

Biopreparations: types, main agents, and promising methods

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Abstract. The article analyses the market of biopreparations used in agriculture in Russia and globally. A comparative analysis of data on biopreparations registered in the State Catalogue of Pesticides and Agrochemicals Authorised for Use in the Russian Federation and the European Union Pesticides Database - (EU Pesticides Database - Active substances) was carried out. On the basis of this analysis, microorganisms used in the production of biopreparations in Russia and European Union countries were selected. The differences between the number of registered microorganisms in these states were identified, and the characteristics of the most widely used microorganisms as components of biopreparations were described.

1 Introduction

According to predictions, the world population will reach 10 billion by 2050, leading to a 50% increase in global demand for agricultural products compared to current levels [1]. This trend leads to the intensification of agriculture, which in turn necessitates the expansion of already limited arable land, as well as an increase in the use of fertilizers and plant protection products [2]. However, it is impossible to increase the doses of fertilizers and pesticides indefinitely, as they have limitations in absorption and possess a cumulative toxic effect on the environment, resulting in toxic rather than stimulating effects. Currently, pesticides play a major role in this context—a collective term encompassing chemical compounds of various classes used to combat harmful organisms in agriculture, healthcare, industry, oil extraction, and other sectors of the economy.

Today, there are several classifications of chemical plant protection products. The classification by application objects includes more than 20 names of pesticides, the most common of which are: acaricides (against representatives of the subclass *Arachnida*), bactericides (against bacterial infections), herbicides (for the destruction of weeds and invasive plant species), insecticides (against insects), and fungicides (to prevent the growth of fungi and their spores). Pesticides are also classified by the method of penetration into the organism and the nature of their action. The penetration methods include: contact (acting on harmful organisms upon direct contact with their body coverings), intestinal (action manifests only after entering the pest's intestine, which occurs through ingestion of

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the poison or sap of the plant containing the agent), and systemic (a pesticide capable of moving through the vascular system of a plant or animal). In terms of action, pesticides are classified as broad-spectrum or selective—acting only on certain classes or species, etc. Another classification of pesticides is based on the chemical composition of substances: inorganic compounds; organic synthetic compounds; substances of natural origin, or so-called biopesticides.

The widespread use of pesticides for controlling harmful organisms is due to their universality, high efficiency, and profitability. However, significant drawbacks of chemical pesticides include high toxicity to humans, animals, and the environment, as well as the high persistence of substances and their metabolites in the environment. Consequently, global norms for the use of chemical plant protection products are changing, and combined preparations are being developed to expand their spectrum of action. Despite these efforts, the increase in selectivity of preparations induces resistance in organisms targeted by the chemical substances [3]. There are several primary reasons for the development of new classes of pesticides, one of the most important being the economic cost of damage caused to agriculture by pests, particularly the rising expenses due to increased resistance to pesticides. Annual losses exceed \$100 billion, and since the 1950s, there has been a consistent increase in the resistance of pathogens to chemical pesticides, as well as the expansion of the habitat of resistant insects, such as the Colorado potato beetle, due to climate change [4].

Simultaneously, there is an increasing demand for agricultural products grown with minimal or no use of chemical agents and fertilizers, known as organic produce. The use of biological control agents not only allows for the production of higher quality products but also positively affects the overall bio-community. One of the methods of greening agriculture is the use of living organisms and/or products of their life activity, that is, the use of biopreparations.

2 Biopreparations

Biopreparations (BP) are means of controlling the population of pests, plant disease agents, and weeds, with active ingredients that are various biological agents, which can include different microorganisms, their metabolites, nematodes, insects, etc. [5].

There are several approaches to classifying biopreparations. One is based on the type of active component included in the preparation. In this regard, preparations containing bacteria, fungi, viruses, microbial metabolites, etc., are distinguished. Another common method of classification involves determining the target object of the preparation's action (similar to pesticides). In this context, biological preparations used in agriculture are divided into bioinsecticides (preparations against insect pests), bioacaricides (against herbivorous mites), bionematicides (against phytopathogenic nematodes), biofungicides (against fungal and bacterial phytopathogens), bioherbicides (against weeds), biocides (against rodents), biofertilizers, and plant growth regulators [5].

