CHAPTER 4

BACTERIA FROM ENVIRONMENTS WITH EXTREME CONDITIONS AS BIOLOGICAL AGENTS FOR THE DEVELOPMENT OF PREPARATIONS FOR PLANT GROWTH PROMOTION

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INTRODUCTION

Environmental pollution with heavy metals and other toxicants caused by military actions or intensive human activity is becoming a global problem and poses one of the most serious environmental threats of our time. Such processes lead to the degradation of natural habitats, disruption of biogeochemical cycles, and a significant reduction in areas suitable for agricultural use[1, 2].

According to the Ministry of Economy, Environment, and Agriculture of Ukraine, the russian-Ukrainian war has caused the greatest ecological disaster in modern European history. Among the key destructive factors are massive explosions of artillery shells and rockets, large-scale fires, particularly at oil depots and industrial facilities, as well as uncontrolled leaks of hazardous chemicals[3]. It has been proven that explosive substances and combustion products significantly alter the physical and chemical properties of soils, contributing to their compaction, reduction in humus content, and biological activity, as well as the accumulation of toxic elements[4, 5].

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Elevated concentrations of copper, lead, nickel, as well as products of incomplete combustion of hydrocarbons, sulfur, and nitrogen compounds, which have high migration capacity and toxicity to living organisms, have already been recorded in the combat zone. The toxic effects of heavy metals are due to their cumulative nature and long half-life, which causes them to accumulate in soils and subsequently enter plants and aquatic ecosystems[6].

According to the State Environmental Inspectorate of Ukraine, the total environmental damage caused by the war has reached 6.01 trillion hryvnia, based on the latest estimates[7]. The accumulation of toxic substances in soil, water, and air poses long-term risks to food security and public health, as hazardous compounds can be transmitted through food chains and cause chronic toxicosis, mutagenic, and carcinogenic effects[8, 9].

The search for effective tools to mitigate the consequences of large-scale human-made and military pollution of the environment necessitates a comprehensive study of microorganisms capable of functioning under conditions of intense environmental stress. In this context, extreme biotopes are of particular scientific and practical value, as they are considered a promising source of microbial strains with unique properties formed as a result of prolonged adaptation to unfavorable living conditions.

The main stress factors in such environments are high concentrations of organic and inorganic toxicants, in particular petroleum products, explosives and their transformation products, as well as heavy metals in high concentrations. In addition, extreme biotopes are often characterized by high salinity, nutrient deficiency, sharp temperature fluctuations, and intense ultraviolet radiation, which further complicates the viability of biota.

The ability of microorganisms to withstand the combined effects of these stresses is due to the presence of specific physiological, biochemical, and genetic adaptation mechanisms, including detoxification systems, metal-binding proteins, antioxidant protection, and effective DNA repair

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6 Kabata-Pendias A. Trace elements in soils and plants. 4th ed. Boca Raton : CRC Press, 2011. 548 p. https://doi.org/10.1201/b10158

7 Оновлена щотижнева інфографіка про збитки, завдані довкіллю внаслідок збройної агресії рф станом на 26.12.2025 : [новина] / Державна екологічна інспекція України. 2025. 29 груд. URL: https://www.dei.gov.ua/post/onovlena-shchotizhneva-infografika-pro-zbitki-zavdani-dovkillyu-26-12-2025 (дата звернення: 30.12.2025).

8 Jaishankar M., Tseten T., Anbalagan N., Mathew B. B., Beeregowda K. N. Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology*. 2014. Vol. 7. No. 2. P. 60–72. https://doi.org/10.2478/intox-2014-0009

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mechanisms. These adaptive properties ensure their competitiveness and stable survival in unfavorable conditions, and also determine their potential for use in biotechnological approaches to remediate contaminated soils and aquatic ecosystems.

In the context of increasing anthropogenic pressure on ecosystems, developing soil bioremediation strategies is a priority task that involves using microorganisms resistant to a wide range of toxic substances. The use of plant growth-promoting microorganisms is considered an effective and environmentally safe alternative for intensifying the productivity of agroecosystems and increasing plant resistance to negative environmental factors[10].

