https://doi.org/10.15407/frg2026.05.396
UDC 633.34:631.847.211:581.557:632.937

EFFICIENCY OF SOYBEAN INOCULATION WITH ACTIVE STRAINS OF NODULE BACTERIA UNDER SEED TREATMENT WITH BIOLOGICAL FUNGICIDES

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Under pot experiment conditions, the influence of soybean inoculation with nodule bacteria *Bradyrhizobium japonicum* B78 and B144 in combination with seed treatment with the biological fungicides Mycosan-N and Phytocid-r on the processes of formation and functioning of the legume—rhizobial symbiosis, plant growth, and grain productivity was studied. An increase in the number of root nodules at the third trifoliolate stage by 8.3—10.6 %, and in their weight by 19—27.8 % under the combined application of *B. japonicum* B78 with biofungicides compared with treatment with inoculants alone was revealed. At the beginning of bloom and full bloom stages, an increase in the number of root nodules on the plants inoculated with rhizobia of both strains under the influence of Mycosan-N by 5.8—21.3 %, and an increase in their weight by 9.3—27.1 % were observed. Under the combined application of *B. japonicum* B78 with Phytocid-r, the increase in the studied parameters amounted to 6.3 and 7.9 %, respectively, only at the beginning of bloom stage. An increase in the nitrogen-fixing activity (NFA) of symbiotic systems under soybean seed treatment with *B. japonicum* B78 and Mycosan-N by 13.0 and 7.8 % at the third trifoliolate stage and budding, respectively, was revealed. In soybean inoculated with *B. japonicum* B144 and treated with this biofungicide, NFA exceeded that of the control plants by 8.8 % only at the beginning of bloom stage. Under the action of Phytocid-r and inoculation with rhizobia B78, an increase in NFA according to the data of three samplings by 6.2—14.6 % was observed. In plants treated with *B. japonicum* B144 and Phytocid-r, a decrease in the studied parameter during vegetation by 7.9—18.3 % was revealed. It was established that seed bacterization with rhizobia both in combination with biofungicides and without their application promoted an increase in the weight of the aboveground part of soybean plants and roots during vegetation compared with plants without pre-sowing treatment. An increase in the grain productivity of soybean plants by 7.6 and 11.5 % was revealed under the combined seed treatment with *B. japonicum* B144 and B78 together with Mycosan-N. Under the combined application of nodule bacteria with Phytocid-r, soybean grain productivity was at the level of the plants of the respective controls (treated with inoculants without biofungicides). Thus, the scientifically substantiated selection of nodule bacteria and biofungicides for application in soybean cultivation technologies makes it possible to ensure the active functioning of a powerful symbiotic apparatus and an increase in grain productivity.

Citation: Kukol K.P., Vorobey N.A., Pukhtaievych P.P., Dovhan A.A., Kots S.Ya. Efficiency of soybean inoculation with active strains of nodule bacteria under seed treatment with biological fungicides. *Fiziol. rosl. genet.*, 2026, 58, No. 5, pp. 396—407. https://doi.org/10.15407/frg2026.05.396

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Key words: *Bradyrhizobium japonicum*, soybean, inoculation, biological fungicides, number and weight of nodules, nitrogen-fixing activity, grain productivity.

In the domestic Ukrainian agrarian market, soybean for many years has held a leading position alongside grain crops in export and production for food and feed purposes, and is also of strategically important significance in ensuring the food and economic security of the country [1]. The fixation of atmospheric nitrogen by microorganisms is of considerable importance in the overall nitrogen balance in the soil. A particular role in this process belongs to bacteria that assimilate atmospheric N_2 in symbiosis with legume plants [2].

Soybean grain yield is positively correlated with total nitrogen uptake, with 44—72 % typically attributed to the biological pathway of nitrogen supply [3]. The active functioning of legume-rhizobial symbiosis ensures an increase in soybean yield, even when this crop is sown on soils with a low or medium level of this element. At the same time, after soybean cultivation, an almost neutral N balance in the soil can be achieved [4, 5]. Therefore, microbial preparations based on active competitive strains of nodule bacteria are widely used on farms of various ownership forms.