The use of biofungicides derived from bacteria and fungi represents a safer and more sustainable method for combating fungal diseases. The popularity of biofungicides has increased among farmers engaged in organic farming and those transitioning to more sustainable practices, driven by the demand for environmentally friendly and high-quality products. It should be noted that the phytosanitary condition in many regions of Russia, especially those located in extreme soil and climatic conditions, remains challenging. This is due to the prevalence of monocultures over vast areas, leading to a reduction in biodiversity and contributing to the rapid spread of pathogenic organisms. Various categories of biopreparations can be effective in combating specific types of pests or diseases, have varying durations of action, and require specific application conditions. The

correct choice of biopreparation in the context of emerging problems is crucial for ensuring effective plant protection and increasing yields. Thus, the classification of biopreparations plays a key role in the systematization and understanding of the diversity of available plant protection means, facilitating their more effective use in agriculture [1].

3 The Market for Biopreparations in Russia and Globally

In recent years, the global market for agricultural biopreparations has been characterized by high growth rates. The world leaders in the production of biological plant protection products are companies such as Corteva AgriScience, Bayer Crop Science AG, Syngenta International AG, BASF SE, Novozymes AG, Agronutrition, Biolchim SpA, Koppert Biological Systems Inc., Symborg Inc., and Trade Corporation International [1].

According to predictions, the revenue of the global market for biological plant protection products will increase to \$25.66 billion by 2033. The growth during the prediction period can be explained by an increase in demand for high-quality food and higher yields, favorable government policies, and rising economic income of the population (<https://www.thebusinessresearchcompany.com/report/agricultural-biologics-global-market-report>).

It is anticipated that the Asia-Pacific region will soon become a leader in the market for biological plant protection products, accounting for a dominant share of 57% in production. Significant investments in agricultural research and development, especially in countries such as China, India, and various Southeast Asian nations, may contribute to market expansion. For example, the volume of the Chinese market for agricultural biological products is estimated at \$4.56 billion in 2024 and is expected to reach \$7.39 billion by 2029, with an annual growth rate of 10.13% during the prediction period (2024-2029) (<https://www.mordorintelligence.com/industry-reports/china-agricultural-biologics-market>). The volume of the Indian market for agricultural biological products is estimated at \$2.82 billion in 2024 and is expected to reach \$3.94 billion by 2029, with an annual growth rate of 6.89% during the prediction period (2024-2029) (<https://www.mordorintelligence.com/industry-reports/india-agricultural-biologics-market>).

An analysis of the global biopreparation market, conducted with regard to their types, showed that in 2023, biofungicides accounted for more than 48.6% of the market share among all groups of biopreparations, holding a dominant position in the market. The leadership of this segment is explained by the increasing prevalence of fungal diseases in agricultural crops and the growing resistance of pathogens to traditional chemical fungicides.

Following biofungicides, a significant portion of the biopreparation market is occupied by bioinsecticides—biopreparations that utilize natural predators, parasites, or microorganisms to detect and control pest populations. Bioinsecticides have gained popularity due to their narrow specialization and minimal impact on non-target species, including pollinators [1].

Based on R.R. Azizbekyan's analysis [1], the total consumption of biological control agents in Russia is only 1% of the total volume of synthetic pesticides used. It is noted that about 90% of the biopreparations used in Russia are imported. The main consumers of biopesticides in Russia are greenhouse and forestry enterprises (80%), private farms (15%), and enterprises growing plants in open fields (5%).

The main reasons for the low usage of biopreparations in Russia are:

- Government agricultural policy subsidizing manufacturers of chemical plant protection products.
- Minimizing costs to increase production profitability is achieved at any cost.

- Lack of large-scale biopesticide production in Russia.