The aim of our work was to analyze the plant growth-promoting effect of bacterial strains resistant to environmental factors, which differ significantly in terms of metabolism type and oxygen requirements.

1. Characteristics of the bacteria used in the study

The studied strains of microorganisms we isolated from biotopes with different physicochemical characteristics. In particular, *Rhodopseudomonas yavorovii* IMV B-7620 bacteria were isolated from Lake Yavorivske, the water of which contained elevated levels of sulfur compounds and metal ions, including Mn(II), Cd(II), Pb(II), and Fe(III), during the period of strain isolation[11]. Lake Yavorivske was formed on the former site of a sulfur quarry. This is Ukraine's largest artificial lake, measured by both depth and volume of water. *R. yavorovii* IMV B-7620 is characterized by flexible metabolism. They can be heterotrophs or autotrophs, depending on lighting conditions, oxygen supply, carbon sources, and electron donors, and are resistant to cobalt(II) chloride, ferric citrate, copper(II) chloride, potassium dichromate[12]. As a result of the formation of lipid peroxidation products under the influence of ferric citrate and cobalt(II) chloride, antioxidant defense enzymes are activated in the cells of these bacteria, which, in combination with other defense strategies, in particular non-enzymatic antioxidants, ensure the

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survival of bacteria under these conditions[13]. Under the influence of ferric citrate, cobalt(II) chloride, copper(II) chloride, and potassium dichromate in the cells of *R. yavorovii* IMV B-7620, changes the qualitative and quantitative composition of photosynthetic pigments (lycopene, anhydrorhodovibrin, bacteriochlorophyll *a*)[14].

Ochrobactrum rhizosphaerae IMV B-7956 isolated from the filtrates of the Lviv solid waste landfill – wastewater containing a complex of organic and inorganic toxicants, the concentration of which exceeds the norm by 5–50 times[15, 16]. *O. rhizosphaerae* IMV B-7956 bacteria synthesize siderophores and auxin-like compounds, are characterized by phosphatase activity, and metabolize a wide range of organic carbon sources. *O. rhizosphaerae* IMV B-7956 bacteria can metabolize compounds in wastewater from an alcohol production plant, reducing chemical oxygen demand by 55 % in four days. These bacteria are resistant to 15 % NaCl and a variety of heavy metal compounds (cadmium chloride, ferrous sulfate, copper(II) chloride, potassium dichromate, manganese(II) chloride, cobalt(II) chloride)[17]. The bacteria *Paenibacillus tundrae* IMV B-7915 were isolated from a sample of Antarctic substrate. In Antarctic conditions, microorganisms are exposed to low temperatures, UV radiation, elevated metal content, among other factors[18, 19]. *P. tundrae* IMV B-7915 are spore-forming microorganisms capable of growing in a temperature range of

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2–37 °C, which ensures their resistance under unfavorable conditions. These microorganisms are characterized by cellulase, amylase, and lipase activities, are capable of synthesizing siderophores and auxin-like compounds, fixing molecular nitrogen, and are resistant to cadmium chloride, ferrous sulfate, copper(II) chloride, potassium dichromate, manganese(II) chloride, and cobalt(II) chloride[20]. The bacteria *O. rhizosphaerae* IMV B-7956 and *P. tundrae* IMV B-7915 are capable of accumulating copper ions in cells. After one hour of incubation in Tris-HCl buffer with different concentrations of copper(II) chloride, 2.3–7.8 mg Cu/g biomass (*O. rhizosphaerae* IMB B-7956) and 1.5–3.4 mg Cu/g biomass (*P. tundrae* IMB B-7915) were detected in the cells[21, 22]. As a result of the loading of these bacterial cells with copper(II) ions, the content of the products of lipid peroxidation and oxidative modification of proteins increases in the cells, and the activity of the enzymes of the antioxidant defense system (catalase, superoxide dismutase, glutathione system enzymes), and bacteria produce more exopolysaccharides compared to the control[23, 24].

