L., Fang C., Cheng Q., Su T., Kou K., Kong L., Zhang C., Li H., Hou Z., Zhang Y., Chen L., Yue L., Wang L., Wang K., Li Y., Gan Z., Yuan X., Weller J.L., Lu S., Kong F., Liu B. (2021). Genetic basis and adaptation trajectory of soybean from its temperate origin to tropics. *Nature Communications, 12*(1), 5445. https://doi.org/10.1038/s41467-021-25800-3
8. El Amine B., Mosseddaq F., Houssa A.A., Bouaziz A., Moughli L., Oukarroum A. (2024). How far can the interactive effects of continuous deficit irrigation and foliar iron fertilization improve the physiological and agronomic status of soybeans grown in

calcareous soils under arid climate conditions? *Agricultural Water Management, 300*, 108926. https://doi.org/10.1016/j.agwat.2024.108926

9. Filassi M., de Oliveira A.L.R. (2021). Competitiveness drivers for soybean exportation and the fundamental role of the supply chain. *Revista de Economia e Sociologia Rural, 60*, 235296. https://doi.org/10.1590/1806-9479.2021.235296
10. Gao W., Gao K., Guo Z., Liu Y., Jiang L., Liu C., Liu X., Wang G. (2021). Different responses of soil bacterial and fungal communities to 3 years of biochar amendment in an alkaline soybean soil. *Frontiers in Microbiology, 12*, 630418. https://doi.org/10.3389/fmicb.2021.630418
11. Guo B., Sun L., Jiang S., Ren H., Sun R., Wei Z., Hong H., Luan X., Wang J., Wang X., Xu D., Li W., Guo C., Qiu L.J. (2022). Soybean genetic resources contributing to sustainable protein production. *Theoretical and Applied Genetics, 135*(11), 4095–4121. https://doi.org/10.1007/s00122-022-04222-9
12. Hughes J., Pearson E., Grafenauer S. (2022). Legumes – a comprehensive exploration of global food-based dietary guidelines and consumption. *Nutrients, 14*(15), 3080. https://doi.org/10.3390/nu14153080
13. Igiehon N.O., Babalola O.O., Cheseto X., Torto B. (2021). Effects of rhizobia and arbuscular mycorrhizal fungi on yield, size distribution and fatty acid of soybean seeds grown under drought stress. *Microbiological Research, 242*, 126640. https://doi.org/10.1016/j.micres.2020.126640
14. Ivaniv M., Vozniak V., Marchenko T., Baklanova T., Sydiakina O. (2023). Varietal features of elements of soybean cultivation technology during irrigation. *Scientific Horizons, 26*(6), 85–96. https://doi.org/10.48077/scihor6.2023.85
15. Jabborova D., Kannepalli A., Davranov K., Narimanov A., Enakiev Y., Syed A., Elgorban A.M., Bahkali A.H., Wirth S., Sayyed R.Z., Gafur A. (2021). Co-inoculation of rhizobacteria promotes growth, yield, and nutrient contents in soybean and improves soil enzymes and nutrients under drought conditions. *Scientific Reports, 11*(1), 22081. https://doi.org/10.1038/s41598-021-01337-9
16. Jarecki W. (2021). Soybean response to seed coating with Chitosan + Alginate/PEG and/or inoculation. *Agronomy, 11*(9), 1737. https://doi.org/10.3390/agronomy11091737
17. Kulig B., Klimek-Kopyra A. (2022). Sowing date and fertilization level are effective elements increasing soybean productivity in rainfall deficit conditions in Central Europe. *Agriculture, 13*(1), 115. https://doi.org/10.3390/agriculture13010115
18. Luo X., Yin M., He Y. (2021). Molecular genetic understanding of photoperiodic regulation of flowering time in Arabidopsis and soybean. *International journal of molecular sciences, 23*(1), 466. https://doi.org/10.3390/ijms23010466
19. Mazur V., Alieksieieva O., Mazur K., Alieksieiev O. (2023). Ecological and economic aspects of the formation of highly productive soybean crops. *Journal of Ecological Engineering, 24*(12), 124–129. https://doi.org/10.12911/22998993/173008
20. Mazur V.A., Tkachuk O.P., Pantsyreva G.V., Kupchuk I.M. (2022). *Soybean in intensive farming.* Vinnytsia: «Nilan-LTD», 220.
21. Nair R.M., Boddepalli V.N., Yan M.R., Kumar V., Gill B., Pan R.S., Wang C., Hartman G.L., Souza R.S., Somta P. (2023). Global status of vegetable soybean. *Plants, 12*(3), 609. https://doi.org/10.3390/plants12030609
22. Official site of Food and Agriculture Organization of the United Nations. Available online: https://www.fao.org/home/en (accessed on 22 February 2025).
23. Peng L., Bahadoran A., Sheidaei S., Ahranjani P.J., Kamyab H., Oryani B., Arain S.S., Rezania S. (2024). Magnetic graphene oxide supported tin oxide (SnO) nanocomposite as a heterogeneous catalyst for biodiesel production from soybean oil. *Renewable Energy, 224*, 120050. https://doi.org/10.1016/j.renene.2024.120050
24. Rahman S.U., McCoy E., Raza G., Ali Z., Mansoor S., Amin I. (2023). Improvement of soybean; A way forward transition from genetic engineering to new plant breeding technologies. *Molecular Biotechnology, 65*(2), 162–180. https://doi.org/10.1007/s12033-022-00456-6
25. Sheteiwy M.S., Abd Elgawad H., Xiong Y.C., Macovei A., Brestic M., Skalicky M., Shaghaleh H., Hamoud Y.A., El-Sawah A.M. (2021). Inoculation with Bacillus amyloliquefaciens and mycorrhiza confers tolerance to drought stress and improve seed yield and quality of soybean plant. *Physiologia Plantarum, 172*(4), 2153–2169. https://doi.org/10.1111/ppl.13454
26. Siamabele B. (2020). Soybeans production, driving factors, and climate change perspectives. *Journal for Creativity, Innovation and Social Entrepreneurship (JCISE), 4*(2), 113–133.
27. Singh P., Krishnaswamy K. 2022. Sustainable zero-waste processing system for soybeans and soy by-product valorization. *Trends in Food Science & Technology, 128*, 331–344. https://doi.org/10.1016/j.tifs.2022.08.015
28. Song W., Liu L., Sun S., Wu T., Zeng H., Tian S., Bincheng Sun B., Wenbin Li W., Liu L., Wang S., Xing H., Zhou H., Nian H., Lu W., Han X., Wang S., Chen W., Guo T., Song X., Tian Z., Han T. (2023). Precise classification and regional delineation of maturity groups in soybean cultivars across China. *European Journal of Agronomy, 151*, 126982. https://doi.org/10.1016/j.eja.2023.126982