However, it should be noted that the demand for biopesticides exceeds supply, which undoubtedly affects the agricultural policy of the state. In some regions of the country, the share of processing certain crops with biopreparations reaches 10%. The level of pre-sowing treatment of crops remains relatively high (8% of the total amount of sowing material, approximately 500,000 tons) [1].

Currently, about 30 names of microbiological preparations for agricultural use are produced in Russia, including 11 fungicides and 17 insecticides. Some Russian regions, such as Bashkortostan, Tatarstan, and Krasnodar Region, produce the overwhelming majority of biopreparations and supply the agricultural sector with the produced products (<https://mcx.gov.ru/ministry/departments/departament-rasteniievodstva-mekhanizatsii-khimizatsii-i-zashchity-rastenyi/industry-information/info-gosudarstvennaya-usluga-pogosudarstvennoy-registratsii-pestitsidov-i-agrokhimikatov/>).

Table 1 presents data from the State Catalogue of Pesticides and Agrochemicals approved for use in the Russian Federation as of April 15, 2024, containing information about microbiological preparations containing microorganisms and/or products of their metabolism.

Table 1. Biopreparations Produced and Sold in the Territory of the Russian Federation.

Categories of biopreparations		
Bioinsecticides		
Name	Organism/metabolite	Manufacturer
Insectobacterin, SP	<i>Bacillus thuringiensis</i> B-82 + <i>Bacillus subtilis</i> B-76	ORTON LTD.
Lepidobactocide, G	<i>Bacillus thuringiensis</i> , var. <i>kurstaki</i> Z-52	SPE LTD. 'ECOSERVICE S'
Lepidocide, P	<i>Bacillus thuringiensis</i> subsp. <i>kurstaki</i> Z-52	OOO PO Sibbiopharm 4/3
Bitoxybacillin, P	<i>Bacillus thuringiensis</i> , var. <i>thuringiensis</i> , strain 98	OOO PO Sibbiopharm
Leptocid, G	<i>Bacillus thuringiensis</i> , var. <i>thuringiensis</i> , strain B-501	LTD. 'Invivo'
Insetim, G	<i>Bacillus thuringiensis</i> , subsp. <i>thuringiensis</i>	LTD. 'PARADIGMA
Biosleep BT, P	<i>Bacillus thuringiensis</i>	ORGANIC PARK LTD. 4/3
Defilignum, SC	<i>Bacillus thuringiensis</i> B-501	Biota Ltd.
Biostop, G	<i>Bacillus thuringiensis</i> + <i>Streptomyces</i> sp. + <i>Beauveria bassiana</i>	Invivo Ltd.
Green Barrier, SP	<i>Beauveria bassiana</i>	LTD. 'FUNGIPACK
Biovert, SP	<i>Lecanicillium lecanii</i> strain B-80	OOO PO Sibbiopharm
Lepidobactocide, G	<i>Bacillus thuringiensis</i> , var. <i>kurstaki</i> Z-52	SPE LTD 'ECOSERVICE S'
Leptocid, G	<i>Bacillus thuringiensis</i> , var. <i>thuringiensis</i> , strain B-501	LTD 'Invivo'
Insetim, G	<i>Bacillus thuringiensis</i> , subsp. <i>thuringiensis</i> , IMP-1140	LTD 'PARADIGMA
Bitoxybacillin, P	<i>Bacillus thuringiensis</i> , var. <i>thuringiensis</i> , strain 98	PO 'Sibbiopharm'
Biostop Super	<i>Bacillus thuringiensis</i> Hi + <i>Beauveria bassiana</i> BB1 + <i>Streptomyces</i> sp.3NN	BIOTA LTD
Biosleep BW, G	<i>Beauveria bassiana</i>	ORGANIC PARK LTD
Biovert, SP	<i>Lecanicillium lecanii</i> strain B-80	PO 'Sibbiopharm'
Metarizine, G	<i>Metarhizium nisopliae</i> P-72	LTD 'Invivo'
Biofort, G	<i>Metarhizium anisopliae</i> P-72	TPC Technoexport
Metawhite, G	<i>Metarhizium anisopliae</i> strain 3873/18L+ <i>Beauveria bassiana</i> strain 119/LT + <i>Bacillus thuringiensis</i> var. <i>thuringiensis</i> strain BF/15L + <i>Streptomyces</i> sp., strain N/15	Organic Line Ltd
Phytoverm, KE	Avermectin C	'Pharmbiomed'