The studied microorganisms differ significantly in terms of metabolism type and physiological needs, ranging from autotrophy in *R. yavorovii* IMV B-7620 to aerobic and microaerophilic heterotrophic growth in *O. rhizosphaerae* IMV B-7956 and *P. tundrae* IMV B-7915, respectively[25, 26, 27.]

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Such metabolic plasticity and natural resistance to stress factors became the basis for further study of their potential in agrobiotechnology.

2. The effect of bacteria resistant to environmental factors on the growth of wheat seedlings

Microbial preparations are widely used today for pre-sowing seed treatment or spraying of growing plants. Their action is aimed at optimizing mineral nutrition, since it is known that microorganisms can promote plant growth by facilitating the bioavailability of nutrients and macroelements (potassium, phosphorus, nitrogen, iron, zinc, copper) in the rhizosphere. Another important aspect is the ability of plant growth-promoting microorganisms to produce a wide range of phytohormones, other biologically active substances, synthesize hydrolytic enzymes, and enzymes of the antioxidant defense system (catalase, superoxide dismutase). This leads to increased plant resistance to phytopathogens, higher yields, and improved quality indicators for agricultural products, as well as enhanced plant adaptability to extreme biotope conditions, and contributes to the revitalization and preservation of soil fertility[28, 29, 30, 31, 32, 33, 34]. The integration of plant growth-promoting microorganisms into plant cultivation technology allows for a significant reduction in the use of mineral fertilizers, synthetic pesticides, and other

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agrochemicals[35]. Wheat (Triticum aestivum L.) is a strategic food crop in Ukraine and the primary source of grain for the world's population. However, its productivity is significantly limited by the influence of biotic and abiotic stressors[36, 37, 38, 39, 40, 41, 42]. In view of this, it is important to develop complex biological products based on non-pathogenic strains of bacteria that are resistant to environmental factors, particularly in conditions of anthropogenic stress. This will not only stimulate plant growth and increase yields, but also minimize ecotoxicological risks to humans. In particular, the use of metal-resistant strains can help reduce the accumulation of heavy metals in plant biomass and grain, thereby preventing them from entering the food chain[43, 44]. Replacing agrochemicals with bacterial preparations reduces the

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overall environmental impact of pesticides and chemical fertilizers, directly improving the quality of life and health of the population[45].

Heterotrophic bacteria *P. tundrae* IMV B-7915 and *O. rhizosphaerae* IMV B-7956 were grown on tryptic soy agar medium for 3 days, and photosynthetic bacteria *R. yavorovii* IMV B-7620 were grown on ATCC No. 1449 mineral medium for 7 days under 200 lx illumination. Wheat seeds of the cultivar Tubalt were soaked for 18 hours in a bacterial suspension (suspension density 5.0 according to McFarland) in a 0.9 % NaCl solution. The control was wheat seeds soaked for 18 hours in a 0.9 % NaCl solution. The seeds were planted into the soil and sprinkled with tap water. Wheat was grown for 8 days at 16–18 °C.

Improvements in plant development are usually characterized by improved seed germination, increased amounts of both above-ground and below-ground plant parts, chlorophyll content, and yield, and flower and/or fruit size[46].

In our study, the effect of seed bacterization with bacterial suspensions was assessed based on its impact on seed germination[47], the length of roots and shoots of 8-day-old seedlings, and the chlorophyll content in their leaves. Bacterization of wheat seeds with suspensions of the studied bacteria had a predominantly positive effect on seed germination (Table 1). In particular, seed germination rates in the experimental variants exceeded those of the control on both the third and eighth days of wheat growth. The most pronounced stimulating effect was found for *P. tundrae* IMV B-7915, which increased germination by 21 % and 10 % on the 3rd and 8th days of seedling growth, respectively. Additionally, under the influence of this strain of bacteria, the dry weight of the seedlings increased slightly (Table 1), whereas in variants with other bacteria, the moisture and dry weight indicators remained at the control level under these conditions.

