https://doi.org/10.15407/microbiolj87.05.003

V.A. VASYUK, V.V. CHOBOTAROVA, N.Y. PARKHOMENKO, A.Yu. CHOBOTAROV, I.K. KURDISH*

D.K. Zabolotny Institute of Microbiology and Virology, NAS of Ukraine,
154 Akademika Zabolotnoho Str., Kyiv, 03143, Ukraine

* Author for correspondence; e-mail: ivan.kurdish2016@gmail.com

EFFECT OF *BACILLUS SUBTILIS* IMV B-7023 ON WHEAT GROWTH, PHOTOPIGMENT CONTENT IN LEAVES, AND GIBBERELLINS IN ROOT EXUDATES

Root exudates of plants contain a significant number of organic compounds of various types, which influence the composition of plant microbiota that, in turn, has a substantial effect on their growth, development, and productivity. Among these compounds, gibberellins play an important role. The effect of Bacillus subtilis IMV B-7023 on gibberellin content in the plant growth zone has not been studied. The aim of this work was to determine the characteristics of the interaction between Bacillus subtilis IMV B-7023— a component of the Azogran preparation—and wheat plants in terms of the production of gibberellin-like substances, their influence on plant growth, and the content of photopigments. ***Methods.*** *Experiments were carried out on wheat of the Shestopalivka variety, the seeds of which were inoculated with suspensions of B. subtilis IMV B-7023. The plants were grown under sterile conditions in a phytotron using a hydroponic setup with Fahraeus medium for 14 days. Plant shoot length and root mass were measured. The content of photosynthetic pigments in the plant leaves was determined spectrophotometrically. Gibberellin-like substances in plant root exudates were identified using a biotesting method based on the stimulation of hypocotyl growth in lettuce (variety Kucheravyi Odeskyi).* ***Results.*** *Inoculation of wheat seeds with B. subtilis IMV B-7023 significantly improved plant growth and the accumulation of chlorophylls a and b, as well as carotenoids, in the leaves. When plants were grown from inoculated seeds in solution, the gibberellin content increased significantly.* ***Conclusions.*** *Inoculating wheat seeds stimulates plant growth under hydroponic conditions and increases the content of photosynthetic pigments—chlorophylls a and b, and carotenoids—in the leaves. Under such conditions, gibberellin levels in the plant growth medium increased by 141—283% compared to the control.*

Keywords: *Bacillus subtilis IMV B-7023, Shestopalivka wheat variety, morphometric indicators, photopigments, gibberellins.*

Citation: Vasyuk V.A., Chobotarova V.V., Parkhomenko N.Y., Chobotarov A.Yu., Kurdish I.K. Effect of *Bacillus subtilis* IMV B-7023 on Wheat Growth, Photopigment Content in Leaves, and Gibberellins in Root Exudates. *Microbiological journal.* 2025 (5). P. 3—11. https://doi.org/10.15407/microbiolj87.05.003

The rapid growth of the human population on our planet necessitates a significant increase in the yield of agricultural crops. To achieve this, chemicals, pesticides, fertilizers, and other agents that can enhance crop yields are widely used in crop production. However, such an approach leads to environmental pollution, a decline in the quality of the resulting product, and harm to ecosystems and human health. As a result, in recent decades, considerable attention has been paid to the biologicalization of crop production, an important component of which is the use of highly effective microbial preparations capable of improving plant productivity (Tingting Wang et al., 2024; Volkogon et al., 2024).

At the D.K. Zabolotny Institute of Microbiology and Virology of the National Academy of Sciences of Ukraine, a highly effective complex bacterial preparation, Azogran, has been developed. It significantly improves the growth, development, and productivity of a number of plant species. It contains nitrogen-fixing bacteria *Azotobacter vinelandii* IMV B-7076 and phosphate-mobilizing bacteria *Bacillus subtilis* IMV B-7023 (Kurdysh, 2010), which are capable not only of enhancing nitrogen and phosphorus nutrition of plants but also of synthesizing a range of biologically active compounds: auxins, carbohydrates, organic acids, proteins, as well as compounds of phenolic and flavonoid nature (Tserkovniak, 2009; Chobotarov et al., 2017; Kurdysh et al., 2024).

Thanks to such a spectrum of biologically active substances, these bacteria are capable of significantly improving plant growth, development, and productivity, as well as protecting plants from the effects of extreme environmental factors, phytopathogenic bacteria, viruses, micromycetes, and also phytophagous insects, including the Colorado potato beetle (Roy et al., 2012; Chuiko et al., 2020; Kurdish et al., 2021; Parchomenko et al., 2023).