In many countries worldwide, the most widespread method of controlling the development of phytopathogenic microorganisms is the chemical method, which involves the use of artificially synthesized substances. The use of pesticides is driven by the necessity of preserving agricultural crop yields; consequently, pesticides continuously circulate in the environment. A hazard is posed not only by the active ingredients of chemical preparations, but also by their metabolic products. With repeated application of persistent pesticides, the soil may become a source of contamination of crop production. In general, pesticide application may cause such negative consequences as a reduction in biological productivity, disruption of soil microbial community functioning, and accumulation of residues of active ingredients and their derivatives in surface water bodies and groundwater [6]. In this regard, there is a need to comprehensively investigate environmentally safe plant protection products (PPPs) in order to identify and apply the most biologically and economically effective ones [7].

In accordance with the adopted concept of phytosanitary optimization of crop production, the 21st century is witnessing a transition from the total use of chemical agents to the application of environmentally safe plant protection methods. One of the approaches to implementing this program is the use of bioagents that regulate the abundance of harmful organisms [8].

It has been established that the proportion of cultivated areas treated with biological PPPs in Ukraine over the past 20 years accounts for only 2.9—8.5 % of the total areas where protective measures are carried out. The introduction of biological preparations based on new microbial strains and their introduction into agrocenoses will make it possible to improve the phytosanitary conditions through a substantial reduction in pesticide load, and to obtain high-quality, environmentally safe products with high competitiveness on both the Ukrainian and European markets [9].

A new direction in the development and use of PPPs against diseases is the stimulation of protective mechanisms of cultivated crops using myco-

biopreparations based on chitin—glucan complexes of fungal origin. In particular, researchers have developed a technology and obtained a biologically active composition based on fungal glucans of the tinder fungus (*Fomes fomentarius*), which formed the basis of the biofungicide Mycosan, intended for seed and vegetating plant treatment (Mycosan-N and Mycosan-V, respectively) [10]. It is known that *F. fomentarius* is a wood-decaying bracket fungus that is well recognized for its wide range of biotechnological applications, including in agricultural production [11].

In many countries worldwide, biopesticides based on bacteria of various species belonging to the genus *Bacillus* are produced. For this purpose, strains of *Bacillus subtilis* are widely used, which, according to numerous studies, are characterized by pronounced growth-stimulating properties and antagonistic activity against a wide spectrum of phytopathogens *in vitro* in pot and field experiments. A reduction in plant disease incidence through the application of preparations based on *B. subtilis* may result from the action of multiple mechanisms, including not only plant growth stimulation, but also antibiosis, competition for space and nutrients, lysis of pathogen hyphae, and induced systemic resistance. Most isolates of *B. subtilis* demonstrate several mechanisms that may affect pathogenesis directly or indirectly [12].

Taking into account the expediency of combining the processes of soybean bacterization and seed treatment with environmentally safe PPPs, studies on the efficiency of seed inoculation with active rhizobial strains under the effect of biopreparations with fungicidal activity are of considerable relevance.

Material and Methods

A pot experiment was conducted with soybean plants (*Glycine max* (L.) Merr.) of the cultivar Diadema Podillia (breeder — Institute of Feed Research & Agriculture of Podillia NAAS; year of registration — 2015; recommended growing zone — Polissia, Steppe; maturity group and use type — early-maturing, grain-type.

Nodule bacteria *B. japonicum* B78 and B144, obtained through transposon mutagenesis of *B. japonicum* 646 with *E. coli* S17-1 harboring the plasmid pSUP5011::Tn5*mob* were used. These rhizobia are preserved in the collection of symbiotic and associative nitrogen-fixing microorganisms of the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine (IPPG NASU).

The following biofungicides were used in the study: Mycosan-N, a 3 % alkaline extract of the aphyllophoroid fungus *F. fomentarius*, with an application rate of working solution of 10 L/t of seed; Phytocid-r, containing viable cells of *B. subtilis* at a concentration of not less than 10^9 CFU/cm^3, with an application rate for soybean seed treatment of 1—2 L/t. For the experiments, 100 mL working solutions of the biofungicidal preparations included in the study were prepared according to the application rates recommended by the manufacturer.