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Table 1

Seed germination and dry weight accumulation of *Triticum aestivum* wheat seedlings of the cultivar Tybalt, the seeds of which were treated with bacteria *Rhodopseudomonas yavorovii* IMV B-7620, *Paenibacillus tundrae* IMV B-7915, *Ochrobactrum rhizosphaerae* IMV B-7956

Bacterial strains	Seed germination, %		Moisture, %	Plant dry weight, %
	3 day	8 day		
Control	69 ± 5	89 ± 4	88.37 ± 0.87	11.62 ± 0.87
O. rhizosphaerae IMV B-7956	78 ± 4	94 ± 3	87.94 ± 0.52	12.06 ± 0.52
P. tundrae IMV B-7915	90 ± 5	99 ± 3	86.49 ± 0.34	13.51 ± 0.34
R. yavorovii IMV B-7620	78 ± 9	85 ± 8	88.86 ± 0.24	11.14 ± 0.24

Bacterization of seeds with suspensions of *P. tundrae* IMV B-7915 or *R. yavorovii* IMV B-7620 resulted in a statistically significant elongation of shoots and roots of seedlings by 3 % and 16 %, respectively (Fig. 1).

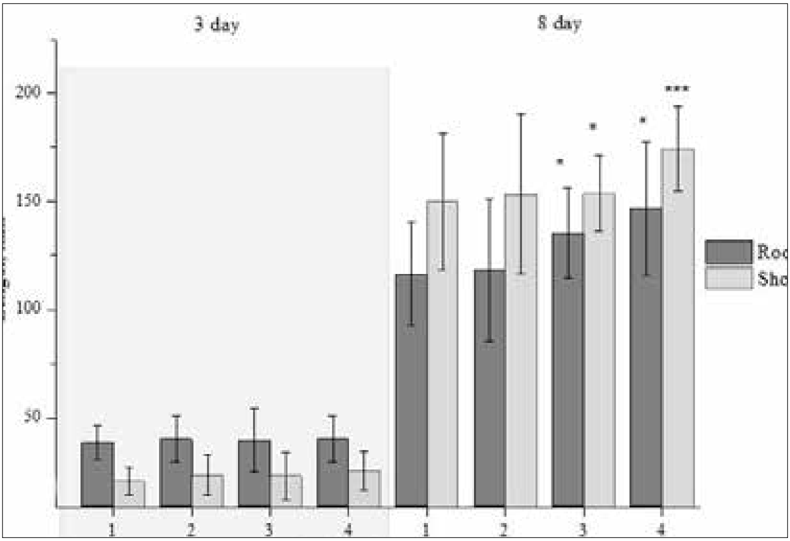

Fig. 1. Root length and shoot height of wheat seedlings the seeds of which were treated with bacteria *Rhodopseudomonas yavorovii* IMV B-7620, *Paenibacillus tundrae* IMV B-7915, *Ochrobactrum rhizosphaerae* IMV B-7956:

1 – control; 2 – *O. rhizosphaerae* IMV B-7956; 3 – *P. tundrae* IMV B-7915; 4 – *R. yavorovii* IMV B-7620 (x±SD, * – $p < 0.05$, *** – $p<0.001$ – probable differences in root or shoot length compared to the control)

Morphological changes in the root system increase the area of contact with the soil, facilitating access to nutrients and their transport to plant organs. Due to the sustainable assimilation of nitrogen, phosphorus, potassium, and microelements, growth processes are activated, which ensures an increase in plant biomass[48]. The total chlorophyll content and chlorophyll *a* content in the leaves of 8-day-old wheat seedlings increased by 15–25 % when wheat seeds were treated with *P. tundrae* IMV B-7915 and *O. rhizosphaerae* IMV B-7956 bacteria (Fig. 2).