Fitoverm M, KE	Versectin C	'Pharmbiomed'
Biofungicides		
Serenade ASO, KC	<i>Bacillus amyloliquefaciens</i> , strain QST-713	Bayer AG
BFTIM KS-2, G	<i>Bacillus amyloliquefaciens</i> KC-2	PARADIGMA LTD
Orgamica C, G	<i>Bacillus amyloliquefaciens</i> , strain OPS-32	ORGANIC PARK LTD
Respecta, G	<i>Bacillus amyloliquefaciens</i> + <i>Pseudomonas aureofaciens</i>	SOCIETY WITH LIMITED RESPONSIBILITY 'AGRICULTURAL NIVA
Mycosar, JV	<i>Bacillus subtilis</i> , strain B-10, <i>Bacillus subtilis</i> , strain M-22, <i>Trichoderma harzianum</i> strain 18	ABT-GROUP LTD.
Phytosporin-M, G	<i>Bacillus subtilis</i> , strain 26 D	BashIncom NVP LLC
Phytosporin-M, PS	<i>Bacillus subtilis</i> , strain 26 D	BashIncom NVP LLC
Phytosporin-M, P	<i>Bacillus subtilis</i> , strain 26 D	BashIncom NVP LLC
Alirin-B, SP	<i>Bacillus subtilis</i> , strain B-10	LTD 'ABT GROUP'
Alirin-B, TAB	<i>Bacillus subtilis</i> , strain B-10	LTD 'ABT GROUP'
Alirin-B, G	<i>Bacillus subtilis</i> , strain B-10	LTD 'ABT GROUP'
Gamair, SP	<i>Bacillus subtilis</i> , strain M-22	LTD 'ABT GROUP'
Gamair, TAB	<i>Bacillus subtilis</i> , strain M-22	LTD 'ABT GROUP'
Biosphere-Fungimen, G	<i>Bacillus subtilis</i> B-76	OOO NPP Biosphere
Phytobacterin+, SP	<i>Bacillus subtilis</i> B-76	ORTON LTD
Vitaplan, SP	<i>Bacillus subtilis</i> BKM B-2604D + <i>Bacillus subtilis</i> BKM B-2605D	ABT Group Management Company Ltd
Bisolbicide, G	<i>Bacillus subtilis</i> , strain BL01	Bisolby-Inter Ltd
Baxis, G	<i>Bacillus subtilis</i> , strain 63-Z	Invivo Ltd
Bactoforte, G	<i>Bacillus subtilis</i> , strain B-2918 + <i>Bacillus amyloliquefaciens</i> , strain HMBB-7100	NIVA LTD
Bactophyte, SC	<i>Bacillus subtilis</i> , strain HPM 215	Sibbiopharm LLC
Bacterra, SP	<i>Bacillus subtilis</i>	LLC 'Your farm'
Phytosporin-AS, G	<i>Bacillus subtilis</i> , strain 26 D+ <i>Bacillus subtilis</i> , strain 1K+ <i>Bacillus subtilis</i> , strain 3K+ <i>Bacillus subtilis</i> , strain 3H+ <i>Bacillus subtilis</i> , strain 8K+ <i>Bacillus subtilis</i> , strain 7K + <i>Bacillus subtilis</i> , strain 3/28+ <i>Trichoderma</i> , strain 4K+ <i>Trichoderma atroviride</i> , strain 10K+ <i>Trichoderma longibrachiatum</i> , strain 9K	IE Maria Vyacheslavovna Kuznetsova
Sporobacterin, SP	<i>Bacillus subtilis</i> + <i>Trichoderma viride</i> , strain 4097	ORTON LTD.
Binal, G	<i>Bacillus subtilis</i> B1018 + <i>Trichoderma viride</i> F2001	BIOM-PRO LTD.
Lavibact, G	<i>Lactobacillus plantarum</i> B 1101	BIOM-PRO LTD.
Metabacterin, SP	<i>Bacillus subtilis</i> 2918	FERMLAB LTD.
Pseudobacterin-2, G	<i>Pseudomonas aureofaciens</i> , strain BS 1393	Federal State Budgetary Institution of Science Institute of Biochemistry and Physiology of Microorganisms named after G.K. Scriabin of the Russian Academy of Sciences
Pseudobacterin-2, PS	<i>Pseudomonas aureofaciens</i> , strain BS 1393	Federal State Budgetary Institution of Science Institute of Biochemistry and Physiology of

