Современная наука и инновации. 2026. № 2. С. 159-169
КРАТКИЕ СООБЩЕНИЯ

Modern Science and Innovations. 2026;(2):159-169
SHORT REPORTS

Научная статья
УДК 614.31:633.1:613.2
https://doi.org/10.37493/2307-910X.2026.2.15

Современные проблемы и возможности использования биопрепаратов в агропромышленном комплексе при возделывании культур (обзор)

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Аннотация. В статье представлен обзор современных исследований (2003–2026 гг.) по применению биологических препаратов в агропромышленном комплексе. Проанализировано действие более 34 биопрепаратов на различные сельскохозяйственные культуры с учетом их сортовой специфичности и влияния почвенно-климатических факторов. Выявлена высокая селективность действия препаратов, а также зависимость их эффективности от гидротермических условий вегетационного периода. Предложена систематизированная классификация биопрепаратов по 8 функциональным группам. Установлено, что наибольший исследовательский интерес вызывают комплексные полифункциональные препараты, в то время как механизмы действия биоинсектицидов и биопрепаратов вспомогательного действия остаются наименее изученными. Значительная доля биопрепаратов, рассмотренных в статье, однократно упоминались в научных работах, что диктует необходимость организации масштабных, многолетних мультилокационных испытаний для подтверждения стабильности их действия в различных почвенно-климатических зонах.

Ключевые слова: агропромышленный комплекс, биопрепараты, азотфиксаторы, фосфатмобилизаторы, биофунгициды, регенеративное сельское хозяйство, фитопатогены, гидротермический коэффициент

Для цитирования: Слепых И. В. Современные проблемы и возможности использования биопрепаратов в агропромышленном комплексе при возделывании культур (обзор) // Современная наука и инновации. 2026. № 2. С. 159–169. https://doi.org/10.37493/2307-910X.2026.2.15

Конфликт интересов: автор заявляет об отсутствии конфликта интересов.

Статья поступила в редакцию 01.12.2025;
одобрена после рецензирования 01.04.2026;
принята к публикации 01.06.2026.

Research article

Modern problems and opportunities for using biological products in the agro-industrial complex for cultivating crops (review)

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Abstract. The article presents an overview of contemporary research (2003–2026) on the application of biological products in the agro-industrial sector. It analyzes the effects of more than 34 biological products on various agricultural crops, taking into account varietal specificity and the influence of soil and climatic factors. The study reveals the high selectivity of the products' action and demonstrates that their efficacy depends on the hydrothermal conditions of the growing season. A systematized classification of biological products into eight functional groups is proposed. It has been established that complex, multifunctional preparations attract the greatest research interest, whereas the mechanisms of action of bioinsecticides and auxiliary biological products remain the least studied. A significant proportion of the biological products discussed in the article have been mentioned only once in scientific literature, highlighting the need for large-scale, multi-year, multi-location trials to confirm the stability of their performance across diverse soil and climatic zones.

Keywords: agro-industrial complex, biological products, nitrogen fixers, phosphate mobilizers, biofungicides, regenerative agriculture, phytopathogens, hydrothermal coefficient

For citation: Slepykh IV. Modern problems and opportunities for using biological products in the agro-industrial complex for cultivating crops (review). *Modern Science and Innovations*. 2026;(2):159-169. https://doi.org/10.37493/2307-910X.2026.2.15

Conflict of interest: the author declares that there is no conflict of interest.

The article was submitted 01.12.2025;
approved after reviewing 01.04.2026;
accepted for publication 01.06.2026.

Introduction. The modern agro-industrial complex (AIC) is undergoing active transformation, focused on developing new directions in crop production using fundamentally new types of fertilizers, biological products, and environmentally friendly plant protection products [1]. The technology of applying biological products, similar to the traditional application of synthetic agrochemicals, is highly relevant but requires in-depth fundamental and applied research. Currently, ground and aerial fine-droplet spraying, as well as ultra-low-volume (ULV) spraying using aerosol technologies with optimal dispersion, are being widely implemented in agronomic practice [2].

A promising vector for the development of the agro-industrial complex is the development of products based on biologically active compounds (BACs) derived from plant materials, adapted to the effects of abiotic and biotic stressors. The concept of regenerative agriculture, which aims not only to exploit but also to restore natural resources, is becoming dominant. Biopreparations are an integral component of this paradigm, as their use allows for a significant increase in crop productivity without disrupting the homeostasis of agrocenoses [3, 4].