The experimental design included the following variants of pre-sowing seed treatment: 1) Without inoculation and biofungicides (control 1); 2) *B. japonicum* B78 (control 2); 3) *B. japonicum* B78 + Mycosan-N; 4) *B. japo-*

nicum B78 + Phytocid-r; 5) *B. japonicum* B144 (control 3); 6) *B. japonicum* B144 + Mycosan-N; 7) *B. japonicum* B144 + Phytocid-r.

To prepare inoculation suspensions, the biomass of nodule bacteria was washed from the surface of the agar nutrient medium with water. The duration of seed bacterization was 60 min. The infectious load was 10^9 cells/mL. In the control, inoculated seeds were not treated with biofungicides.

Soybean was grown at 10 plants per 15-kg pot, previously sterilized with a 20 % H_2O_2 solution, on river sand supplemented with Hellriegel's nutrient mixture enriched with the microelements molybdenum, boron, and copper, and nitrogen-depleted to 0.25 of the standard rate (one standard rate corresponding to 708 mg $Ca(NO_3)_2 \cdot 4H_2O$ per kg of sand), under natural lighting and optimal water supply (60 % of field capacity), on a specially equipped experimental plot of the IPPG NAS of Ukraine. The experiment was conducted with six replications.

Plant sampling was performed at the third trifoliolate (V3), beginning bloom (R1), and full bloom (R2) stages. The nitrogen-fixing activity of soybean root nodules was determined by the acetylene reduction method [14] and expressed in micromoles of ethylene produced by the nodules of one plant per 1 hour. The gas mixture was analyzed using an Agilent Technologies 6850 Network GC System gas chromatograph (USA). Gases were separated on a column (Supelco Porapak N) at a thermostat temperature of 55 °C and a detector temperature of 150 °C. Nitrogen was used as the carrier gas (50 mL/min), and determinations were performed in four replications.

Biometric parameters — fresh weight of the aboveground part of plants, roots, and nodules — were determined in ten replications.

Statistical processing of experimental data was performed using the Microsoft Excel 2019 software package. The tables present arithmetic mean values and their standard errors.

Results and Discussion

An increase in the number of root nodules at the third trifoliolate stage (V3) by 8.3—10.6 % and in their weight by 19.0—27.8 % was observed under the combined application of *B. japonicum* B78 with the biofungicides Phytocid-r and Mycosan-N, compared with treatment using inoculants alone (controls 2 and 3) (Table 1). An increase in 15.5 % in the weight of root nodules formed with the participation of *B. japonicum* B144 was observed under Mycosan-N seed treatment. At the beginning of bloom stage (R1), an increase in the number of nodules formed on the roots was found in the variants with inoculation using rhizobia of both strains under Mycosan-N treatment — by 7.7—21.3 % — as well as an increase in their weight by 14.1—27.1 %, compared with the plants of the corresponding controls. Under the combined application of Phytocid-r with the inoculant based on *B. japonicum* B78, the increase in the parameters studied amounted to 6.3 % and 7.9 %, respectively. At the same time, under the effect of this biofungicide on rhizobia of strain B144, a decrease of 5.2 % in nodule number was observed at the beginning of bloom stage (R1), whereas nodule weight was at the level in the control plants. At the full bloom stage

TABLE 1. Number and weight of nodules (per plant) on soybean plants of Diadema Podillia cultivar under treatment with biofungicides and inoculation with nodule bacteria

Treatment	Plant growth stage					
	Third trifoliolate (V3)		Beginning of bloom (R1)		Fooll bloom (R2)	
	Number, pcs	Weight, g	Number, pcs	Weight, g	Number, pcs	Weight, g
Without inoculation and biofungicide (control 1)	0	0	0	0	0	0
B. japonicum B78 (control 2)	30.3±1.5	0.079±0.004	35.2±1.8	0.277±0.015	38.2±1.7	0.627±0.030
B. japonicum B78 + Mycosan-N	33.5±1.6	0.101±0.006	42.7±2.6	0.352±0.017	40.4±2.0	0.685±0.034
B. japonicum B78 + Phytocid-r	32.8±1.4	0.094±0.005	37.4±2.4	0.299±0.014	39.0±1.9	0.622±0.027
B. japonicum B144 (control 3)	26.2±1.3	0.058±0.002	28.7±1.3	0.157±0.007	29.0±1.4	0.588±0.026
B. japonicum B144 + Mycosan-N	24.9±1.2	0.067±0.003	30.9±1.5	0.179±0.008	34.7±1.8	0.652±0.029
B. japonicum B144 + Phytocid-r	18.2±0.8	0.043±0.002	27.2±1.0	0.160±0.007	29.5±1.2	0.618±0.030