A significant impact on plant growth, development, and productivity is exerted by phytohormones, among which gibberellins play a key role. They represent the most numerous classes of plant hormones, comprising more than 130 isoforms. However, physiological activity is characteristic only of certain gibberellic acids (GA_1, GA_3, GA_4, GA_5, GA_6, and GA_7), while others are considered their precursors or inactive forms (Sponsel & Hedden, 2010).

The main functions of gibberellins include the regulation of seed germination processes, coordination of cell division and elongation, sex determination, development of pollen and flowers, induction of flowering, as well as seed and fruit formation (Gantait et al., 2015; Gupta, Chakrabarty, 2013).

Representatives of the *Bacillus* genus are capable of synthesizing gibberellins in varying amounts. For instance, it has been reported that *B. amyloliquefaciens* synthesized 10 gibberellins in concentrations ranging from 0.013 ng/mL to 17.88 ng/mL (Shahzad et al., 2016). In *B. subtilis* strains (LDA-1, LDA-2, and LDA-3), GA3 was detected in the range of 1.64—1.97 μg/mL (Abdelmoteleb et al., 2023), while *B. subtilis* strain JW1 produced GA1, GA4, and GA7 (Kang et al., 2019). Bacterial phytohormones influence the metabolism of endogenous growth regulators in plants (Sorty et al., 2016).

It is known that bacterial endophytes can enhance gibberellin synthesis in plants. For example, the inoculation of wheat seeds with *B. subtilis* QM3 induced the biosynthesis of endogenous gibberellins by significantly increasing the expression of the key gene *TaGA3ox-B2* (Hu et al., 2024). In soybean plants inoculated with *B. aryabhattai* SRB02, the production of GA12, GA4, and GA7 was enhanced (Park et al., 2017). It was also shown that in rice plants inoculated with *B. amyloliquefaciens* RWL-1, there was a significant increase in the levels of endogenous GA1, GA4, GA7, and GA9 (Shahzad et al., 2016).

To date, the effect of *Bacillus subtilis* IMV B-7023 on the accumulation of gibberellins in wheat root exudates has not been studied. In view of this, the aim of the present study was to determine the characteristics of the interaction between *Bacillus subtilis* IMV B-7023 — a component of the preparation Azogran — and wheat plants in terms of the production of gibberellin-like substances, their effect on plant growth, and the content of photosynthetic pigments.

Materials and Methods. *Bacillus subtilis* IMV B-7023 bacteria were cultivated for 48 hours in 700 mL Erlenmeyer flasks, each containing 100 mL of Minkin's medium (Menkina,1950), at a temperature of 28 °C on a rotary shaker at 120 revolutions per minute.

Wheat plants of the Shestopalivka variety were used in the experiments. The seeds were sterilized for 5 min in a 1:1 solution of 96% ethanol and 50% hydrogen peroxide. They were then rinsed five times with sterile distilled water and germinated on the surface of potato agar until roots 1—2 cm in length developed.

Uncontaminated seedlings were treated with suspensions of *B. subtilis* IMV B-7023 for 1 hour, with bacterial concentrations of 10^6, 10^7, and 10^8 CFU/mL. After treatment, both the bacterized and untreated (control) seeds were placed in groups of 10 on sterile stainless steel mesh in sterile 1.5 L glass vessels, each containing 80 mL of liquid Fahraeus nutrient medium (Willson, 1995). This medium contained the following components (g/L): $CaCl_2$ — 0.1; $MgSO_4 \cdot 7H_2O$ — 0.12; KH_2PO_4 — 0.1; $Na_2HPO_4 \cdot 12H_2O$ — 0.15. Additionally, $(NH_4)_2SO_4$ was added at 0.5 g/L, along with trace amounts of micronutrients: Fe citrate — 0.005; $FeSO_4{\cdot}7H_2O$; $CuSO_4$; $ZnSO_4 \cdot 7H_2O$; $MnSO_4 \cdot 5H_2O$; H_3BO_3; and $(NH_4)_2MoO_4 \cdot 2H_2O$. The pH of the medium was adjusted to 6.5. The plants were grown in a phytotron under 12.000 lux illumination for 16 hours per day at a temperature of 21°C for 14 days.

At the end of the plant cultivation period, the medium containing root exudates was aseptically collected and centrifuged at 6600 rpm for 15 min. The resulting supernatant was lyophilized (freeze-dried) and stored for further biochemical analysis. In the plants, stem length, root mass, and the content of photosynthetic pigments were determined.