The aim of the study was to analyze and systematize the results of modern scientific research on the use of drugs based on biologically active compounds in the agro-industrial complex.

The objectives of the study were: 1) searching for relevant scientific publications in electronic databases; 2) comprehensive analysis and systematization of the obtained empirical data.

Materials and methods. An information search of scientific publications was conducted using Google Scholar, as well as the scientific electronic libraries RSCI (eLibrary) and CyberLeninka. The analytical review is based on the results of 31 independent studies published between 2003 and 2026.

During the study, 34 biological products were analyzed and standardized according to a unified classification system. The microbial strains used, their combinations with plant-based bioactive compounds, their mechanisms of action, and the resulting agronomic performance were taken into account.

Results and discussion. The classification we propose includes the following groups:

1. Nitrogen fixers. In recent years, there has been an intensification of research into microbiological fertilizers based on nitrogen-fixing bacteria, which is critically important for ensuring sustainable development of the agricultural sector [5, 6]. Data analysis shows high variability in the effectiveness of the preparations depending on the genotype of the host plant. Thus, when cultivating the lentil variety "Vostochnaya", pre-sowing inoculation of seeds with Rizotorfin and Rizobin (*Rhizobium sp., Sinorhizobium sp., Bradyrhizobium sp.*) contributed to the formation of up to 14 nodules per plant (weight 78 mg/plant). At the same time, on the chickpea variety "Avatar", the use of Rizobin formed only 5 nodules (45-49 mg/plant). On the chickpea variety "Krasnokutsky 123", the effectiveness was even lower: the nodule weight when using Rizobin was only 23-38 mg/plant [7]. The use of Myzorin (*Arthrobacter mysorens)* and Flavobacterin (*Flavobacterium sp.*) on the Salamanca pea variety showed high results. Their use increased the number of nodules by 7.5 and 2.8 pcs. /plant, respectively, and the weight of fresh nodules by 39.9 and 20.3 kg/ha. This ensured a yield increase of 0.38 and 0.26 t/ha, increasing the level of production profitability by 11.1% and 4.6% [8].

Nitrogen fixers also demonstrate positive dynamics in cereal crops. The use of Azotovit (*Beijerinckia fluminensis)* on spring wheat of the 'Element 22' variety increased grain yield by 0.44 t/ha. Maximum efficiency (an increase of 0.64 t/ha) was achieved with a combination of Azotovit, Phosphatovit and the organomineral fertilizer Humate K [9]. When cultivating potatoes of the 'Alena' and 'Bylina Sibiri' varieties, the use of the MF-1 strain (*Bacillus subtilis*) provided a yield increase of 2.17 t/ha and 3.83 t/ha, respectively, which confirms the varietal specificity of the response to inoculation [10].

2. Phosphate mobilizers. Phosphorus biofertilizers are used to optimize the absorption of hard-to-reach soil phosphates by plants [11]. The preparation Organit P, Zh (*Bacillus megaterium)* reliably increases the productivity of spring barley of the Yaromir variety by 9–18.2% [12]. Of particular interest are long-term studies (2009–2012) on the use of Fosfatovit (*Paenibacillus mucilaginosus)* together with Azotovit on winter wheat of the Krasnodarskaya 99 variety. A complex dependence of efficiency on the predecessor and dosage was revealed. With “black fallow” as a predecessor, the standard dose (0.4 l/ha) together with ammonium nitrate gave a maximum increase of 2.8 c/ha. However, an increase in the dosage of biopreparations to 0.8 l/ha led to a paradoxical decrease in the increase to 0.7 c/ha. With the "winter wheat" predecessor, the same increased dose (0.8 l/ha) provided an increase of 2.3 c/ha. This indicates the need for strict calibration of application rates depending on the agrochemical background of the soil [13].

3. Complex biopreparations. This group is the most representative in modern literature. These multifunctional preparations are used to comprehensively address nutritional and protective needs.

In potato studies (Zhukovsky ranniy, Gorskiy 17, and Osetinskiy varieties), a three-component tank mixture was used: Fulvumin (fulvic acids) + Kelik-K Max Kali + Fitosporin-M + Izabion (amino acids). This enhanced combination reduced susceptibility to late blight (*Fusarium)*, rhizoctonia (*Rhizoctonia*), and alternaria (*Alternaria*) by 24% compared to the control [14].