		Microorganisms named after G.K. Scriabin of the Russian Academy of Sciences
Pseudobacterin-3, G	<i>Pseudomonas aureofaciens</i> , strain B-2391Д	ORGANIC PARK LTD.
Risoplan, G	<i>Pseudomonas fluorescens</i> , strain AP-33	BIOPESTICIDES LTD.
Binoram, G	<i>Pseudomonas fluorescens</i> , strain 7Г, 7Г2К, 17-2	AGROIMPEX LTD.
Guapsinplus, G	<i>Pseudomonas aureofaciens</i> , strain IMBB-7096+ <i>Pseudomonas aureofaciens</i> , strain IMBB-7097	Agrotechnologies Ltd.
Gliocladin, TAB	<i>Trichoderma harzianum</i> , strain 18	Management Company Ltd 'ABT Group
Tetris, SP	<i>Trichoderma viride</i> F 2001+ <i>Trichoderma harzianum</i> F 2009+ <i>Trichoderma longibrachiatum</i> F 2124	BIOM-PRO LTD.
Biotrichoderma, SP	<i>Trichoderma viride</i> F-2030+ <i>Trichoderma harzianum</i> F-2477	ORTON LTD.
Trichoplant, SK	<i>Trichoderma longibrachiatum</i>	BIOTECHSOYUZ LTD.
Organica F, G	<i>Trichoderma asperellum</i> , strain OPF-19	ORGANIC PARK LTD.
Phytotrix, G	<i>Trichoderma asperellum</i> M18 strain F-1395	NPI 'Biopreparaty' Ltd.
Trianum P, VDG	<i>Trichoderma harzianum</i> , strain T-22	OOO KOPPERT RUS
Trianum G, G	<i>Trichoderma harzianum</i> , strain T-22	OOO KOPPERT RUS
Trichoderma veridae	<i>Trichoderma viride</i> , strain 471	Agrotechnologies Ltd.
Trichophyte Plus, G	<i>Trichoderma viride</i> , strain M-10	Agrotechnologies Ltd.
BFTIM KS-2, G	<i>Bacillus amyloliquefaciens</i> KC-2	PARADIGMA LTD.
Organomics C, G	<i>Bacillus amyloliquefaciens</i> , strain OPS-32	ORGANIC PARK LTD.
Bacterra, SP	<i>Bacillus subtilis</i>	LLC 'Your farm'
Baxis, J	<i>Bacillus subtilis</i> , strain 63-Z	Invivo Ltd.
Alirin-B, SP	<i>Bacillus subtilis</i> , strain B-10	LTD. 'ABT GROUP'
Alirin-B, TAB	<i>Bacillus subtilis</i> , strain B-10	LTD. 'ABT GROUP'
Alirin-B, G	<i>Bacillus subtilis</i> , strain B-10	LTD. 'ABT GROUP'
Bisolbicide, J	<i>Bacillus subtilis</i> , strain BL01	Bisolby-Inter Ltd.
Bactophyte, SC	<i>Bacillus subtilis</i> , strain IPM 215	Sibbiopharm LLC
Bactophyte, SP	<i>Bacillus subtilis</i> , strain IPM 215	Sibbiopharm LLC
Gamair, KS	<i>Bacillus subtilis</i> , strain M-22	LTD. 'ABT GROUP'
BisolbiSan, G	<i>Bacillus subtilis</i> strain CH-13	Bisolby-Inter Ltd.
Pralin Extra, SP	<i>Bacillus subtilis</i> , B1018	BIOM-PRO LTD.
Sporobacterin, SP	<i>Bacillus subtilis</i> + <i>Trichoderma viride</i> , strain 4097	ORTON LTD.
Insectobacterin, SP	<i>Bacillus thuringiensis</i> B-82 + <i>Bacillus subtilis</i> B-76	ORTON LTD.
Lavibacte, G	<i>Lactobacillus plantarum</i> B 1101	BIOM-PRO LTD.
Guapsin Plus, G	<i>Pseudomonas aureofaciens</i> , strain IMBB-7096+ <i>Pseudomonas aureofaciens</i> , strain IMBB-7097	LLC 'Agrotechnologies'
Biocomposite-Pro, J	<i>Pseudomonas asplenii</i> , strain 11 RW	JSC 'Shchelkovo Agrochem'
Binoram, J	<i>Pseudomonas fluorescens</i> , strain 7G, 7G2K, 17-2	AGROIMPEX LTD.
Risoplan, G	<i>Pseudomonas fluorescens</i> , strain AP-33	BIOPESTICIDES LTD.
Trichoplant, SK	<i>Trichoderma longibrachiatum</i>	BIOTECHSOYUZ LTD.
Plant growth regulators		
Emistim, R	<i>Acremonium lichenicola</i>	IE Yanina Margarita Mikhailovna