To determine the gibberellin content in wheat root exudates, 3 mg of the dry exudate was homogenized in a small volume of 80% ethanol. The extraction of free gibberellin-like substances (GLS) was carried out three times with 80% ethanol over 24 hours. After filtration, the extracts were evaporated to an aqueous phase using a rotary evaporator at 40 °C. The aqueous residues were then frozen and kept at —18 °C for 24 hours. The test solutions were subsequently thawed, acidified with 2N HCl to pH 2.8, and centrifuged at 10,000 × g for 15 min. The supernatant was extracted three times with ethyl acetate. The combined fractions were evaporated to dryness on a rotary evaporator. The dry residue was then dissolved in 500 μL of ethanol and applied to Silufol UV 254 silica gel plates for thin-layer chromatography (TLC) using a solvent system of isopropanol:ammonia:water (10:1:1). After drying the plates, they were divided into 10 sections under UV light.

To determine the physiological activity of the components, the sorbent layer was eluted with 80% methanol and evaporated to dryness on a rotary evaporator. The residues were then used for testing. GLS activity was assessed using a bioassay based on the stimulation of hypocotyl growth in lettuce (*Lactuca sativa*, cultivar Kucheravyts Odesky) (Agnistikova, 1977). Total GLS activity was expressed in GA_3 equivalents. The amount of GLS was calculated using a calibration curve constructed with GA_3.

Results. It was established that growing wheat plants under hydroponic conditions in the presence of *Bacillus subtilis* IMV B-7023 had a noticeable effect on plant growth, the content of photosynthetic pigments in the leaves, and the accumulation of gibberellin-type phytohormones in the nutrient solution.

When wheat was grown from seeds treated with a bacterial suspension containing 10^6 CFU/mL, stem length was 23.5% greater than in the control.

When the seeds were treated with a suspension containing 10^8 CFU/mL, stem length exceeded control values by almost 33%.

The root mass in the control group was 0.07 g, whereas in the plants grown from seeds treated with a suspension of *Bacillus subtilis* IMV B-7023, this value increased. Specifically, with a suspension containing 10^7 CFU/mL, root mass was 42.9% higher than in the control (Table 1).

Table 1. **Effect of *Bacillus subtilis* IMV B-7023 on the morphometric parameters of wheat under hydroponic cultivation**

Variants	Length of stem		Root weight	
	cm	%	g	%
Control	17.3 ± 0.5	100.0	0.07 ± 0.01	100.0
10^6 CFU/mL	21.4 ± 2.8	123.7	0.08 ± 0.01	114.3
10^7 CFU/mL	20.4 ± 1.9	117.9	0.09 ± 0.01	128.6
10^8 CFU/mL	23.0 ± 2.4	132.9	0.10 ± 0.02	142.9

Table 2. **Photopigment content in wheat leaves following seed treatment with various doses of *Bacillus subtilis* IMV B-7023**

Variants	Content of photopigments, mg/g		
	chlorophyll a	chlorophyll b	carotenoids
Control	0.96 ± 0.1	0.24 ± 0.06	0.24 ± 0.04
10^6 CFU/mL	1.06 ± 0.07	0.25 ± 0.04	0.28 ± 0.04
10^7 CFU/mL	1.12 ± 0.1	0.32 ± 0.04	0.40 ± 0.07
10^8 CFU/mL	1.12 ± 0.06	0.33 ± 0.01	0.38 ± 0.06

Table 3. **Total content of gibberellin-like substances in the wheat growth medium under different seed inoculation doses of *Bacillus subtilis***

Variants	Content of GLS, μg/mL
Control	9.50±0.25 / 100.00%
10^7 CFU/mL	36.39±1.82 / 383.00%
10^8 CFU/mL	22.93±1.15 / 241.40%

Cultivating wheat plants from seeds treated with *Bacillus subtilis* IMV B-7023 contributed to an increase in the content of photopigments in the plant leaves (Table 2).

If in the control plants (grown without bacteria), the content of chlorophyll a was 0.96 mg per 1 g of fresh leaf mass, then with seed bacterization at a concentration of 10^6 CFU/mL, this indicator reached 1.06 mg/g, and at concentrations of 10^7 CFU/mL and 10^8 CFU/mL, it increased to 1.12 mg/g (Table 2).

Bacteria had a noticeable effect on the content of chlorophyll b and carotenoids in the leaves of wheat. When plants were grown without bacteria, the content of chlorophyll b as well as carotenoids was 0.24 mg/g of leaves. At the same time, seed bacterization with bacilli significantly increased the pigment content. The most notable increase in the photopigment content was observed when seeds were bacterized in suspensions containing 10^7 and 10^8 CFU/ml of *Bacillus subtilis* IMV B-7023 (Table 2).