On corn hybrids (Rodnik 292 MV, Etna), the use of Albit (*Bacillus megaterium*) and Nikfan (metabolites *of Glomus* and *Trichoderma*) together with chemical seed dressings increased resistance to helminthosporiosis (*Exserohilum turcicum*) and bladder smut (*Ustilago maydis*) by 28% [15]. When cultivating the Darina MV and Diana MV hybrids, Albit and Nikfan provided a yield increase of 2 to 3.2 t/ha, while the difference between the use of pure biopreparations and their combination with chemical seed dressings did not exceed 0.4 t/ha [16].

A pronounced growth-promoting effect was recorded on the Yenisei sunflower variety when treated with Fitop 8.67 and AFG. In 2023, the experimental plants exceeded the control plants in height by 1.4 times. The maximum head weight reached 790.5 g (an increase of 103.6–257.5 g over the control), and the head diameter increased to 27.5 cm (versus 15.5 cm in the control). Disease prevalence decreased by 15–24.3% [17].

The effectiveness of complex preparations strongly depends on the hydrothermal coefficient (HTC). In studies on spring wheat ‘Novosibirskaya 31’, the preparations Fitop 8.67-9 and AFG reduced the disease development index (DDI) of root rot by 3.4–3.5% in the wet year of 2019 (HTC=1.02) and by 7.7–8% in the dry year of 2022 (HTC=0.69) [18]. Similarly, on spring barley of the ‘Arat’ variety, the combination of Sprintalga + Forsage provided a biological yield of 5.32 t/ha in the favorable year of 2022, but under the conditions of extreme drought in 2024 (HTC=0.1), the yield dropped to 0.74–0.84 t/ha, regardless of the treatments [19].

4. Biofungicides. The use of phytopathogen antagonists is an environmentally friendly alternative to chemical pesticides. An isolated viable strain of the micromycete *Trichoderma viride* demonstrated pronounced antagonistic properties against the pathogens *Phytophthora spp.*, *Alternaria solani* , and *Septoria lycopersici* [20].

In greenhouse complexes (BIOM technology), the use of a complex of biofungicides (Vitariz Extra, Binal Extra, Tetris SP, Trikhokhit) on cucumber hybrids “MewaF1” and “ValogoraF1” provided a yield increase of 4.3–5.4 kg/m² [21].

Bacillus mojavensis PS17 and *Bacillus amyloliquefaciens KS-25 AU* in synergy with succinic and ascorbic acids in an experiment on spring wheat reduced the development of diseases by 32–77%, increasing yield by 13.3% [22].

When cultivating lentils, the use of a combination of Rhizobin and Ecobacillus in the dry year of 2024 increased yield by 4–16.5%, and in 2025, during a wetter period, the effectiveness of the same combination of biopreparations increased yield by 25–49% [23].

5. Bioinsecticides and mycorrhizal agents. Bioinsecticides are very limited in modern research. The preparation Aktarofit 1.8 (a complex of avermectins) was used in integrated grain protection systems, providing an increase in the yield of spring wheat by 1 c/ha [24]. Bitoxybacillin (*Bacillus thuringiensis*) was successfully used in two treatments against Colorado potato beetle larvae on the Adretta potato variety as part of organic technology [25]. Mycorrhizal agents (based on arbuscular mycorrhizal fungi of the genus *Glomus)* improve mineral nutrition. The preparations "Green Section" and "Dolina Plodorodiya" reliably increased the productive weight of curly parsley by 1.3-1.4 g [26]. The use of the “Liquid Mycorrhiza” preparation on potatoes increased the yield by 3.74 t/ha (increase in tuber weight by 1660 g) [25].

6. Experimental and auxiliary drugs. The latest developments include strains 18-5 (*Pseudomonas sp.*) and 38-22 (*Sphingomonas spiritivorum*). Their testing on six spring barley varieties revealed strict varietal specificity. On the 'Volzhsky Pervy' variety, the incidence of root rot decreased to 1.5–4.2% with a yield of 2.56–2.88 t/ha. In contrast, on the 'Mikhailo' variety, the incidence remained high (up to 12.7%), and the yield did not exceed 2.17 t/ha [27].