Based on a comparative analysis of data on the preparations approved for use in Russia, microorganisms used in the Russian Federation were selected, and the presence/absence of selected microorganisms in biopreparations permitted for use in the EU was analyzed (Table 2). This analysis was conducted based on data from the State Catalogue of Pesticides

and Agrochemicals Authorised for use in the Russian Federation (<https://mcx.gov.ru/ministry/departments/departament-rasteniievodstva-mekhanizatsii-khimizatsii-i-zashchity-rastenyi/industry-information/info-gosudarstvennaya-usluga-pogosudarstvennoy-registratsii-pestitsidov-i-agrokhimikatov/>) and the EU Pesticides Database - Active Substances. Unlike the aforementioned catalogue, the EU Active Substances Database includes microorganisms that are under review and not registered at the time of database formation. The State Catalogue of Pesticides and Agrochemicals approved for use in the Russian Federation does not have similar information publicly available.

Table 2. Comparative Analysis of Microorganisms Approved for Use in the Russian Federation and the European Union.

Microorganisms used	Number of authorised strains in Europe for the production of biopreparations	Number of authorised strains in Russia for the production of biopreparations
<i>Bacillus amyloliquefaciens</i>	6	3
<i>Bacillus thuringiensis</i>	8	4
<i>Bacillus subtilis</i>	1	17
<i>Beauveria bassiana</i>	8	3
genus <i>Lecanicillimlecanii</i>	0	1
genus <i>Streptomyces</i>	2	2
genus <i>Metarhiziumanisopliae</i>	0	2
genus <i>Trichoderma</i>	13	18
<i>Pseudomonas aureofaciens</i>	0	3
genus <i>Lactobacillus</i>	0	1
<i>Pseudomonas fluorescens</i>	0	4

The largest number of bacterial biopreparations in the Russian Federation is based on the use of *Bacillus subtilis*, with 17 registered strains. This is likely due to the characteristics of the microorganism, specifically its ability to form spores that survive in the soil for extended periods under various environmental conditions, the presence of direct and indirect mechanisms for suppressing pathogens, the ability to convert phosphorus into a form accessible to plants, and the capability to fix nitrogen and produce siderophores, which enhance stress resistance in host plants by triggering the expression of stress response genes, phytohormones, and stress-related metabolites [6].