(R2), under seed treatment with nodule bacteria combined with Mycosan-N, an increase in the number of root nodules by 5.8—19.7 % and in their weight by 9.3—10.9 % was observed, whereas under Phytocid-r treatment these parameters were at the level in the control plants.

An increase in the nitrogen-fixing activity (NFA) of symbiotic systems was found under seed treatment with *B. japonicum* B78 combined with Mycosan-N — by 13.0 % at the third trifoliolate stage (V3) and by 7.8 % at the beginning of bloom stage (R1) — compared with the control 2 plants (Table 2). In soybean inoculated with *B. japonicum* B144 and treated with this biofungicide, NFA at the third trifoliolate (V3) and full bloom (R2) stages was at the level of the control 3 plants, whereas at the beginning of bloom stage (R1) it exceeded the latter by 8.8 %.

Under the effect of Phytocid-r combined with inoculation using rhizobia B78 strain, an increase in NFA compared with the control plants was observed — by 6.2 % at the third trifoliolate stage (V3), by 14.6 % at the beginning of bloom stage (R1), and by 7.2 % at the full bloom stage (R2). In plants whose seeds were treated with nodule bacteria B144 strain combined with Phytocid-r, a decrease in the parameter studied throughout the entire growing season of 7.9—18.3 % was found compared with the control plants.

It was revealed that seed bacterization with rhizobia, both in combination with biofungicides and without their use, contributed to an increase in the fresh weight of the aboveground part and roots of soybean plants throughout the growing season, compared with untreated plants. The combined seed treatment of soybean with *B. japonicum* B78 and Mycosan-N contributed to an increase in root weight by 4.9 % at the third trifoliolate stage (V3), 7.2 % at the beginning of bloom stage (R1), and 8.0 % at the full bloom stage (R2) (Table 3). Throughout the entire growing season, the

TABLE 2. Nitrogen-fixing activity in soybean plants of Diadema Podillia cultivar (μmol C_2H_4/(plant·h)) under treatment with biofungicides and inoculation with nodule bacteria

Treatment	Plant growth stage		
	Third trifoliolate (V3)	Beginning of bloom (R1)	Fooll bloom (R2)
Without inoculation and biofungicide (control 1)	0	0	0
B. japonicum B78 (control 2)	1.61±0.08	8.99±0.42	14.54±0.73
B. japonicum B78 + Mycosan-N	1.82±0.09	9.69±0.48	14.70±0.75
B. japonicum B78 + Phytocid-r	1.71±0.08	10.3±0.55	15.58±0.80
B. japonicum B144 (control 3)	1.70±0.07	7.20±0.36	15.54±0.77
B. japonicum B144 + Mycosan-N	1.75±0.08	7.83±0.40	15.45±0.60
B. japonicum B144 + Phytocid-r	1.43±0.06	6.44±0.32	14.32±0.65

aboveground weight of soybean in this treatment was at the level of the plants treated with the inoculant alone.

Under Phytocid-r treatment combined with B78 bacterization, a decrease in the aboveground weight of soybean plants compared with the control was observed by 5.4 % — only at the third trifoliolate stage (V3). In plants of this treatment, an increase in root weight of 21.3 % and 10.1 % was found at the third trifoliolate (V3) and beginning of bloom (R1) stages, respectively.