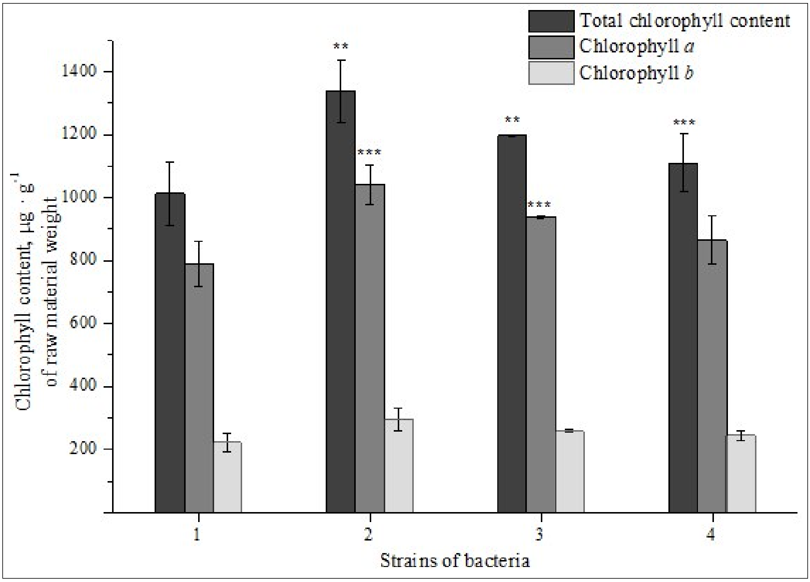

Fig. 2. Chlorophyll content in the leaves of 8-day-old wheat seedlings, the seeds of which were treated with bacteria *Rhodopseudomonas yavorovii* IMV B-7620, *Paenibacillus tundrae* IMV B-7915, *Ochrobactrum rhizosphaerae* IMV B-7956:
1 – control; 2 – *O. rhizosphaerae* IMV B-7956; 3 – *P. tundrae* IMV B-7915; 4 – *R. yavorovii* IMV B-7620 (x±SD, ** – $p < 0.01$, *** – $p<0.001$ – probable differences in chlorophyll content compared to the control)

It has been established that among the strains studied in monoculture, *P. tundrae* IMV B-7915 has the most pronounced stimulating effect on seed

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germination and wheat seedling development. The data we obtained are consistent with the information available in the literature regarding the high growth-promoting potential of representatives of the genera to which the selected strains belong[49, 50, 51].

In particular, it is known that bacteria of the genus *Ochrobactrum* are capable not only of intensifying the growth of agricultural crops, but also of neutralizing the toxic effects of heavy metals. For example, *Ochrobactrum* sp. MGJ11 stimulates soybean growth at the same time, reducing the negative impact of cadmium on the root system of these plants[52], and *Ochrobactrum* sp. Pv2Z2 promotes an increase in bean biomass and optimizes nitrogen assimilation compared to non-inoculated plants[53].

The plant growth-promoting effect of *Rhodopseudomonas palustris* strains has been described for various model plants. Bacterization of cucumber seeds with bacteria *R. palustris* G5 improves seedling growth parameters and stimulates induced systemic resistance under salt stress conditions[54]. The use of *R. palustris* SC06 reduces cadmium translocation into rice tissues during growth on contaminated soil[55]. With prolonged (5 years) application

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of *R. palustris* ISP-1, peanut yield increased by 12.5 %[56, 57], and strain *R. palustris* GJ-22 promoted the growth of *Nicotiana benthamiana* and increased resistance to tobacco mosaic virus[58].

The modern market for biological products in Ukraine offers a wide range of products for various groups of agricultural crops (cereals, legumes, industrial crops, etc.). They usually contain live cultures of microorganisms, often in combination with their metabolic products, biologically active substances, and microelements in chelated form[59].

Specialists pay particular attention to bacteria of the genus *Paenibacillus*. Based on the *P. polymyxa* KB strain, the preparation "Polymyxobacterin" was developed (Institute of Agricultural Microbiology and Agroindustrial Production of the National Academy of Agrarian Sciences). Its use intensifies the development of nitrogen-fixing microbiota in the rhizosphere of winter wheat[60], increases grain yield and quality (protein and gluten content) on different soil types[61, 62]. An important characteristic of this strain is its protective effect against the toxic effects of lead and cadmium[63].

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3. The effect of compositions of resistant to environmental factors strains of bacteria on the morphological and physiological parameters of wheat seedlings

The development of multicomponent complex microbial preparations is a relevant area for modern agrobiotechnology. The use of several types of bacteria in a single preparation requires careful consideration of their ecological and physiological compatibility[64].