Biopreparations based on micromycetes include the most numerous groups of preparations utilizing fungi from the genus *Trichoderma*. The State Catalogue of Pesticides and Agrochemicals lists 18 strains approved for use in the production of biopreparations. *Trichoderma* fungi can provide control over harmful insects directly through parasitism and the production of insecticidal secondary metabolites. Biopreparations based on microorganisms from the *Trichoderma* genus in agriculture are effective not only against phytopathogens but also against insect pests [7].

For example, *Trichoderma harzianum* in some biopreparations is one of the most frequently used antagonists of phytopathogens, capable of functioning not only as a mycoparasite but also producing antibiotics. Moreover, it can stimulate the activation of plant defense mechanisms [7].

It is important to note that some strains of the *Trichoderma* genus, such as *Trichoderma atroviride* G79/11, are known to produce cellulases but can also produce other enzymes, making them suitable for antifungal biopreparations. By producing chitinase, they can act as mycoparasites by disrupting the integrity of pathogen cell walls. The range of pathogens

affected by *Trichoderma* species is very broad and includes the following genera: *Armillaria*, *Botrytis*, *Chondrostereum*, *Colletotrichum*, *Dematophora*, *Diaporthe*, *Endothia*, *Fulvia*, *Fusarium*, *Fusicladium*, *Helminthosporium*, *Macrophomina*, *Monilia*, *Nectria*, *Phoma*, *Phytophthora*, *Plasmopara*, *Pseudoperonospora*, *Pythium*, *Rhizoctonia*, *Rhizopus*, *Sclerotinia*, *Sclerotium*, *Venturia*, *Verticillium*.

Microorganisms such as *Lecanicillium lecanii* and bacteria from genus *Lactobacillus* are less frequently used for the production of biopreparations. Biopreparations based on *Lecanicillium lecanii* are used as agents for insect mycoses: aphids, whiteflies. They can parasitize on mites, nematodes, and rust and powdery mildew fungi. Specific species and strains are pathogen-specific for various insects [8].

The primary application of *Lactobacillus* bacteria is in the food industry. However, in the production of biopreparations, species such as *Lactobacillus plantarum* exhibit pronounced bactericidal activity, effectively suppressing the development of phytopathogenic bacteria (both gram-positive and gram-negative). *Lactobacillus plantarum* also has selective fungicidal activity. The mechanism of action of lactic acid microorganisms used in biopreparations is associated with disrupting the permeability of pathogen cytoplasmic membranes [9].

According to the classification of biopreparations by target object action, biofungicides (75) and bioinsecticides (25) are the most popular. The ratio of registered biofungicides to bioinsecticides is 3:1.

In the EU, as in the Russian Federation, strains belonging to the species *Bacillus thuringiensis* are approved for use—8 strains are registered in the EU, which is twice as many as in the RF.

Below is a more in-depth description of the microorganisms most frequently used in the production of biopreparations based on our analysis.

Bacillus thuringiensis is a gram-positive spore-forming bacterium that produces insecticidal proteins known as δ -endotoxins during the sporulation phase, such as Cry and Cyt toxins. Structurally, Cry proteins consist of three domain components based on amino acid sequences. Cry toxins are classified into 67 families (from Cry1 to Cry67) with more than 500 genes. These proteins are toxic to certain groups of insects, such as the orders *Lepidoptera*, *Coleoptera*, *Hymenoptera*, and *Diptera*, but are safer for humans, other vertebrates, and plant species. Cyt proteins are primarily toxic to dipterans and have cytolytic activity [10].