Under pre-sowing application of *B. japonicum* B144 combined with Mycosan-N, a slight decrease in the aboveground weight of plants by 4.5—10.6 % and in root weight by 6.1—9.5 % was observed throughout the growing season compared with the control 3 plants. A similar tendency was

TABLE 3. Aboveground and root weight (g/plant) of soybean plants grown under the effect of biofungicides and inoculation with nodule bacteria

Treatment	Plant growth stage					
	Third trifoliolate (V3)		Beginning of bloom (R1)		Fooll bloom (R2)	
	Aboveground weight	Root weight	Aboveground weight	Root weight	Aboveground weight	Root weight
Without inoculation and biofungicide (control 1)	4.25±0.21	0.82±0.04	5.60±0.27	4.01±0.28	8.35±0.41	6.90±0.33
B. japonicum B78 (control 2)	4.59±0.19	1.03±0.04	7.29±0.34	5.14±0.21	14.54±0.65	8.04±0.39
B. japonicum B78 + Mycosan-N	4.71±0.22	1.08±0.05	7.23±0.30	5.51±0.24	14.59±0.67	8.68±0.35
B. japonicum B78 + Phytocid-r	4.34±0.17	1.45±0.07	7.70±0.37	5.66±0.25	14.87±0.70	8.04±0.40
B. japonicum B144 (control 3)	4.55±0.14	0.93±0.05	7.10±0.30	6.03±0.24	12.28±0.61	6.67±0.31
B. japonicum B144 + Mycosan-N	4.17±0.18	0.86±0.05	6.35±0.27	5.66±0.24	11.72±0.55	6.15±0.26
B. japonicum B144 + Phytocid-r	4.31±0.15	1.06±0.05	6.48±0.29	6.57±0.29	10.91±0.47	7.92±0.37

also found under the combined seed treatment with rhizobia of B144 strain and Phytocid-r. The decrease in aboveground weight of plants compared with the control (inoculation without biofungicides) amounted to 5.3 % at the third trifoliolate stage (V3), 8.7 % at the beginning of bloom stage (R1), and 11.1 % at the full bloom stage (R2). Root weight of soybean in this treatment exceeded that of the control plants by 14.0 %, 9.0 %, and 7.5 % at the third trifoliolate (V3), beginning bloom (R1), and full bloom (R2) stages, respectively (see Table 3).

The results of our previous studies, as well as data obtained by other authors, also indicate the presence of an effect of cultivar-specific characteristics of the crop on the efficiency of plant—microbial interaction in agrobiocenoses [15, 16]. That is, genotypic differences in plants may determine the intensity of the formation of associative and symbiotic relationships, the level of root system colonization by microorganisms, as well as the nature of the physiological and biochemical response of plants to inoculation [17, 18]. Taking into account cultivar-specific characteristics is an important prerequisite for increasing the efficiency of microbial preparation application in modern agrotechnologies.

The results indicate the strain-specificity of the interaction between nodule bacteria and biofungicides, which is also consistent with current understanding of the complex nature of effective symbiosis formation. The increase in symbiotic parameters under Mycosan-N application may be associated with the activation of physiological and biochemical processes in plants and the stimulation of the nodulation capacity of rhizobia. At the same time, their slight decrease under the combined application of strain B144 and Phytocid-r may indicate certain specific features of intermicrobial interaction between nodule bacteria and representatives of the genus *Bacillus*, conditioned by the synthesis of specific metabolites [19, 20].

It is known that the individual productivity of plants reflects the effect of the factors under study on the realization of the biological and genetic potential of cultivars. The lowerst level of grain productivity of soybean cultivar Diadema Podillia was found in plants grown without the application of inoculants and biofungicides (Table 4). From control 2 and control 3 plants, which were bacterized with rhizobia prior to sowing, 2.70 and 2.51 g/plant were harvested, respectively, which is 2.2 and 2.0 times higher compared with control 1, where the corresponding parameter amounted to only 1.22 g/plant. An increase in grain productivity of soybean plants by 7.6 % and 11.5 % was found under the combined seed treatment with *B. japonicum* B144 and B78 combined with Mycosan-N. Under the combined application of nodule bacteria with Phytocid-r, the grain productivity of soybean plants was at the level of the corresponding control plants (treated with inoculants without biofungicides).