Typically, microbial compositions demonstrate higher efficacy and stability compared to individual strains because they are capable of functional complementarity[65]. The combination of two or more plant growth-promoting microorganisms can promote plant growth, combat stress, and control pathogens[66]. After the combined application of *Bradyrhizobium japonicum* (TAL-378 and TAL-379) and phosphate-solubilizing *Pseudomonas* sp. for soybean inoculation, the yield of these plants increased[67].

The formation of such associations is based on a detailed analysis of interspecies interactions. The main criteria for selecting cultures are: functional diversity (combination of strains with different types of metabolism and growth stimulation mechanisms); resistance of components to changing environmental conditions (pH, temperature, presence of toxicants); biological compatibility, which prevents the suppression of some cultures by others; the possibility of effective adsorption on the seed coat or stable development in the rhizosphere of plants[68, 69]. The promising application of these compositions

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is due to their ability to form a stable microbiocenotic system that is more resistant to biotic and abiotic stresses compared to individual strains[70].

Three strains of bacteria resistant to environmental factors were used to form the compositions (Table 2). Before forming the compositions, interspecies interactions were analyzed using an antagonism test. The study found no growth inhibition between any of the strains studied, confirming their biological compatibility.

The most pronounced difference in seed germination between bacterized seeds and controls was observed on the third day of the experiment.

In particular, when using binary compositions of *O. rhizosphaerae* IMV B-7956 and *R. yavorovii* IMV B-7620 (mixture 3), as well as the combination of *O. rhizosphaerae* IMV B-7956 with *P. tundrae* IMV B-7915 (mixture 1), seed germination exceeded 90 % on the third day.

Table 2

Composition of mixtures used in the study

Mixture	Bacterial strains
1	*O. rhizosphaerae* IMV B-7956 + *P. tundrae* IMV B-7915
2	*P. tundrae* IMV B-7915 + *R. yavorovii* IMV B-7620
3	*O. rhizosphaerae* IMV B-7956 + *R. yavorovii* IMV B-7620
4	*O. rhizosphaerae* IMV B-7956 + *P. tundrae* IMV B-7915 + *R. yavorovii* IMV B-7620

By the end of the observation period (8 days), the germination rate in the mixture 1 variant reached 99±1 %. Also, after applying this composition for seed bacterization, the dry weight of seedlings increased (Table 3).

Table 3

Seed germination and dry weight accumulation of *Triticum aestivum* wheat seedlings of the cultivar Tybalt, the seeds of which were treated with bacteria *Rhodopseudomonas yavorovii* IMV B-7620, *Paenibacillus tundrae* IMV B-7915, *Ochrobactrum rhizosphaerae* IMV B-7956

Mixture	Seed germination		Moisture, %	Plant dry weight, %
	3 day	8 day		
Control	69±5	89±4	88.37±0.87	11.62±0.87
1	94±3	99±1	87.04±0.15	12.96±0.15
2	68±2	92±3	88.39±0.31	11.61±0.31
3	92±3	98±3	88.92±0.17	11.08±0.17
4	78±3	88±3	88.87±0.32	11.13±0.32

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Data on the morphogenesis of the root system are of particular interest, since the root is the primary organ of contact with the rhizosphere microbiota and ensures the absorption of nutrients. A statistically significant increase in root length of 17 % was recorded after inoculation of wheat seeds with mixture 2 (*P. tundrae* IMV B-7915 + *R. yavorovii* IMV B-7620). The highest root length growth rate (33 %) was achieved with mixture 3 (*O. rhizosphaerae* IMV B-7956 and *R. yavorovii* IMV B-7620) (Fig. 3). These results indicate a pronounced synergistic effect of these strains, which significantly activates the development of the wheat root system in the early stages of growth.