It was established that in wheat plants grown from non-inoculated seeds, only small amounts of gibberellin-like substances (GLS) with Rf values of 0.1—0.4 were detected in the root exudates. It was shown that in the upper part of the chromatogram, the activity of GLS with Rf values of 0.7, 0.9, and 1.0 was 235%, 290%, and 184% respectively, relative to GA_3 (Fig. 1). The total content of GLS in the root exudate of control plants was 9.5 μg/mL (Table 3).

It was established that with an increase in the seed inoculation dose, the total content of GLS in the wheat growth medium also increased. When wheat was grown from seeds bacterized with a suspension containing 10^7 and 10^8 CFU/mL of *Bacillus subtilis* IMV B-7023, the GLS content increased by 283% and 141%, respectively, compared to the control (Table 3).

No significant differences in the qualitative composition were observed between the control plants and those grown from bacterized seeds. When wheat was grown from seeds inoculat-

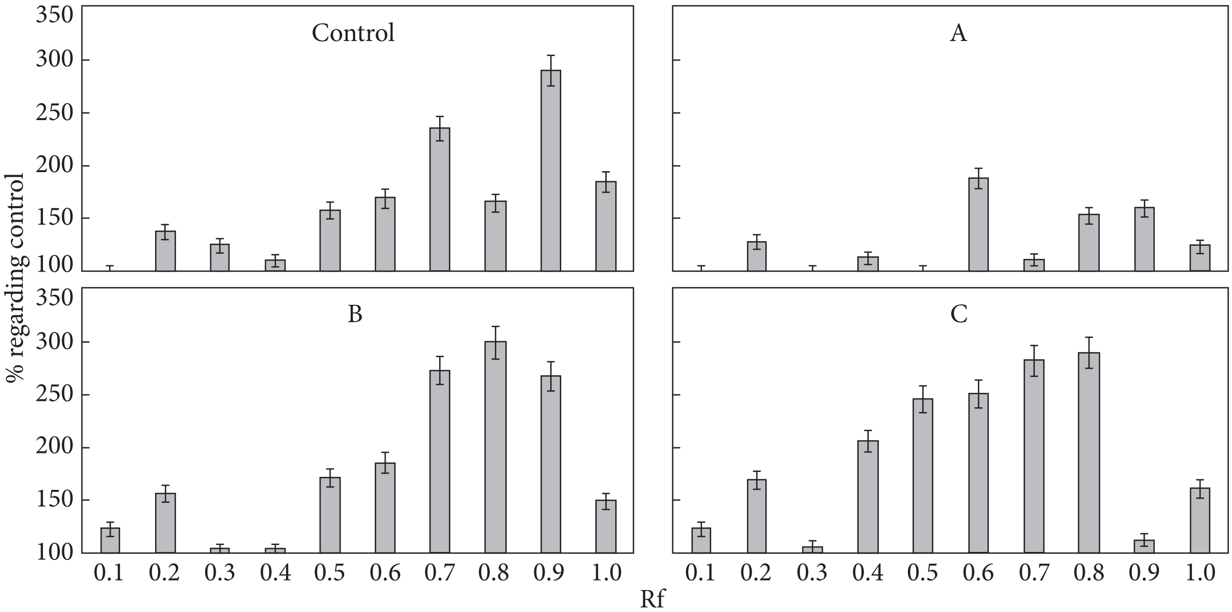

Fig. 1. Gibberellin-like substances in wheat root exudates under different seed inoculation doses with *B. subtilis*: control — plants without bacterisation; A — seed bacterization with a suspension containing *B. subtilis* at 10^6 CFU/mL, B — 10^7 CFU/mL, C — 10^8 CFU/mL

ed with suspensions containing 10^6, 10^7, and 10^8 CFU/mL of *Bacillus subtilis* IMV B-7023, an increase in the quantity of GLS was detected in the zone with an Rf value of 0.2. This increase amounted to 140%, 155%, and 169% respectively, relative to GA_3 (Fig. 1 A, B, C).

This suggests a possible influence of the bacteria on the accumulation of GLS in the growth medium, stimulating phytohormone production either by the plant itself or by the bacteria. In control plants, high activity of GLS with an Rf value of 0.9 was detected; however, this compound content decreased significantly when seeds were bacterized with *Bacillus subtilis* IMV B-7023 at concentrations of 10^6 and 10^8 CFU/mL, and partially at 10^7 CFU/mL. It is possible that the bacteria may utilize this GLS for their own growth or suppress its production.