According to Zhang et al. [21], the primary chemical constituents of the fungus *F. fomentarius* are considered to be triterpenoids and ergosterols. The researchers also identified novel structures in its composition — two pentacyclic lupane-type triterpenes, 3-formyloxybetulin and 3-formyloxybetulinic acid, as well as two rare carbon-degraded ergosterol derivatives. The most important phenolic compounds in the *F. fomentarius* extract are benzoic acid, rutin, quercetin, and protocatechuic acid; the presence of

TABLE 4. Grain productivity of soybean plants of Diadema Podillia cultivar under treatment with biofungicides and inoculation with Bradyrhizobium japonicum B78 and B144

Treatment	Grain weight per plant, g
Without inoculation and biofungicide (control 1)	1.22±0.07
B. japonicum B78 (control 2)	2.70±0.13
B. japonicum B78 + Mycosan-N	3.01±0.15
B. japonicum B78 + Phytocid-r	2.64±0.11
B. japonicum B144 (control 3)	2.51±0.10
B. japonicum B144 + Mycosan-N	2.70±0.12
B. japonicum B144 + Phytocid-r	2.46±0.10

p-hydroxybenzoic acid, catechin, syringic, *p*-coumaric, and vanillic acids has also been reported [22]. It is likely that owing to the diverse composition of substances in natural fungal extracts, their application in agrotechnologies can enhance the efficiency of induced disease protection in plants.

Literature data indicate that *Bacillus* spp. strains are capable of producing a variety of substances that disrupt the cell walls of phytopathogens. By synthesizing chitinase, protease, cellulase, glucanase, or lipopeptides — which are capable of damaging the cells of pathogenic bacteria, fungi, nematodes, or pests — they contribute to the control of their populations in plants and soil. In addition, these bacteria are also capable of forming endospores, which help them maintain viability under various environmental conditions [23]. Among the most thoroughly studied lipopeptides of *Bacillus* spp. are fengycins, iturins, and surfactins. Researchers have determined which strains are capable of synthesizing these substances, and have described their biological activity and a number of functional properties that define the spectrum of various applications of these microorganisms [24]. These compounds are indisputably the leading basis for the development of biopreparations.

A need has emerged worldwide for rational, ecologically grounded natural resource management. Issues of biological and food security of nations have become increasingly acute. One of the relevant directions is the implementation of organic farming, which envisages the formation of sustainable agricultural production based on the use of local renewable resources, promotes the preservation of biodiversity, and stimulates the interaction between microorganisms and plants. The application of plant protection methods and products with minimal negative impact on the environment represents an important and pressing issue in both organic farming and modern agro-industrial production. Biological fungicides are precisely such plant protection products. Therefore, researchers continuously work on increasing the efficiency of biopesticides using the most advanced technologies. There is a likelihood of a reduction in the cost of finished products of this type, which is also associated with the development of production technologies, realized through the support of government programs and commercial investors [25, 26].

An important role in the enrichment of soils with fixed nitrogen is performed by the process of biological fixation of molecular N_2 by soil nitro-

gen-fixing microorganisms. Researchers in various countries worldwide are working to obtain, through various selection methods, highly active, competitive strains of nodule bacteria for use as the basis of biopreparations in legume crop cultivation technologies. New strains are tested for their capacity to form effective symbioses under the influence of various biotic or abiotic factors [27]. To ensure the high quality of inoculants, scientists study the viability of nitrogen-fixing microorganisms in various carriers, and, where necessary, adjust the storage conditions of finished preparations, as well as the composition or quantity of additional components introduced (adhesives, protective agents, etc.) [28—30].

The results confirm that the efficiency of microbial preparations of various purposes in soybean cultivation technologies depends to a considerable extent on the compatibility of their components. A scientifically grounded selection of nodule bacterial strains and biofungicides can ensure a synergistic effect of their combined application, which will be reflected in plant resistance to biotic factors and in the realization of their productive potential.

An increase in the production and application of biological preparations for plant protection and for meeting plant nitrogen requirements will make it possible to obtain environmentally clean crop production, contribute to a reduction in the anthropogenic (chemical) load on agroecosystems, and promote the restoration of soil fertility. Therefore, further investigation of the efficiency of combined soybean seed treatment with nitrogen-fixing microorganisms and biofungicides under field experiment conditions is advisable.