29. Soybeans. Agricultural Market Information System. Available online: http://www.amis-outlook.org/amis-about/amis-crops/crops-soybeans/en/ (accessed on 22 February 2025).
30. Staniak M., Szpunar-Krok E., Kocira A. (2023). Responses of soybean to selected abiotic stresses – Photoperiod, temperature and water. *Agriculture, 13*(1), 146. https://doi.org/10.3390/agriculture13010146
31. Szpunar-Krok E., Bobrecka-Jamro D., Pikuła W., Jańczak-Pieniążek M. (2023). Effect of nitrogen fertilization and inoculation with Bradyrhizobium japonicum on nodulation and yielding of soybean. *Agronomy, 13*(5), 1341. https://doi.org/10.3390/agronomy13051341
32. Szpunar-Krok E., Wondołowska-Grabowska A. (2022). Quality evaluation indices for soybean oil in relation to cultivar, application of N fertiliser and seed inoculation with Bradyrhizobium japonicum. *Foods, 11*(5), 762. https://doi.org/10.3390/foods11050762
33. Szpunar-Krok E., Wondołowska-Grabowska A., Bobrecka-Jamro D., Jańczak-Pieniążek M., Kotecki A., Kozak M. (2021). Effect of nitrogen fertilisation and inoculation with Bradyrhizobium japonicum on the fatty acid profile of soybean (*Glycine max* (L.) Merrill) seeds. *Agronomy, 11*(5), 941. https://doi.org/10.3390/agronomy11050941
34. Ushkarenko V.O., Nikishenko V.L., Holoborodko S.P., Kokovikhin S.V. (2008). *Dispersion-correlation analysis in agricultural and plant husbandry*. Kherson: Ailant, 272.
35. Vogel J.T., Liu W., Olhoft P., Crafts-Brandner S.J., Pennycooke J.C., Christiansen N. (2021). Soybean yield formation physiology – a foundation for precision breeding based improvement. *Frontiers in plant science, 12*, 719706. https://doi.org/10.3389/fpls.2021.719706
36. Yu S.F., Wang C.L., Hu Y.F., Wen Y.C., Sun Z.B. (2022). Biocontrol of three severe diseases in soybean. *Agriculture, 12*(9), 1391. https://doi.org/10.3390/agriculture12091391
37. Zhang W., Mao G., Zhuang J., Yang H. (2023). The co-inoculation of Pseudomonas chlororaphis H1 and Bacillus altitudinis Y1 promoted soybean [*Glycine max* (L.) Merrill] growth and increased the relative abundance of beneficial microorganisms in rhizosphere and root. *Frontiers in Microbiology, 13*, 1079348. https://doi.org/10.3389/fmicb.2022.1079348