An increase in the quantity of GLS with Rf values of 0.7 and 0.8 was observed under bacterization, while their content was negligible in the control. This may indicate hormone accumulation due to enhanced production by the bacteria.

Discussion. The results of our research demonstrate a significant influence of the phosphate-mobilizing strain *Bacillus subtilis* IMV B-7023 on the photosynthetic activity of wheat, leading to a marked increase in its growth activity and the accumulation of biologically active GLS in the root exudates.

Root exudates contain certain compounds that act as signaling molecules mediating motility, chemotaxis, biofilm formation, and symbiotic interactions, playing a key role in facilitating colonization of the plant root system by soil rhizobacteria (Sasse et al., 2018; Upadhyay et al., 2022; Liu et al., 2024). The composition and quantity of root exudates depend on the plant genotype, its developmental stage, as well as ecological, biotic, and abiotic factors (Chen & Liu, 2024).

Root exudates are capable of influencing the rhizospheric interactions and creating an environment with a certain degree of specificity for bacteria by releazing carbohydrates, fatty acids, essential amino acids, organic acids, hydrolytic enzymes, growth-regulating hormones, vitamins, nucleotides, flavonoids, polyphenols, and sterols. These interactions may induce changes in the plant metabolome as well as in the activity of its microbiota (Hartmann et al., 2009; Hu et al., 2018; Iannucci et al., 2021).

The functioning of *Bacillus subtilis* in the plant root zone can enhance plant growth through the direct synthesis of plant hormones (Barea et al., 2005). The increase in stem, root, and lateral root length of wheat following rhizobacterial inoculation may be associated with cell division and elongation regulated by gibberellins and indole-3-acetic acid (Saleemi et al., 2017; Wang et al., 2020).

Our findings show that when wheat plants are grown under sterile hydroponic conditions in Fahraeus medium, low levels of gibberellins are detected in the root exudates. However, the content of these compounds increased significantly when seeds were bacterized with *B. subtilis* IMV B-7023. High levels of gibberellin-like substances in the root exudate were recorded in the treatments where *B. subtilis* IMV B-7023 was applied at concentrations of 10^7 and 10^8 CFU/mL (Table 3). This may be due to stimulation of gibberellin synthesis by the plant in response to the bacterial presence, as well as direct synthesis of these compounds by the bacteria.

Moreover, at these levels of seed bacterization, an increase in the content of photosynthetic pigments and an improvement in morphometric parameters of wheat stems were also observed (Tables 1 and 2).

Rhizobacteria promote plant growth by stimulating the proliferation of root hairs, enhancing their branching, improving seed germination, increasing leaf area and biomass, raising levels of plant hormones, and improving nutrient uptake (Vicciante et al., 2022). *Bacillus subtilis* bacteria can enhance plant growth through various mechanisms, including nitrogen fixation, the synthesis of organic acids, amino acids, phenols, and flavonoids, siderophore production, improved phosphorus compound availability, and the production of phytohormones such as auxins, cytokinins, and gibberellins (Margues et al., 2010; Radhakrishan et al., 2017; Tahir et al., 2017; Yi et al., 2018; Ahmed et al., 2021; Di et al., 2022; Hu et al., 2024; Ocheretyanko et al., 2015; Skorochod et al., 2020).

In addition to significantly affecting the gibberellin content in the wheat cultivation medium, *B. subtilis* IMV B-7023 also markedly enhances plant protection against phytopathogens and phytophages (Chuiko et al., 2020; Kurdish et al., 2021; Parchomenko & Kurdish, 2023).

Thus, the results of the study indicate that inoculating wheat seeds with *Bacillus subtilis* IMV B-7023, followed by cultivation under hydroponic conditions, significantly improves plant growth and development, increases the content of photosynthetic pigments in the leaves, and substantially elevates the gibberellin content in the cultivation medium.

Conflicts of Interest. The authors declare no conflict of interest concerning the article.

REFERENCES

Abdelmoteleb, A., Moreno-Ramírez, L., Valdez-Salas, B., Seleiman, M. F., El-Hendawy, S., Aldhuwaib, K. J., Alotaibi, M., & González-Mendoza, D. (2023). New *Bacillus subtilis* Strains Isolated from *Prosopis glandulosa* Rhizosphere for Suppressing Fusarium Spp. and Enhancing Growth of Gossypium hirsutum L.
Biology, 12(1), 73.

Agnistikova, N. V. (1977). Determination of natural reggibberellins in plant tissues. In the book Plant growth and primordial regulators. Moscow: Nauka, 89—105.