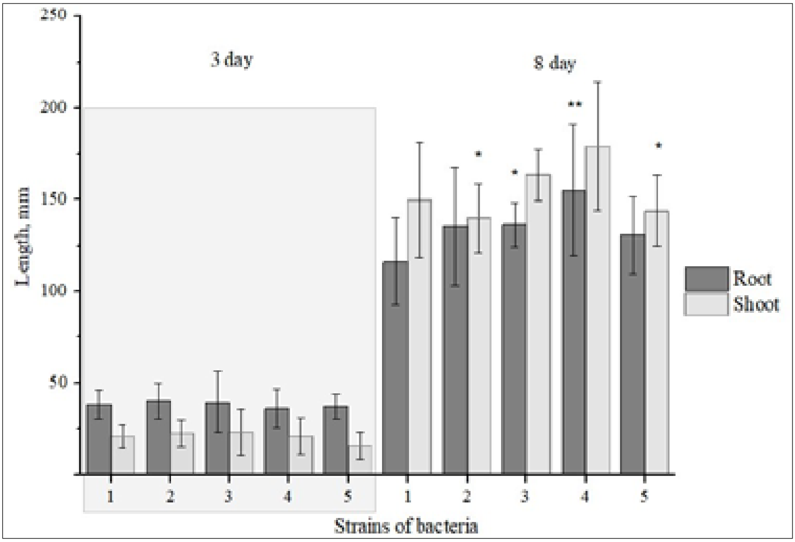

Fig. 3. Root length and shoot height of wheat seedlings, the seeds of which were treated with mixtures:
1 – control; 2 – mixture 1; 3 – mixture 2; 4 – mixture 3, 5 – mixture 4; (x±SD, * – p≤0,05, ** – p≤0,01 – probable diferences in root or shoot length compared to the control)

An important criterion for assessing the physiological state of wheat seedlings under the influence of microbial compositions is the content of photosynthetic pigments. This is due to the fact that about 90 % of plant biomass is formed as a result of CO_2 assimilation, therefore plant growth rates directly depend on the intensity of photosynthesis processes[71].

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Increased chlorophyll content not only optimizes photosynthesis, but also contributes to the overall intensification of plant growth[72].

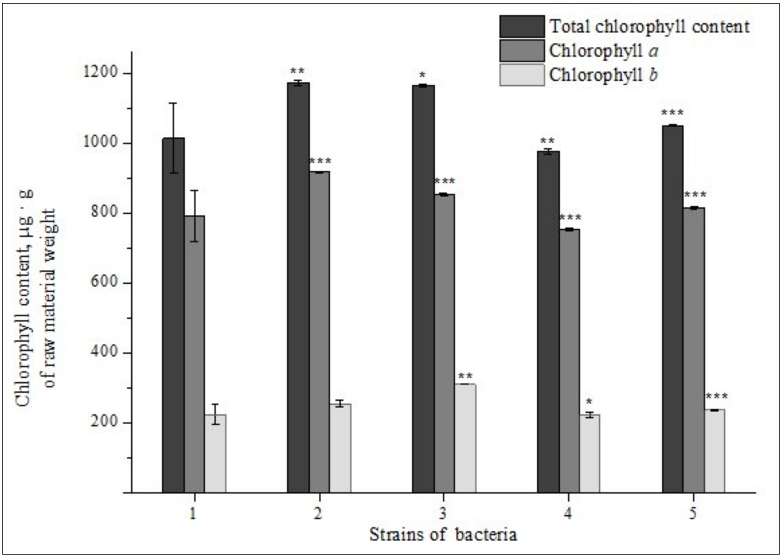

Fig. 4. Chlorophyll content in the leaves of 8-day-old wheat seedlings, the seeds of which were treated with mixtures :
1 – control; 2 – mixture 1; 3 – mixture 2; 4 – mixture 3; 5 – mixture 4, (x±SD, * – p≤0,05, ** – p≤0,01 – probable diferences in chlorophyll content compared to the control)

It was found that the application of mixture 1 (*P. tundrae* IMV B-7915 and *O. rhizosphaerae* IMV B-7956) contributed to an increase in the total chlorophyll and chlorophyll a content in the leaves of 8-day-old seedlings by 16 % compared to the control (Fig. 4). The application of a mixture of *P. tundrae* IMV B-7915 and *R. yavorovii* IMV B-7620 (mixture 2) resulted in an increase in the total chlorophyll content in leaves by 15–34 %, chlorophyll *a* by 8–28 %, and chlorophyll *b* by 39–54 % compared to the control. When *O. rhizosphaerae* IMV B-7956 and *R. yavorovii* IMV B-7620 (mixture 3) were used together, the chlorophyll content in the leaves was slightly lower than in the control.