Author Contributions: *study conception and design* — Kateryna P. Kukol, Nadiia A. Vorobey, Sergii Ya. Kots; *data collection* — Kateryna P. Kukol, Nadiia A. Vorobey, Petro P. Pukhtaievych, Anhelina A. Dovhan; *analysis and interpretation of results* — Kateryna P. Kukol, Nadiia A. Vorobey, Petro P. Pukhtaievych, Anhelina A. Dovhan; *writing — original draft* — Kateryna P. Kukol, Nadiia A. Vorobey, Petro P. Pukhtaievych; *writing — review & editing* — Petro P. Pukhtaievych, Sergii Ya. Kots.

All authors reviewed and approved the final version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

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Received 09.07.2026. Accepted 22.07.2026. Published 30.09.2026

ЕФЕКТИВНІСТЬ ІНОКУЛЯЦІЇ СОЇ АКТИВНИМИ ШТАМАМИ БУЛЬБОЧКОВИХ БАКТЕРІЙ ЗА ОБРОБКИ НАСІННЯ БІОЛОГІЧНИМИ ФУНГІЦИДАМИ

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В умовах вегетаційного досліду вивчали вплив інокуляції сої бульбочковими бактеріями *Bradyrhizobium japonicum* В78 і В144 сумісно з обробкою насіння біологічними фунгіцидами мікосан-н та фітоцид-р на процеси формування, функціонування бобово-ризобіального симбіозу, ріст рослин та їх зернову продуктивність. Виявлено підвищення кількості кореневих бульбочок у фазу трьох справжніх листків на 8,3—10,6 % та їхньої маси на 19—27,8 % за комплексного застосування *B. japonicum* В78 із біофунгіцидами порівняно з обробкою лише інокулянтами. У фази бутонізації та повного цвітіння відзначено підвищення показників кількості кореневих бульбочок у варіантах з інокуляцією ризобіями обох штамів за впливу мікосану-н на 5,8—21,3 % та збільшення їхньої маси на 9,3—27,1 %. За комплексного застосування *B. japonicum* В78 з фітоцидом-р підвищення досліджуваних показників становило 6,3 та 7,9 % лише у фазу бутонізації. Виявлено підвищення азотфіксувальної активності (АФА) симбіотичних систем за обробки насіння сої *B. japonicum* В78 і мікосаном-н на 13,0 і 7,8 % у фази трьох справжніх листків і бутонізації, відповідно. У сої, інокульованої *B. japonicum* В144 і обробленої цим біофунгіцидом, АФА лише у фазу бутонізації на 8,8 % перевищувала контрольні рослини. За дії фітоциду-р та інокуляції ризобіями В78 спостерігалось підвищення АФА за даними трьох відборів на 6,2—14,6 %. У рослин, оброблених *B. japonicum* В144 і фітоцидом-р, виявлено зниження досліджуваного показника упродовж вегетації на 7,9—18,3 %. У результаті аналізу маси надземної частини рослин сої і коренів встановлено, що бактеризація насіння ризобіями як комплексно з біофунгіцидами, так і без їх застосування сприяла підвищенню дос-

ліджуваних показників упродовж вегетації порівняно із рослинами без передпосівної обробки. Підвищення зернової продуктивності рослин сої на 7,6 та 11,5 % відзначено за комплексної обробки насіння *B. japonicum* B144 і B78 із мікосаном-н. За сумісного застосування бульбочкових бактерій із фітоцидом-р зернова продуктивність сої була на рівні рослин відповідних контролів (оброблених інокулянтами без біофунгіцидів). Таким чином, науково обґрунтований добір бульбочкових бактерій і біофунгіцидів для застосування у технологіях вирощування сої дає змогу забезпечити активне функціонування потужного симбіотичного апарату та підвищення зернової продуктивності.

Ключові слова: *Bradyrhizobium japonicum*, соя, інокуляція, біологічні фунгіциди, кількість і маса бульбочок, азотфіксувальна активність, зернова продуктивність.

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