An innovative approach is the use of the supernatant of the microalga *Chlorella vulgaris.* Under laboratory conditions, lettuce grown under heterotrophic (HC) and mixotrophic (MK) cultivation conditions produced dry matter of 1.32 and 1.66 g/L, respectively, which was more than twice that of the classic autotrophic regime [28]. Adding a chlorella suspension to agrochernozems reduced the soil bulk density to 0.79–0.81 g/cm³ [29].

Auxiliary preparations (Biopolistim, Rhizoprotector), which act as adhesives and stabilizers (polysaccharides), increase the overall efficiency of tank mixtures in organic soybean cultivation technologies, providing an increase in yield of up to 0.4 t/ha [30].

A comprehensive analysis of 48 scientific papers allows us to identify several fundamental patterns in the use of biopreparations in modern agriculture.

Firstly, the high selectivity and varietal specificity of microbiological preparations have been confirmed. The works of E.V. Kubasova [10], V.N. Bagrintseva [31] and G.P. Guryev [7, 23] irrefutably prove that the same strain of microorganism enters into symbiotic or associative relationships with varying degrees of intensity depending on the genetics of the host plant. The difference in yield increase between corn hybrids (Mashuk 250 MV and Mashuk 355 MV) when treated with Borogum-M reached twofold values (4.9% versus 10.3%).

Secondly, a "dose paradox" described in the research of O.V. Semenyuk [13] was identified. An increase in the concentration of the biopreparation (from 0.4 to 0.8 l/ha) against the background of bare fallow led to a sharp decrease in agronomic efficiency (the increase fell from 2.8 to 0.7 c/ha). This indicates that oversaturation of the rhizosphere with introduced microorganisms can cause intraspecific competition or disrupt the established soil microbiocenosis.

Thirdly, a strict dependence of efficiency on hydrothermal conditions has been established.

In dry years (HTC $\leq$ 0.69), the biological activity of the preparations decreases, but their protective function (reduction of IRB of root rot) is maintained and even increases as a percentage of the control [18].

Due to the lack of a unified nomenclature, based on the analyzed array (94 preparations), we proposed a classification that includes 8 functional groups: 1) Nitrogen fixers; 2) Phosphate mobilizers; 3) Complex biological products; 4) Biofungicides; 5) Bioinsecticides; 6) Mycorrhiza formers; 7) Auxiliary; 8) Experimental (Fig. 1)