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The increase in chlorophyll content is considered to be a fundamental mechanism of wheat tolerance to abiotic stresses. Along with indicators such as cell membrane stability and proline accumulation, high pigment levels ensure resistance to moisture deficiency and enable high productivity to be maintained in drought conditions[73, 74, 75, 76]. Since heavy metals are one of the critical factors that inhibit photosynthesis, the ability of the studied bacterial strains to maintain and increase chlorophyll levels, as established by us, is a strong basis for their use in biotechnologies for the restoration of technologically polluted areas.

Although the results of numerous studies confirm that the use of a mixture of plant growth-promoting bacteria is a more effective tool compared to mono-inoculation[77, 78, 79], our data indicate the selective nature of such influence depending on the composition of the mixture. The combined application of the studied strains revealed significant potential for enhancing wheat growth, particularly in terms of root system development and photosynthetic pigment accumulation.

At the same time, further research is needed to move from experimental mixtures to the creation of a targeted bacterial preparation. The primary tasks remain: optimizing the quantitative ratio of cultures in the compositions; establishing a critical cell titer that will ensure stable plant growth-promoting activity; studying the viability of strains in the compositions during long-term storage.

The results obtained provide a scientific basis for the development of complex preparations aimed at increasing the productivity of agroecosystems, particularly under conditions of technogenic stress.

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CONCLUSIONS

It has been established that strains of microorganisms resistant to environmental factors *P. tundrae* IMV B-7915, *O. rhizosphaerae* IMV B-7956, and *R. yavorovii* IMV B-7620 have pronounced plant growth-promoting activity on wheat (*Triticum aestivum* L.). In monoculture, the most effective stimulator of wheat seedling growth was the strain *P. tundrae* IMV B-7915, bacterization with which increases seed germination by 21 % and stimulates root growth by 16 %. A synergistic effect was observed when using mixtures of bacterial cultures, as mixtures ensured faster seed germination (germination rate >90 % on the third day) compared to monocultures. Bacterization of wheat seeds with a mixture of two cultures, *O. rhizosphaerae* IMV B-7956 and *R. yavorovii* IMV B-7620, significantly stimulated the growth of seedling roots. Bacterization of seeds with the studied bacteria had a positive effect on the chlorophyll content in the leaves of seedlings. The highest increase in chlorophyll content (by 15–34 %) is provided by compositions based on *P. tundrae* IMV B-7915 and *R. yavorovii* IMV B-7620.

SUMMARY

The current state of agroecosystems is characterized by progressive soil degradation and increasing anthropogenic pressure, particularly heavy metal pollution resulting from industrial activities and military operations. This creates critical abiotic stress for agricultural crops, leading to the suppression of photosynthetic processes, metabolic disorders, and a significant reduction in wheat yields, which poses a threat to global food security. Traditional agricultural technologies often prove ineffective in such extreme conditions, which creates an urgent need for the development of environmentally safe biotechnological agents for plant protection and growth stimulation.

This section presents the results of a study on the effect of three strains of microorganisms resistant to environmental factors (*Rhodopseudomonas yavorovii* IMV B-7620, *Paenibacillus tundrae* IMV B-7915, and *Ochrobactrum rhizosphaerae* IMV B-7956) on the growth and development of wheat seedlings. Seed inoculation with bacterial mixtures promotes germination, stimulates root system development, and increases chlorophyll *a* and *b* accumulation. Synergistic effects were observed when using binary mixtures, resulting in a 33 % increase in root length and a 15–34 % increase in chlorophyll content. The results are of practical importance for the development of complex bacterial preparations designed to enhance the yield of grain crops under conditions of technogenic stress.

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