Ahmed, H. F. A., Seleiman, M. F., Al-Saif, A. M., Alshiekheid, M. A., Battaglia, M. L., & Taha, R. S. (2021). Biological Control of Celery Powdery Mildew Disease Caused by *Erysiphe heraclei* DC In Vitro and In Vivo Conditions. *Plants, 10*(11), 2342.

Andrii Chobotarov, Mykola Volkogon, Lesya Voytenko, & Ivan Kurdish. (2017). Accumulation of phytohormones by soil bacteria *Azotobacter vinelandii* and *Bacillus subtilis* under the influence of nanomaterials. *Journal of Microbiology, Biotechnology and Food Science,* 2017.18.7.3. 271—274.

Anton Ocheretyanko, Alla Roy, Iryna Skorocod, & Ivan Kurdish. (2015). Accumulation of phenolic compounds in the cultural media of phosphate-mobilizing bacteria of genus *Bacillus* Cohn. *International Journal of Scientifis research in Knowledge*, 131—138.

Barea, J. M., Pozo, M. J., Azcon, R., & Azcon-Aguilar, C. (2005). Microbial co-operation in the rhizosphere. *J Exp Bot, 56*(417), 1761—1778.

Di, Y., Kui, L., Singh, P., Liu, L. F., Xie, L. Y., He, L. L., & Li, F. (2022). Identification and characterization of *Bacillus subtilis* B9: A diazotrophic plant growth-promoting endophytic bacterium isolated from sugarcane root. *J Plant Growth Regul*, *42*, 1720—1739.

Chen, L., & Liu, Y. (2024). The function of root exudates in the root colonization by beneficial soil rhizobacteria. *Biology, 13*(2), 95.

Chuiko, N. V., Chobotarov, A. Yu., Savchuk, Ya. I., Kurchenko, I. M., & Kurdish, I. K. (2020). Antagonistic activity of *Azotobacter vinelandii* IMV B-7076 against phytopathogenic microorganisms. Mikrobiol Z, 83(5), 21—30.

Gantait, S., Sinniah, U. R., Ali, M. N., & Sahu, N. C. (2015).Gibberellins — a multifaceted hormone in plant growth regulatory network. *Curr Protein Pept Sci, 16*(5), 406—412.

Gupta, R., & Chakrabarty, S. K. (2013). Gibberellic acid in plant: Still a mystery unresolved. *Plant Signal Behav, 8*(9), e25504.

Hartmann, A., Schmid, M., Tuinen, D., & Berg, G. (2009). Plant-driven selection of microbes. *Plant Soil, 321*(1—2), 235—275.

Hashem, A., Tabassum, B., & Allah, E. F. A. (2019). *Bacillus subtilis*: A plant-growth promoting rhizobacterium that also impacts biotic stress. *Saudi J Biol Sci, 26*(6), 1291—1297.

Hu, L., Robert, C. A. M., Cadot, S., Zhang, X., Ye, M., Li, B., Manzo, D., Chervet, N., Steinger, T., Marcel, G. A., van der Heijden, M. G. A., Schlaeppi, K., & Erb, M. (2018). Root exudate metabolites drive plant-soil feedbacks on growth and defense by shaping the rhizosphere microbiota. *Nat Commun, 9*, 2738.

Hu, Q., Xiao, Y., Liu, Z., Huang, X., Bingqi Dong, D., & Wang, Q. (2024). *Bacillus subtilis* QM3, a Plant Growth-Promoting Rhizobacteria, can Promote Wheat Seed Germination by Gibberellin Pathway. *J Plant Growth Regul, 43*, 2682—2695.

Iannucci, A., Canfora, L., Nigro, F., De Vita, P., & Beleggia, R. (2021). Relationships between root morphology, root exudate compounds and rhizosphere microbial community in durum wheat. *Applied Soil Ecology, 158*, 103781.

Iryna Skotochod, Alla Roy, Ivan Kurdish, & Ulzijargal Erdenetsogt. (2020). Content of organic acids in the cultural medium of *Bacillus subtilis* IMV B-7023 at cultivation with different sources of the phosphorus nutrient. *Journal of Microbiology, Biotechnology and Food Science,* 73—77.

Kang, S.-M., Hamayun, M., Khan, M. A., Iqbal, A., & Lee, I.-J. (2019). *Bacillus subtilis* JW1 enhances plant growth and nutrient uptake of Chinese cabbage through gibberellins secretion. *Journal of Applied Botany and Food Quality, 92*, 172—178.