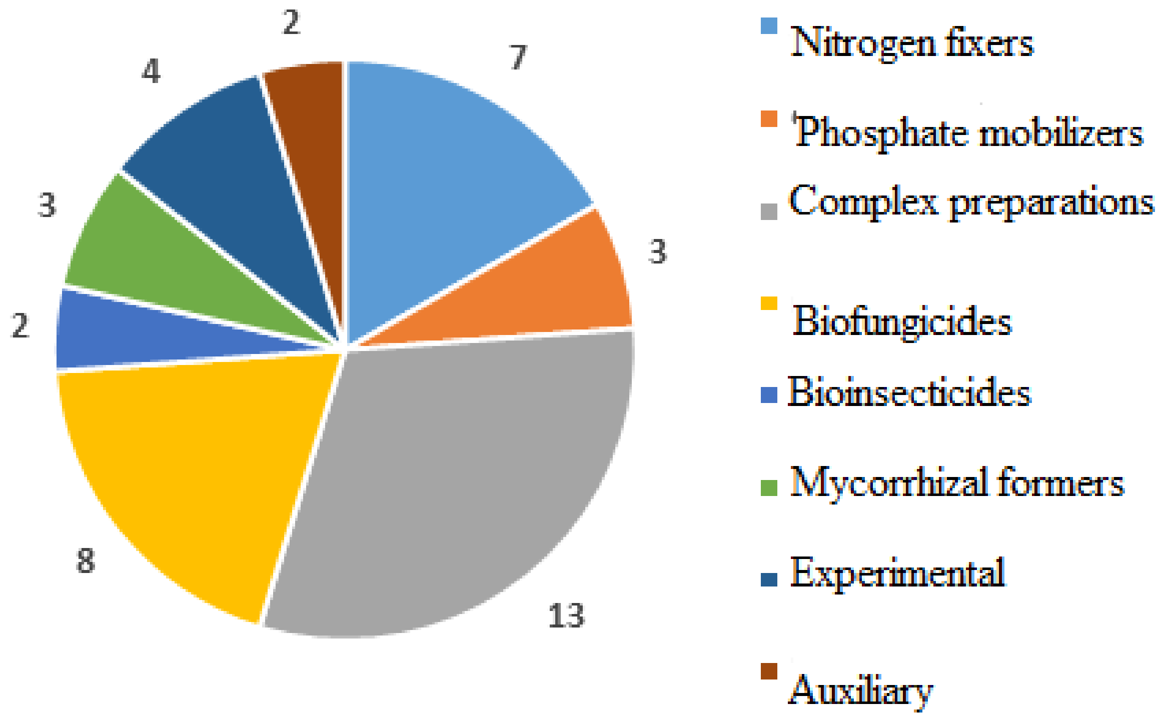

Figure 1. Proposed classification of biopreparations
(from the analysis of experimental studies for the period 2022-2026)

An analysis of the frequency of mentions shows that the most studied are drugs with complex, multifunctional action (13 biologics, Figure 1). However, 27 drugs appear in only a few publications, indicating fragmented knowledge of their properties (Figure 2).

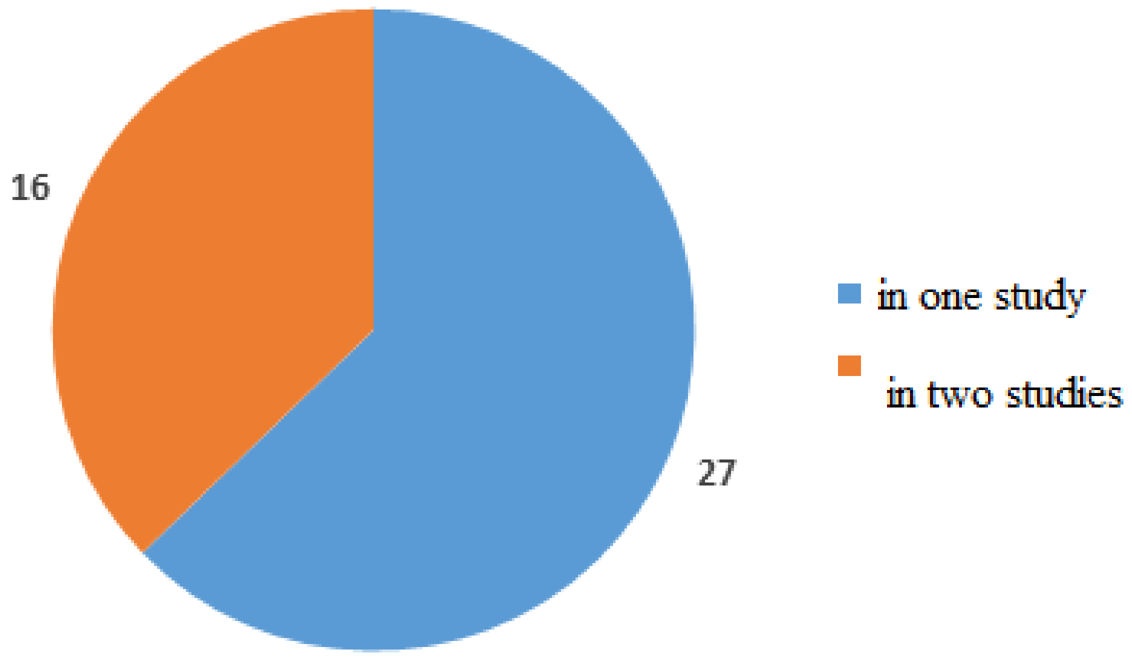

Figure 2. Distribution of biological preparations by frequency of mention in scientific studies

Conclusions. The effectiveness of using biological preparations in the agro-industrial complex is strictly specific and is determined by the genotype of the agricultural crop (variety/hybrid), as well as the hydrothermal conditions of the growing season.

A systematization of the modern biopharmaceutical market into eight functional groups is proposed. It has been established that complex, multifunctional products, which simultaneously address plant nutrition and plant protection issues, are of greatest research and practical interest.

A gap in scientific data has been identified in the bioinsecticide and adjuvant biopreparations segment. These groups are the least studied, hindering the implementation of fully biobased pest control systems.

The high proportion of preparations studied only once in short-term experiments dictates the need to organize large-scale, multi-location trials to confirm the stability of their action in various soil and climatic zones.

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