This is why the biopreparation based on *Bacillus thuringiensis* is used as a microbial insecticide to enhance plant resistance through genetic modification [11]. Another toxin produced by *Bacillus thuringiensis*, Thuringiensin, also known as Thu, is a thermally stable β -exotoxin that can retain its biological activity at 121 °C for 15 minutes and is produced by *B. thuringiensis* during vegetative growth. The target insect orders for Thuringiensin include *Lepidoptera*, *Coleoptera*, *Hymenoptera*, *Diptera*, and *Orthoptera*, as well as several species of nematodes. The mechanism of insect destruction by Thuringiensin is still not fully understood. However, it primarily affects pupation and molting in insects by inhibiting RNA synthesis through interference with RNA polymerase, where it acts as an ATP analog and competes with ATP binding sites [10].

Bacillus amyloliquefaciens is also commonly found in biopreparations, with 6 strains registered in the EU, which is also twice as many as those registered in the RF.

Bacillus amyloliquefaciens enhances the bioavailability of nutrients in the soil, including improving the supply of nitrogen, phosphorus, and potassium to plants and the production of siderophores, thus improving the availability of mineral elements for plants and their growth conditions. Additionally, *B. amyloliquefaciens* can increase plant resistance to biotic stresses caused by soil pathogens by stimulating nutrient competition,

through the production of cyclic lipopeptides, polyketides, and volatile organic compounds to directly counteract pathogens and induce systemic resistance in plants [12].

Much less popular as a biocontrol agent in the EU is *Bacillus subtilis* (1 registered strain compared to 17 in the RF). *Trichoderma* micromycetes are widely represented in both the Russian Federation and the EU (13 registered strains). Despite the widespread use of *Pseudomonas* bacteria as components of biopreparations, species such as *Pseudomonas aureofaciens* and *Pseudomonas fluorescens* are not registered in the EU Active Substances Database. In the RF, the use of *Pseudomonas fluorescens* for the production of biopesticides is widespread due to its following properties: the culture grows quickly in vitro and can be produced in large quantities; the microorganism effectively utilizes seed and root exudates, quickly colonizes the rhizosphere, and reproduces within it. In the rhizosphere of plants, *P. fluorescens* produces a wide range of bioactive metabolites, such as antibiotics, siderophores, volatile compounds, and growth-stimulating substances; it aggressively competes with other microorganisms; and quickly adapts to environmental stresses [13].

In contrast to the EU countries, *Pseudomonas aureofaciens* is also frequently used in the Russian Federation for the production of biopesticides. *P. aureofaciens* is effective against phytopathogenic fungi and also exhibits antibacterial activity. These bacteria can produce extracellular compounds that negatively affect the development of disease agents; some strains exhibit high activity against helminthosporiosis (caused by *Helminthosporium sativum*). *P. aureofaciens* can influence plant immunity by indirectly healing the rhizosphere and positively affecting crop structure through the production of phytohormones [14].

Additionally, strains of *Lecanicillium lecanii*, *Metarhizium anisopliae*, and *Lactobacillus* bacteria are not registered in the EU. Meanwhile, the number of strains currently under review in the EU is 12.

Unlike in the EU countries, the fungus *Metarhizium anisopliae* is not used. In the Russian Federation, this species is widely used due to its insecticidal properties. *Metarhizium anisopliae* is a fungus that affects insects, primarily beetle larvae. Once the spores of the fungus attach to the external surface of an insect, they germinate and begin to develop. By penetrating the insect's exoskeleton, they grow rapidly inside the insect, leading to its death. It can infect both larvae and adults [15].

The leadership of the biofungicide segment in both the Russian Federation and the EU countries is explained by the increasing prevalence of fungal diseases in agricultural crops and the growing resistance of phytopathogens to traditional chemical fungicides (<https://market.us/report/biological-crop-protection-market/>).

The popularity of biofungicides has sharply increased due to the demand for safer and more sustainable methods of disease control, as well as the growing demand for environmentally friendly and waste-free products. Following biofungicides, bioinsecticides have captured a significant portion of the market both in the Russian Federation and in the EU countries. Bioinsecticides have gained popularity due to their specificity and minimal impact on non-target species, including pollinators. The rise in infestations of agricultural crops and the shift towards integrated pest management strategies further stimulate their adoption.

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