Kurdish, I. K. (2010). Introduction of Microorganisms into Agroecosystems. Kiyv. Naukova Dumka, 253.

Kurdish, I. K., Roy, A. O., & Skorochod, I. O. (2021). Effeciency of the complex bacterial preparation Azogran application in protecting Potatoes from the *Colorado potato* beetle depending on the stage of its development. *Mikrobiol Z, 83*(1), 3—11.

Kurdish, I. K., Chobotarov, A. Yu., Brovarska, O. S., Parchomenko, N. Y., & Chobotarova, V. V. (2024). The Influence of *Azotobacter vinelandii* IMV B-7076 on the Buckwheat Development and Exometabolite Composition in the Root Zone. *Mikrobiol Z, 86*(5), 39—46.

Liu, Y., Xu, Z., Chen, L., Xun, W., Shu, X., Chen, Y., Sun, X., Wang, Z., Ren, Y., Shen, Q., et al. (2024). Root Colonization by Beneficial Rhizobacteria. *FEMS Microbiol Rev, 48*(1), fuad066.

Marques, A. P., Pires, C., Moreira, H., Rangel, A. O., & Castro, P. M. (2010). Assessment of the plant growth promotion abilities of six bacterial isolates using Zea mays as indicator plant. *Soil Biol Biochem, 42*, 1229—1235.

Menkina, R. A. (1950). Bacteria Mineralizing Organic Phosphorus Compounds. *Microbiology, 19*(4), 30—8316.

Parchomenko, N. Y., & Kurdish, I. K. (2023). The influence of the complex bacterial preparation Azogran on some physiological-biochemical propertits and productivity of potato plants infected potato virus X. *Microbiol Z, 6*, 66—76.

Park, Y. G., Mun, B. G., Kang, S. M., Hussain, A., Shahzad, R., Seo, C. W., Kim, A.-Y., Lee, S.-Y., Oh, K.Y., Lee, D.Y., Lee, I.-J., & Yun, B.-W. (2017). *Bacillus aryabhattai* SRB02 tolerates oxidative and nitrosative stress and promotes the growth of soybean by modulating the production of phytohormones. *PLOS ONE*, *12*, e0173203.

Radhakrishnan, R., Hashem, A., & Abd_Allah, E. F. (2017). *Bacillus*: a biological tool for crop improvement through bio-molecular changes in adverse environments. *Front Physiol, 8*, 667.

Roy, A. A., Pasychnyk, L. A., Tserkovniak, L. S., Khodos, S. F., & Kurdish, I. K. (2012).The effect of bacteria of the genus *Bacillus* on the causative agents of bacterial cancer of tomatoes. *Mikrobiol Z, 74*(5), 74—80.

Saleemi, M., Kiani, M. Z., Sultan, T., Khalid, A., & Mahmood, S. (2017). Integrated Effect of Plant Growth-Promoting Rhizobacteria and Phosphate-Solubilizing Microorganisms on Growth of Wheat (*Triticum aestivum* L.) under Rainfed Condition. *Agric Food Secur, 6*, 46.

Sasse, J., Martinoia, E., & Northen, T. (2018). Feed Your Friends: Do Plant Exudates Shape the Root Microbiome? *Trends Plant Sci, 23*(1), 25—41.

Shahzad, R., Waqas, M., Khan, A. L., Asaf, S., Khan, M. A., Kang, S. M., Kang, S. M., Yun, B. W., & Lee, I.-J. (2016). Seed-borne endophytic *Bacillus amyloliquefaciens* RWL-1 produces gibberellins and regulates endogenous phytohormones of *Oryza sativa*. *Plant Physiol Biochem, 106*, 236—243.

Sorty, A. M., Meena, K. K., Choudhary, K., Bitla, U. M., Minhas, P. S., & Krishnani, K. K. (2016). Effect of plant growth promoting bacteria associated with halophytic weed (*Psoralea corylifolia* L.) on germination and seedling growth of wheat under saline conditions. *Appl Biochem Biotechnol, 180*(5), 872—882.

Sponsel, V., & Hedden, P. (2010). Gibberellin Biosynthesis and Inactivation. Plant Hormones. Davies P. J. (Ed.). Springer, Dordrecht. 63—94.

Tahir, H. A., Gu, Q., Wu, H., Raza, W., Hanif, A., Wu, L., Colman, M.V., & Gao, X. (2017). Plant growth promotion by volatile organic compounds produced by *Bacillus subtilis* SYST2. *Front Microbiol, 8*, 171.

Tingting Wang, Jiaxin Xu, Jian Chen, et al. (2024). Progress in Microbial Fertilizer Regulation of Crop Growth and Soil Remediation Research. *Plants (Basel), 13*(3), 346.

Upadhyay, S. K., Srivastava, A. K., Rajput, V. D., Chauhan, P. K., Bhojiya, A. A., & Minkina, T. (2022). Root Exudates: Mechanistic Insight of Plant Growth Promoting

Rhizobacteria for Sustainable Crop Production. *Front Microbiol, 13*, 916488.

Vocciante, M., Grifoni, M., Fusini, D., Petruzzelli, G., & Franchi, E. (2022). The role of plant growth-promoting rhizobacteria (PGPR) in mi tigating plant's environmental stresses. *Appl Sci, 12*(3), 1231.

Volkogon, V. V., Kurdish, I. K., Moskalenko, A. M., et al. (2024). The Effectiveness of Microbial Preparations in the Technologies of Growing Agricultural Crops. P.6—44. In the Book «Microorganisms in the Stabilization of Agroecosystems». V. P. Patika & V.V. Volkogon (Eds). Nizhyn, 349 p.

Wang, X., Xie, H., Ku, Y., Yang, X., Chen, Y., Yang, N., Mei, X., & Cao, C. (2020).Chemotaxis of *Bacillus cereus* YL6 and Its Colonization of Chinese Cabbage Seedlings. *Plant Soil, 447*(1—2), 413—430.

Wilson, K. J. (1995). Molecular technigues for the study of rhizobial ecology in the field. *Soil Biology and Biochemistry, 27*(4—5), 501—514.

Yi, Y., Li, Z., Song, C., & Kuipers, O. P. (2018). Exploring plant-microbe interactions of the rhizobacteria *Bacillus subtilis* and *Bacillus mycoides* by use of the CRISPR-Cas9 system. *Environ Microbiol, 20*, 4245—4260.

Received 15.04.2025

В.А. Васюк, В.В. Чоботарьова,
Н.Й. Пархоменко, А.Ю. Чоботарьов, І.К. Курдиш

Інститут мікробіології і вірусології ім. Д.К. Заболотного НАН України,
вул. Академіка Заболотного, 154, Київ, 03143, Україна

ВПЛИВ *BACILLUS SUBTILIS* IMB B-7023 НА РІСТ ПШЕНИЦІ, ВМІСТ ФОТОПІГМЕНТІВ У ЇЇ ЛИСТКАХ ТА ГЕБЕРЕЛІНІВ У КОРЕНЕВИХ ЕКСУДАТАХ

Кореневі ексудати рослин містять значну кількість органічних сполук різної природи, які впливають на склад мікробіоти рослин, що спричиняє суттєвий вплив на їх ріст, розвиток і продуктивність. Серед таких сполук важливу роль відіграють гібереліни. Вплив *Bacillus subtilis* IMB B-7023 на вміст гіберелінів у зоні росту рослин не досліджено. **Метою** даної роботи було визначити особливості взаємодії *Bacillus subtilis* IMB B-7023 — компонента препарату Азогран, з рослинами пшениці щодо продукування гіберелоподібних речовин, їх впливу на ріст рослин та вміст фотопігментів. **Методи.** Досліди проводились на пшениці сорту Шестопалівка, насіння якої бактеризували суспензіями *B. subtilis* IMB B-7023. Рослини вирощували стерильно у фітотроні в гідропонних умовах в середовищі Фареуса впродовж 14 діб. У рослинах вимірювали довжину пагонів і масу коріння. Вміст фотосинтетичних пігментів в листках рослин визначали спектрофотометричним методом. Гіберелоподібні речовини в кореневих ексудатах рослин визначали методом біотестування, заснованим на стимуляції росту гіпокотилів салату (сорт Кучерявиць Одеський). **Результати.** Інокуляція насіння пшениці бактеріями *B. subtilis* IMB B-7023 значно покращувала ріст рослин та накопичення в їхніх листках хлорофілів а та *b* і каротиноїдів. За вирощування рослин із бактеризованого насіння в розчині суттєво підвищувався вміст гіберелінів. **Висновки.** Бактеризація насіння пшениці стимулює ріст рослин за вирощування їх у гідропонних умовах та вміст у листках фотосинтетичних пігментів хлорофілу а та *b* і каротиноїдів. За таких умов вміст гіберелінів у середовищі вирощування рослин зростав у порівнянні з контролем на 141—283 %.

Ключові слова: *Bacillus subtilis IMB B-7023, пшениця сорту Шестопалівка, морфометричні показники, фотопігменти, гібереліни.*